



Good sleep, good learning, good life

[Dr Piotr Wozniak](#), May 2012 (updated Oct 21, 2017)

I have for years been interested in sleep research due to my professional involvement in memory and learning. This article attempts to produce a synthesis of what is known about sleep with a view to practical applications, esp. in people who need top-quality sleep for their learning or creative achievements. Neurophysiology of sleep is an explosively growing branch of science. Many theories that are currently contested will soon be forgotten as a result of new findings. Consequently, this text is likely to grow old very quickly (compare the old version from the year 2000 [here](#)). Still, some basic truths about sleep are well-established, and practical conclusions can be drawn with the benefit to human creativity and intellectual accomplishment. In this text, I provide some links to research papers and popular-scientific articles that advocate disparate and contradictory theories. Please consult other sources to be certain you do not get a one-sided view! This article includes some indications on how to use free running sleep in the treatment of insomnia, advanced and delayed phase shift syndromes, and some other sleep disorders. If your own experience can contribute to the ideas presented herein, I will gladly hear from you (esp. in the context of learning and creativity).

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insists on exercise,
play, and plentiful
sleep: "*the great
cordial of nature.*"

— [John Locke](#) (1632-1704)

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Foreword

It is everyone's dream to wake up fresh, happy, and ready for action on a daily basis. Sadly, in the modern world, only a small minority lives that dream. Yet the dream is within reach for most healthy people given:

1. a bit of knowledge, and
2. a readiness to make some lifestyle sacrifice.

I hope that this article compiles all the basic ingredients of knowledge that are helpful in accomplishing refreshing sleep. As for the sacrifice, it is important to begin with the understanding that one cannot eat one's cake and have it too. Healthy sleep may be incompatible with some modern habits, some cravings, or some lifestyle choices. At worst, refreshing sleep may be incompatible with one's job or even long-term goals. Due to the latter fact, this article cannot provide a solution for everyone. Moreover, having a happy and fresh mind on a daily basis is a difficult thing to accomplish even with an arsenal of knowledge and full focus on good sleep. However, let me state it emphatically, **good sleep on most nights is feasible for most people!**

This article was originally written [a decade ago](#). I have always been interested in memory, learning, and sleep. In addition, in my job, sleep is as important as oxygen. As we all move deeper into the [Information Age](#) and [Knowledge Economy](#), the issues discussed herein will become more and more important for each of us. After writing the original article, I had the great pleasure of getting in touch with hundreds of people experiencing various sleep problems. I came to see first hand how knowledge of sleep helps solve their problems. I could also see how the industrialized age lays obstacles in one's quest for good sleep and high productivity. I have witnessed a true epidemic of sleep phase disorders, an explosion of interest in polyphasic sleep, and an exponential increase in interest in the matters of sleep in general. Despite my pleas, many people just cannot avoid using an alarm clock, running all-nighters before exams, waking their kids cranky for school, popping pills before sleep, leaving babies in their cots to [cry it out](#) for sleep, etc. The picture would be pretty sad and alarming were it not for the fact that there is hope in knowledge. With a degree of determination, everyone can improve his, her, or their kids' sleep.

This article is a compilation of the most important and the most interesting things about the biology of sleep. It is

supposed to help you gain knowledge needed to achieve high quality refreshing sleep that will boost your mental powers. The article explains why sleep is vitally important for health and for the brain. It argues that sleep deserves highest respect, and that most people could get excellent sleep if they only followed the prescribed rules.

Since writing the original [Good sleep, good learning, good life](#), tremendous progress has been made in the science of sleep. My own work with tools such as [SleepChart](#) and [SuperMemo](#) has shed some interesting light on the connection between sleep and learning. As I kept addressing the progress in sleep science in minor articles and FAQs, some visitors to [supermemo.com](#) complained that valuable nuggets of information are dispersed throughout the site instead of being organized in a more encyclopedic manner in a single article. Here then comes a comprehensive compilation, in which I would like to retain the focus on practical knowledge that is helpful in achieving good sleep. However, I would still like to smuggle in some lesser known research findings that might be inspiring for an average reader and/or a scientist working in the fields of sleep, memory, and learning. If you believe I left out anything important that others should know, please [let me know](#).

As the article grew to be insanely long, you may wish to begin with the [summary at the bottom of the article](#). And if even that is too long, here are the highlights:

- respect sleep as your tool for high IQ and good learning
- free running sleep can help you resolve many sleep problems
- **biphasic sleep** schedule is probably the healthiest schedule for creative people
- do not wake up kids for school; if they cannot wake up in time, let them skip a class or two, or consider homeschooling
- let babies and young children sleep on demand, co-sleeping is a great idea (even if many pediatricians will tell you otherwise)
- exercise, learning, and sleep are your best tools for brain growth!
- avoid regulating sleep and alertness with substances, esp. sleeping pills, alcohol, illegal drugs, nicotine, and **caffeine**

Notes

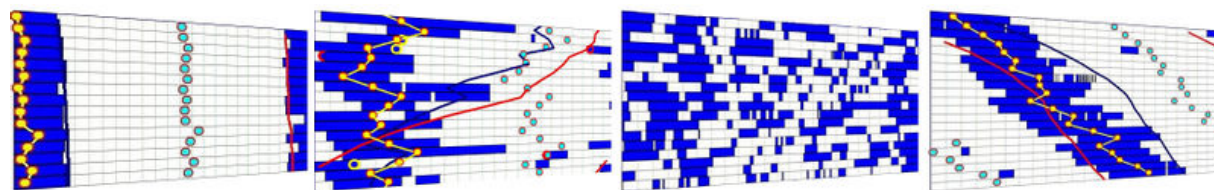
Incremental writing: Due to the size of the material, this article was written using a technique called [incremental writing](#). Incremental writing is helpful in organizing a large body of earlier writings into a single linear piece. The main advantage of incremental writing is a reasonable degree of coherence despite speedy processing of materials taken from disparate sources. Texts produced with incremental writing are particularly suitable for learning with the help of [incremental reading](#) as they produce small independent Wikipedia-style sub-articles. For a linear reader, however, this may mean a degree of bloatedness and an annoying repetitiveness of the main themes for which I apologize. If the size of the article is intimidating, you could try reading it incrementally (e.g. with [SuperMemo 2004 Freeware](#))?

References: Due to the volume of the material, I was not able to provide references for all statements included in the text. Some of these are common sense, some are common knowledge, others I took from memory or from SuperMemo without digging deep to the direct source. If you cannot find a reference for a particular claim, please [let me know](#)

Importance of sleep

Why understanding sleep is important?

Too few people realize how important sleep is! The alarm clock is an often-used fixture in an overwhelming majority of households of the modern world. By using electric lighting, alarm clocks, sleeping pills, and shift-work, we have wreaked havoc on the process of sleep.



Four examples of sleep logs that illustrate that modern human sleep patterns are as varied as snowflakes.

Over the last hundred years of the twentieth century, we have intruded upon a delicate and finely regulated process that was perfected by several hundred million years of evolution. Yet only recently have we truly become aware that this intrusion may belong to the most important preventable factors that are slowing societal growth in industrial

nations! In a couple of years from now, we may look at alarm clocks and "sleep regulation" in the same way that we look today at other "great" human inventions in the league of cigarettes, asbestos materials, or radioactive cosmetics.

Check this list below and see which applies to you:

- I often have problems with falling asleep at the right time
- I often find it painful to get up in the morning due to sleepiness
- I am often awfully drowsy at school or at work
- I regularly cut my sleep by 2-3 hours as compared with what my body seems to need
- I use the alarm clock and truly hate it
- I drink buckets of coffee or coke
- I often take 2-4 hour naps in the evening
- for me, at least one of the above is a source of regular stress or reduced productivity

I bet that chances are around 90% you could subscribe to one of the above. Perhaps this is why you are reading this article. It is also highly likely you have already learned to accept the status quo, and you do not believe you can do much about it. This article may hint at some remedies. However, the bad news is that for a real solution you will probably need to change your family life, your work, your boss, or some social rules!

Sleep isn't just a form of rest! Sleep plays a critical physiological function, and is indispensable for your intellectual development! Those who do not respect their sleep are not likely to live to their full mental potential!

Modern society has developed a set of well-entrenched rules that keep sleep in utmost disregard. This has been driven to pathological levels in American society. Here are some bad rules that hurt sleep:

- it is ok to use an alarm clock to cut sleep short
- it is ok to work in shifts
- it is ok to travel people around the world without much attention to the jet lag problem
- it is ok to save time by sleeping less and working more
- it is ok to pull kids out of bed in time for school
- it is ok to skip nights before important exams, etc.

Cutting down on sleep does not make people die ([at least not immediately](#)). It does make them feel miserable, but the ease with which we recover by getting just one good night of sleep seems to make sleep look cheap. Even the reports from the Guinness World Record attempt at sleeplessness ([Randy Gardner's](#) awakathon in 1964 lasted 11 days) trivialized the effects of sleeplessness. Many books on psychiatry and psychology still state that there aren't any significant side effects to prolonged sleeplessness! This is false! The Guinness Book of Records has since withdrawn its [sleep deprivation](#) category due to the involved health risks.

In 1992, when Bill Clinton was running for president, he proudly admitted that he went 48 hours without sleep because he really wanted to become the next president. Former Senator Bob Dole "improved" the record in 1996 presidential campaign: *We have been going 78 hours. We've got to go 96. We have been going around the clock for America.* Dole's feat was matched by Vice President Albert Gore Jr., who kept campaigning for three days before the election day of November 7, 2000. After the election, Gore still kept on his feet by going into extra hours of the concede-retract cycle of his cliffhanger contest against Governor George W. Bush of Texas. When Barack Obama was asked about his most desired Christmas gift after over a year of campaigning for president, he answered without hesitation: *8 hours of sleep.*

The bad example of disrespect for sleep comes from the most important people in the nation!

Yet some dramatic facts related to [sleep deprivation](#) have slowly come into light. Each year sleep disorders add \$16 billion to national health-care costs (e.g. by contributing to high blood pressure and heart disease). That does not include accidents and lost productivity at work. For this, the National Commission on Sleep Disorders estimates that [sleep deprivation](#) costs \$150 billion a year in higher stress and reduced workplace productivity^[1]. 40% of truck accidents are attributable to fatigue and drowsiness, and there is an 800% increase in single vehicle commercial truck accidents between midnight and 8 am. Major industrial disasters have been attributed to [sleep deprivation](#) (Mitler et al. 1988^[2])(incl. Three Mile Island, Chernobyl, the gas leak at Bhopal, Zeebrugge disaster, and the Exxon Valdez oil spill).

It has been known since the 1920s that sleep improves [recall](#) in learning. However, only at the turn of the millennium, research by [Dr Robert Stickgold](#), Associate Professor of Psychiatry at Harvard Medical School, has made international headlines. Dr Stickgold's research proves a fact that has long been known yet little appreciated: **sleep is necessary for**

learning (Stickgold 2005^[3])! With less sleep, we reduce the **recall** of facts we learned before or after a shortened night. Studying nights before an exam may be sufficient for passing the exam, yet it will leave few useful traces in long-term memory. The exam on its own replaces knowledge as the main purpose of studying!

By cutting down on sleep, we learn less, we develop less, we are less bright, we make worse decisions, we accomplish less, we are less productive, we are more prone to errors, and we undermine our true intellectual potential!

A change in societal sleep habits can spell a social revolution in learning, health, and productivity on a scale that few imagine! *"Judging from history, it would seem that fundamental changes in the way we think about sleep will be required for policy changes that would protect society from sleepy people who make catastrophic errors in industry and transportation"* (Merrill Mitler, PhD)

I have studied student personalities among users of [SuperMemo](#) for over twenty years now. There are a couple of determinants that make a good, efficient and persistent student. Here are some characteristics of a person who is likely to be successful in learning:

- highly optimistic
- sleeps well
- knowledge hungry
- stress-tolerant
- energetic, but able to slow down at the time of learning

Here are some unfortunate characteristics that do not correlate well with the ability to study effectively:

- prone to depression or mood swings
- problems with sleep (esp. **insomnia**)
- high levels of stress
- hyperactive and unfocused
- low stress tolerance (smokers, abusers of mood altering substances, drinkers, etc.)

Sleeping well appears to be one of the most important factors underlying success in learning!

Why do we sleep?

For many years, the physiological function of sleep has not been clear. In most people's mind, sleep is associated with rest and time for mental regeneration. Restorative, protective and energy-conserving theories of sleep have been quite popular until quite recently, when it has become apparent that one long-lasting sleep episode with suppression of consciousness does not seem to be the right way for evolution to tackle depleted resources, toxic wastes, or energy conservation. For example, muscles do not need to shut off completely to get rest. The critical function of sleep is dramatically illustrated in experiments in which rats chronically deprived of sleep eventually die usually within 2.5 weeks (for more see: [If you do not sleep, you die!](#)).

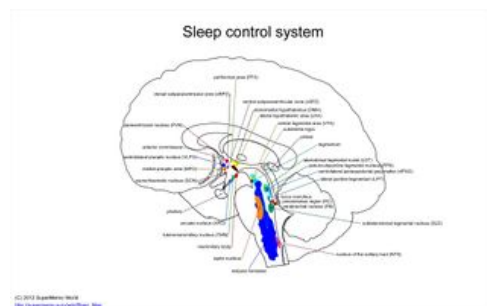
In evolutionary terms, sleep is a very old phenomenon and it clearly must play a role that is critical to survival. Only quite recently, it has been proven beyond doubt that the function of sleep is related to learning ([not all scientists agree!](#))

Researchers have long known about the importance of the hippocampus, a small brain organ, for memory formation. Yet it has always been difficult to find out what is special about the hippocampus that distinguishes it from other areas of the cerebral cortex that also show synaptic plasticity, i.e. the ability to store memories.

A collective effort of a number of researchers resulted in the proposition of the concept of [neural optimization in sleep](#) (see the next section for a metaphorical explanation: [Disk and RAM metaphor](#)). Ground-breaking theories of Dr György Buzsáki and his two-stage model of memory trace formation have shed new light on what might actually be happening during sleep (Buzsáki 1989^[4])(important: do not confuse this two-stage model with the [two-component model of memory](#) (Wozniak et al 1995^[5]) or with the [two-component model of sleep regulation](#) (Borbely 1982^[6]) below). Using his knowledge of neural networks, ingenious experiments on neuronal firing, and sophisticated mathematical analysis of spatiotemporal neuronal firing patterns, Buzsáki provided a good model explaining how the two components of sleep, **REM** and **NREM** sleep, work together to optimize memories. The hippocampus acts as the central switchboard for the brain that can easily store short-term memory patterns. However, these patterns have to be encoded in the neocortex to provide space for coding new short-term memories. This complex process of rebuilding the neural network of the brain takes place during sleep. Unlike rest or conservation of energy, this highest feat of

evolutionary neural mathematics requires the brain to be shut off entirely from environmental input (in most animals)! This automatic rewiring is the main reason for which we sleep and why there is no conscious processing involved! During sleep, the brain works as hard as during SAT or GRE exams. It rewires its circuits to make sure that all newly gained knowledge is optimally stored for future use.

We sleep so that the brain can integrate new knowledge and form new associations. As we must sleep for our brain to continue its function, our body attached dozens of important processes to run in sleep as well. In simplest terms, in waking we use and burn, while in sleep we restore and synthesize. Sleep affects the function and health of the entire body.



Sleep is controlled by a complex set of brain nuclei. Interference with this system disrupts the function of sleep.
 For more see: [Sleep control system](#)

For more see:

- [Neural optimization in sleep](#)
- [Not all scientists agree.](#)

Disk and RAM metaphor

A metaphor can help understand the role of sleep and why alarm clocks are bad. We can compare the brain and its NREM-REM sleep cycles to an ordinary PC. During the day, while learning and experiencing new things, you store your new data in RAM memory. During the night, while first in NREM, you write the data down to the hard disk. During REM, which follows NREM in the night, you do the disk defragmentation, i.e. you organize data, sort them, build new connections, etc. Overnight, you repeat the write-and-defragment cycle until all RAM data is neatly written to the disk (for long-term use), and your RAM is clear and ready for a new day of learning. Upon waking up, you reboot the computer. If you reboot early with the use of an alarm clock, you often leave your disk fragmented. Your data access is slow, and your thinking is confused. Even worse, some of the data may not even get written to the disk. It is as if you have never stored it in RAM in the first place. In conclusion, **if you use an alarm clock, you endanger your data.** If you do not care about your intellectual performance, you may want to know that there are many other biological reasons for which using alarm clocks is unhealthy. Many people use alarm clocks and live. Yet this is not much different from smoking, abusing drugs, or indulging in fat-dripping pork. You may abuse your brain with alcohol for years, and still become president. Many of mankind's achievements required interrupted sleep. Many inventions were produced by sleepy brains. But nothing is able to change the future as much as a brain refreshed with a healthy dose of restful sleep.

Bad sleep kills and costs billions

Sleep deprivation is a killer! It kills precious life via airplane crashes, nuclear power station failures, car crashes, oil spills, etc. **Sleep deprivation** can change the course of history. Charles Lindbergh would have been just a footnote in history if he had failed to recover the *Spirit of St. Louis* from a dive caused by microsleep. **Sleep deprivation** has changed the future of nuclear fission and the future of oil exploration. Poor sleep kills as many people on the roads as alcohol. [1550 annual fatalities](#) in the US can be attributed to drowsy driving. That's nearly an equivalent of six WTC collapse tragedies in a decade! Amazingly, as the pain and suffering is diluted in the population, drowsy driving does not nearly make as many headlines as a terrorist attack. At least a third of Americans have fallen asleep behind the wheel at least once! During the shift to DST in spring, car accidents increase by 9%. **Sleep deprivation** carries an astronomical cost to industrialized societies. There are zillions of hours wasted on unproductive learning in schools, and zillions of man-hours wasted on futile tossing and turning in bed. There is also a cost to grumpy behaviors and snappy outbursts. The quest for better sleep provokes desperate solutions such as the [Uberman polyphasic sleep](#), "safe alarm" contraptions, hundreds of books and thousands of blogs with good advice on [falling asleep fast](#), getting up early, or sleeping little. At the same time real solutions are simple and obvious! Read portions of this article and try

[free running sleep](#) for at least a month to quadruple your knowledge about sleep and its potential to change your life for the better. **We need to respect sleep, let kids sleep, design smarter night-shift schedules, and minimize sleep deprivation in jobs that weigh on life and death** (e.g. the medical profession).

In a comment to the conclusion of a [sleep deprivation](#) debate organized by the Economist, [Karen M. wrote](#): *"We don't get enough sleep, and we are not going to "change our ways" because there are already too few hours in most people's days to do things they enjoy. Call it a sad fact of life because that's what it is".* Even though Karen attempted to represent the entire population saying "we", many readers of this article will disagree and do their best to get as much sleep as physiologically necessary. Otherwise my writing effort would not be needed. Good sleep makes us nicer, smarter, and saves lives!

See: [10 Things to Hate About Sleep Loss](#) from WebMD.

If you do not sleep, you die!

Nearly everyone has pulled an all nighter once upon a time. Even if this is often an unpleasant experience, it nearly always ends up with a 100% recovery after a single night of solid sleep. It is therefore a bit surprising to know that that a week or two of [sleep deprivation](#) can result in death! Sleep researchers constructed a cruel contraption that would wake up rats as soon as they fell asleep. This contraptions showed that it takes an average of 3 weeks to kill a rat by [sleep deprivation](#) (or some 5 months by [REM sleep deprivation](#) alone)(Rechtschaffen 1998^[7]). [Dr Siegel](#) demonstrated brain damage in sleep-deprived rats (Siegel 2003^[8]). Due to an increase in the level of glucocorticoids, neurogenesis in some portions of the brain is inhibited by lack of sleep^[9]. In short, [sleep deprivation](#) is very bad for the health of the brain.

Sleep deprivation is a well-known form of torture. Yet, for ethical reasons, the rat experiment could not be reproduced in humans (to its ultimate end). However, we have a rough idea as to the degree of human durability in sleep deprived state due to fact that we can study the effects of sleep disorders. One of them is [fatal familial insomnia](#), in which a mutation causes the affected people to suffer from a progressively worsening insomnia that ends in death within a few months. Another example is the [Morvan's syndrome](#) in which an autoimmune disease destroys neuronal potassium channels that lead to severe insomnia and death (unless the disease progresses into remission).

You may have heard of reports of people who do not sleep at all. These are certainly inaccurate or false. Those who report never sleeping are either boasting or experiencing a sleep state misperception that leaves them with an illusion that they do not sleep when resting in bed.

Brain's garbage collection

Why is [sleep deprivation](#) fatal? Death of [sleep deprivation](#) is like death of an old age in general. Very often, multiple causes conspire to produce the final inevitable outcome. Probably nobody knows the exact answer to this mystery. However, research into the role of sleep gives us pretty strong hints. [One of the most important functions of sleep is the re-organization of neural networks in the brain](#). During the day, we learn new things, memorize, acquire skills, figure things out, set new memories through creative associations, etc. After a long day of waking, the brain is full of disorganized pieces of information that need to be integrated with things we have learned earlier in life. Without this re-organization, the brain would harbor chaos, and would quickly run out of space to store new memories. This neural role of sleep is so fundamental that [sleep deprivation](#) affects nearly all functions of the body that are governed by the nervous system. Without a regular garbage collection, individual networks begin to malfunction. These initially minor malfunctions can add up to a serious problem for the entire organism. Most prominent effects of [sleep deprivation](#) are problems with thermoregulation, decline in immune function, hormonal changes (e.g. increase in [glucocorticoids](#) and [catecholamines](#)), metabolic changes[link: Sleep and Glucose metabolism], malnutrition, hallucinations, autonomic system malfunction, changes in cell adhesion, increase in inflammatory factors (e.g. [IL-6](#), [TNF](#), [C-reactive protein](#), etc.), skin lesions, [oxidative stress](#), DNA damage, etc. Those problems become serious enough to kill. Metaphorically speaking, if we compared a less developed organism to a WW1 bomber, we could imagine that the process of evolving into a human being is like acquiring the software needed to fly a B-2 bomber. Even though B-2 is ages ahead of a plane constructed during the life of [Orville Wright](#), it is enough to plant a bug in its software to make it fall out of the sky. Human body in [sleep deprivation](#) is like a B-2 with a progressive software malfunction. It may be technologically advanced, it may be smart, and yet it is very vulnerable. The reliance on advanced software or neural function is always dangerous! Luckily, all we need to eliminate the danger is to just go to sleep every day. For more see: [Neural optimization in sleep](#).

Sleep protection

There is a second layer of trouble in **sleep deprivation**. Due to the importance of sleep, **all advanced organisms implement a sleep protection program**. This program ensures that **sleep deprivation** results in unpleasant symptoms. It also produces a remarkably powerful sleep drive that is very hard to overcome. Staying awake becomes unbearable. Closing one's eyes becomes one of the most soothing things in the universe. Are these symptoms a result of network malfunction? Definitely not. If they were, the drive to sleep might malfunction as well. Moreover, recovery from **sleep deprivation** would not be as fast, as easy, and as complete! Sleep protection program is there, and it can make the effects of **sleep deprivation** worse. Like a **cytokine storm** in an overzealous immune system, sleep protection program can potentially add to the damage caused by the network malfunction in **sleep deprivation**.

Anabolic sleep

Last but not least, **sleep has evolved to become a chief anabolic state of the organism**. Without it, the body keeps using itself up, without much time to rebuild. Turning on anabolic state does not require turning off the consciousness, however, the time of night rest seems to be the best time for the body to do all the rebuilding. As we must sleep anyway, that anabolic functions became consolidated with other functions of sleep, and now may be indispensable. The anabolic state, and the nighttime increase in **GH** or **testosterone**, also affects the neural networks and the status of our "mind software". Hormonal changes stimulate and/or inhibit neural growth. Dr Michael Stryker, best known for demonstrating the role of sleep in brain development (Stryker et al. 2001^[10]), says that nighttime hormonal changes may "*play a crucial role in consolidating and enhancing waking experience*"^[11]. One of the leading causes of death in **sleep deprivation** seems to have been opportunistic bacterial infections caused by a decline in the immune function (e.g. no febrile response). That decline could be caused equally well by (a) poor neural control of the immune function or (b) straight effect of **hypercatabolism**. Whatever the cause, scientists have quickly figured out that application of antibiotics did not help much in preventing death from those infections. Sleep deprived rats would die anyway. The infection might speed up death that was otherwise inevitable.

Why do we die without sleep?

It is impossible to quantify the contribution of those three factors to the fatal outcome of prolonged sleep deprivation:

1. **network malfunction**, or
2. secondary effects of **sleep protection program**, or
3. continuous **catabolic state**.

Even though the latter two could possibly be remedied pharmacologically, there is no way around network remodeling in sleep. Researchers who hope to find a remedy against sleep are plodding a blind path. Without some serious nanotechnology bordering on science fiction, sleep is here to stay with human race for many years to come. Even though, **sleep deprivation** could kill, sleep is good news. It makes us smarter! We should all embrace the blessings of healthy unrestrained sleep. After all, there are few better things in life than a good night sleep after a well-spent day. Sleep should be listed among basic human rights!

Two components of sleep

Electric lighting and stress are the two chief culprits that have converted the natural process of sleep into a daily struggle for millions. In the new millennium, we can rarely hope to get a good night sleep without understanding the science and the art of sleep. Currently, the societal understanding of sleep and its functions is as dismal as the understanding of the health risks of cigarettes in the 1920s. A majority of the population inflict pain, misery and mental torture on themselves and their children by trying to regulate their sleep with alarm clocks, irrational shift-work patterns, sleeping pills, alcohol, caffeine, etc.

For a chance to break out from unhealthy sleep habits, you need to understand the two-component model of sleep regulation.

There are two components of sleepiness that drive you to bed:

- **circadian component** - sleepiness comes back to us in cycles which are usually about one day long
- **homeostatic component** - sleepiness increases with the length of time we stay awake

Only a combination of these two components determines the optimum time for sleep. Most importantly, you should remember that even strong sleepiness resulting from the **homeostatic** component may not be sufficient to get good sleep if the timing goes against the greatest sleep propensity determined by the **circadian** component.

Circadian component

There are around hundred known body functions that oscillate between maximum and minimum values in a day-long cycle. Because these functions take about a day's time to complete, the term **circadian** rhythm was coined by Dr Franz Halberg of Germany in 1959 (in Latin *circadian* means *about a day*). The overall tendency to maintain sleep is also subject to such a **circadian** rhythm. In an average case, the maximum sleepiness comes in the middle of the night, reaches the minimum at awakening, and again increases slightly at **siesta** time in the afternoon. However, the **circadian** sleepiness is often shifted in phase as compared with your desired sleep time. Consequently, if your maximum sleepiness comes in the morning, you may find it difficult to fall asleep late in the evening, even if you missed a lot of sleep on the preceding day. In other words, the optimum timing of your sleep should take into consideration your **circadian** rhythm.

Homeostatic component

Homeostasis is the term that refers to maintaining equilibrium or balance in physiological and metabolic functions. If you drink liquids containing lots of calcium, **homeostatic** mechanisms will make sure that you excrete calcium with urine or deposit it in the bones. This is used to make sure your blood levels of calcium remain the same. Similar mechanisms are used to regulate overall sleepiness and its multiple subcomponents. The longer you stay awake, the more you learn, the more you think, the higher your tendency to fall asleep. On the other hand, caffeine, stress, exercise and other factors may temporarily reduce your **homeostatic** sleepiness. The **homeostatic** mechanism prepares you for sleep after a long day of intellectual work. At the same time it prevents you from falling asleep in emergencies.

Clock and Hourglass metaphor

A metaphor is useful in explaining the two components of sleep (for a more scientific explanation see: [Borbely model](#)). Deep in the brain, your **body clock** is running a 24 hours cycle of activity. Every 24 hours, metaphorically, the clock releases a sleepy potion that puts you to sleep (for details see: [Why we fall asleep](#)). If you try to sleep at wrong hours, without the sleepy potion, you may find it very hard to fall asleep. All insomniacs suffer from the lack of sleepy potion. If they go to sleep too early, before they get their fix of sleepy potion, they will toss and turn. Often for hours. You need to listen to your body clock to know the right moment to go to sleep.

It is important to know that sleepy potion produced by the body clock is not enough to put you to sleep. The brain also uses the hourglass of mental energy that gives you some time every day that you can devote to intellectual work. When you wake up, the hourglass is full and starts being emptied. With every waking moment, with everything your brain absorbs, with every mental effort, the hourglass is less and less full. Only when the hourglass of mental energy is empty will you be able to quickly fall asleep.

To get a good night sleep, you need to combine two factors:

- your body clock must be saying "time to sleep" (circadian component of sleep)
- your hourglass of power must be saying "no more mental work" (homeostatic component of sleep)

If your sleepy potion tries to put you to sleep but your hourglass of mental energy is full, you will be very groggy, tired, but you will not fall asleep. If, on the other hand, you try to sleep without the sleepy potion while the hourglass of power is empty, you may succeed, but you will wake up very fast with your hourglass full again. That will make sleeping again nearly impossible. Insomniacs go to sleep before the body clock releases the sleepy potion. When you wake up early with an alarm clock, you can hardly get to your feet because your body is full of sleepy potion, which begs you to go back to sleep. When you are drowsy in the afternoon, your hourglass of mental power might be almost empty. A quick nap will then help you fill it up again and be very productive in the evening. If you drink coffee in the morning, it helps you charge the hourglass and add some extra mental energy. But coffee combined with the sleepy potion produces a poisonous mix that engulfs your brain in sickly miasma. If you try to drink coffee to stay up in the night, you will feel like a horse kicked you in the stomach. That's the acme of a criminal attack on your brain's health.

The fundamental theorem of good sleep

Let us now formulate the fundamental theorem of good sleep:

To get high quality night sleep that maximizes your learning effects your sleep start time should meet these two criteria:

- **strong homeostatic sleepiness:** this usually means going to sleep not earlier than 15-19 hours after awakening from the previous night sleep
- **ascending circadian sleepiness:** this means going to sleep at a time of day when you usually experience a rapid increase in drowsiness. Not earlier and not later! Knowing the timing of your **circadian** rhythm is critical for good night sleep

You should be aware that using the **circadian** component will only work when all its physiological subcomponents run in sync (as it is the case in [free running sleep](#)). People with irregular sleep hours and highly stressful lives may simply be unable to locate the point of ascending **circadian** sleepiness as this point may not exist! For a visual illustration of **circadian** and **homeostatic** components, see section [Two-component sleep model in SuperMemo](#). For more on the two components of sleep see: [Borbely model](#).

When good sleep might not come?

You may be surprised to find out that your internal **circadian** oscillation is based on a period that is closer to 25 hours than to 24 hours! To be exact, it varies between individuals, seasons, and other daily factors such as stress, timing of sleep, timing of the light period, intensity of light, exercise, and many more. Usually it falls into the range from 24.5 hours to 25.5 hours.

Most of us are able to entrain this 25 **circadian** rhythm into a 24-hour cycle by using factors that reset the oscillation. These factors include intense morning light, work, exercise, etc. German scientists have named these factors *zeitgebers* (i.e. factors that give time). As a result of the influence of *zeitgebers*, in a well-adjusted individual, the cycle can be set back by 30-60 minutes each day. However, the **entrainment** to the 24-hour cycle may come with difficulty to many individuals due to factors such as:

- blindness (i.e. the inability to use the main *zeitgeber*: light)
- short-sightedness (i.e. reduced sensitivity to light *zeitgeber*)
- increased demand for sleep (e.g. as a result of intense learning, highly creative job position, exercise, etc.)
- stress
- endocrine disorders
- sleep disorders
- adolescence

A great deal of sleep disorders can be explained by **entrainment failure** (i.e. the failure to reset the 25-hour **circadian** rhythm to the 24-hour daylight cycle). In other words, in the interdependence between sleep disorders and **entrainment** failure, the cause-effect relationship will often be reversed! Due to the physiological function of sleep, which is the [rewiring of the neural networks of the brain](#), we can naturally expect that the demand for sleep be associated with the amount of learning on the preceding days. This link may also explain a decreased demand for sleep in retirement due to a decrease in intellectual activity. This age-related drop in the demand for sleep is less likely to be observed in highly active individuals. For similar reasons, the **entrainment** failure can often be found among students during exams. It is not clear how much of this failure can be attributed to stress, or to the desire to do more on a given day, or to the actual increase in the demand for sleep.

Formula for good sleep

There is a little-publicized formula that acts as a perfect cure for people who experience continual or seasonal problems with **sleep entrainment**. This formula is **free running sleep!**

Free running sleep is defined by the abstinence from all forms of sleep control such as alarm clocks, sleeping pills, alcohol, caffeine, etc. Free running sleep is a sleep that comes naturally at the time when it is internally triggered by the combination of your [homeostatic and circadian components](#). In other words, free running sleep occurs when you go to sleep only then when you are truly sleepy (independent of the relationship of this moment to the actual time of day). Night sleep on a free running schedule lasts as long as the body needs, and ends in natural awakening. No form of sleep disruption is allowed. In particular, any use of an alarm clock is the cardinal violation of the free running sleep principle.

The greatest shortcoming of free running sleep is that it will often result in cycles longer than 24 hours. This

eliminates free running sleep from a wider use in society. However, if you would like to try free running sleep, you could hopefully do it on vacation. You may need a vacation that lasts longer than two weeks before you understand your [circadian](#) cycle. Even if you cannot afford free running sleep in non-vacation setting, trying it once will greatly increase your knowledge about natural sleep cycles and your own cycle in particular. You should also know that it is possible to entrain one's sleep to a desired sleep bracket (e.g. early rising). However, the [entrainment](#) requires iron self-discipline and the religious adherence to the [entrainment](#) rules.

Free running sleep

Free running sleep is sleep that is not artificially controlled to match our schedules and desires. It is a sleep without alarm clocks and sleeping pills. Mankind has practised free running sleep for as long as it existed. Our ancestors were gently encouraged to retire to bedtime at sunset, and would wake up naturally, probably after having spent no less than 8-10 hours in bed (see also [Segmented sleep](#)). All departures from that healthy practise were an imposition of culture, habit, religion, and/or tradition. Despite our ancestors' lives being fraught with danger, superstition, wars and disease, we should pause and ponder the marvellous impact of this naturally undisturbed sleep on their health. The arrival of fire and candlelight did not provide much incentive to stay up except for those few that have always had much to do in the evening: the first bookworms and artists. Only the genius of Edison and the like brought in the true sleep scourge: the electricity. With the wide dissemination of printed matter and electric lighting, millions would find their evening book far more interesting than sleep. Enter the web. In 2012 AD, we have an endless spectrum of entertainments and distractions that lure everyone away from bed and healthy slumber. More and more, we want to squeeze sleep into designer brackets. We wish to fall asleep at a specific time, and wake up at a specific time. Amazingly, a big chunk of the population does not realize that this is not possible without a detriment to health! Luckily, nearly everyone has the intuition that sleep is vital for healthy living. Those who would want to dispense with sleep altogether form a tiny minority. Nearly all creative people would wish to wake up fresh and ready for action. Preferably at a specified time. The same people wish to be less tired in the evening before sleep, and fall asleep instantly. Preferably at a specified time. Let me then state it in bold print:

If we exclude unhealthy techniques:

1. **It is not possible to fall asleep whenever we wish.**
2. **It is not possible to wake up whenever we wish.**
3. **It is not possible to eliminate evening sleepiness.**

However disappointing this might be, everyone would do better in life if those truths were assimilated. If we agree to wake up naturally at one's body's preferred time, it should be possible to be fresh and dandy from the waking moment. However, a decline in mental capacity over the waking day is inevitable. It is natural. Midday dip in alertness is also inevitable. And the optimum bedtime is hardly movable. If you try to advance it, you will likely experience [insomnia](#). If you try to delay it, you will cut down on sleep and possibly wake up unrefreshed. If you try to wake up earlier than your natural hour, e.g. by employing an alarm clock, you will wake up with a degree of [sleep deprivation](#) that will affect the value of sleep for your learning and creativity. Don't be fooled by the illusive boost in alertness caused by the alarm clock. Yes. This happens to some people, some of the time. This perpetuates the myth that it is possible to wake up fresher with the ring of the alarm.

**There is only one formula for healthy and refreshing sleep: Go to sleep only when you are very tired.
Not earlier. Not later. Wake up naturally without an alarm clock.**

This simple formula is called **free running sleep**. For many people, after years of sleep abuse, even free running sleep can be tricky. It will take a while to discover one's own body's rules and to accept them. You will know that you execute your free running sleep correctly if it takes no more than 5 min. to fall asleep (without medication, alcohol or other intervention), and if you wake up pretty abruptly with the sense of refreshment. Being refreshed in the morning cannot be taken for granted. Even minor misalignment of sleep and the [circadian](#) phase will take the refreshed feeling away. After months or weeks of messy sleep, some [circadian](#) variables might be running in different cycles and free running sleep will not be an instant remedy. It may take some time to regulate it well enough to accomplish its goals. It cannot even be excluded that after years of shift-work or jetlag, some brain cells in the sleep control centers might have died out making it even harder to achieve well aligned refreshing sleep. In addition to all these caveats, stress is one of the major factors contributing to destroying the fabric of sleep. In free running sleep, stress will make you go to sleep later, take longer to fall asleep, and wake up faster, far less refreshed. [Combating stress](#) is one of the most important things in everyone's life for the sake of longevity and productivity.

Partners and spouses can free run their sleep in separate cycles, but they will often be surprised to find out that it is easier to synchronize with each other than with the rest of the world (esp. if they have similar interests and daily

routines). If they are co-sleeping, one of the pair will usually get up slightly earlier and work as a strong zeitgeber for the other. The problem will appear only when the length of the naturally preferred sleep cycles differs substantially between the two. In such cases, instead of being a zeitgeber, the other person becomes a substitute for an alarm clock.

Even if you are not convinced, you should try free running sleep to better understand the concept of the sleep phase, and how the sleep phase is affected by various lifestyle factors. You will often notice that your supposed sleep disorder disappears! Note that the free running sleep period is not solely genetic. Various factors in the daily schedule are able to shorten or lengthen the period. Of the obvious ones, bright light in the morning or melatonin in the evening may shorten the cycle. Exciting activities in the evening will lengthen it. The period changes slightly with seasons. It will also change when you leave on vacation. It often gets shorter with age. Try free running sleep to understand your own sleep parameters. This will help you synchronize with the rest of the world, or at least get quality refreshing sleep. Please read more about free running sleep in this article. Throwing away the alarm clock is not a panacea. You may need to learn a bit about the hygiene of sleep.

Should we free run our sleep?

As it will be discussed later, free running sleep can be used to solve a number of sleep disorders except for those where there is an underlying organic disorder that disrupts natural sleep mechanisms. However, you will often hear two arguments against adopting the use of free running sleep:

- **Argument 1** - free running sleep will often result in a day that is longer than 24 hours. This ultimately leads to sleeping in atypical hours. This seems to go against the natural 24-hour cycle of light and darkness. Less often, the cycle will be less than 24 hours
- **Argument 2** - sleep can be compared to eating. Your body will always try to get more than it actually needs. This will result in spending more time in sleep than necessary. In other words, free running sleep is time-inefficient

Argument 1: Phase shifts

It is true that free running sleep will often run against the natural cycle of light and darkness. However, the departure from the natural rhythm is a direct consequence of using electric lighting and modern lifestyle. Our ancestors could expect little but darkness and boredom past sunset. Prolonged darkness and boredom are quite efficient in lulling humans to sleep. If we stubbornly refuse to use electric lighting beyond a certain hour, we will still find it difficult to run away from the excitements of modern lifestyle. To shut your brain to sleep efficiently in the early evening you would probably need to quit your current job and pick some uninspiring one, give up your intense family life, give up your hobbies and interests, give up the Internet, evening TV, etc. We live more stressful and more exciting lives than our grandparents. Turning the lights off in the early evening would probably only be wasteful. Additionally, shortsightedness, the ailment of the information age, makes us less sensitive to the light zeitgeber and artificially prolongs the **circadian** cycle. There are a number of downsides to free running sleep. The worst shortcoming is a difficulty in establishing an activity cycle that could be well synchronized with the rest of the world. Stabilization of the cycle is possible with self-discipline in adhering to cycle-reset rules such as morning exercise, bright light, sleep protective zone in the evening, etc.

Argument 2: Excessive sleeping

It is true that people who try to free run their sleep may find themselves sleeping outrageously long in the very beginning. This, however, will not last in a healthy individual as long sleep is a body's counter-reaction to various sleep deficits resulting from **sleep deprivation**. Unlike it is the case with foods, there does not seem to be any evolutionary advantage to getting extra sleep on days when we can afford to sleep longer. In the course of evolution, we have developed a tendency to overeat. This is a protection against periods when food is scarce. Adipose tissue works as a survival kit for bad times. However, considering the function of sleep, the demand for sleep should be somewhat proportional to the amount of new learning received on preceding days. In ancient times, we did not have exam days as opposed to lazy days. Consequently, the link between learning and demand for sleep is quite weak. The body clock will still make us sleep 7-8 hours on nights following the days of total inaction. Secondly, every extra minute of sleep might improve the quality of neural wiring in the brain. Sleep would better be compared to drinking rather than eating. We do not have much capacity to survive without drinking due to our poor water storage ability. Similarly, we cannot sleep in advance in preparation for a double all-nighter before an exam or important deadline. **The claim that free running sleep increases the natural need for sleep is false! If you happen to sleep longer in free running sleep, it indicates that you were sleep deprived before running free. This longer sleep stage is transient.** On occasion, if you go to sleep very early, you can also clock an excess number of sleeping hours. For more see [Excessive sleeping](#).

In my view, everyone should always free run his or her sleep unless it makes it impossible to function in society along one's chosen profession, specialization, education, etc., or where it makes it impossible to take care of the young ones.

Free running sleep is stressless

Someone suggested that if any change is stressful, switching to free running sleep would be stressful too. The opposite is the case. Perhaps after an exclusion of the initial adjustment period in which people with lesser understanding of chronobiology make mistakes that may result in a decline in their sleep quality. Saying that any change is stressful is a generalization that goes too far. Changing your T-shirts daily does not imply stress. In addition, the degree of change is important. The same change can produce overstress or be a welcome factor in life depending on its degree. Letting your sleep free run does not imply any degree of stress, unless free running sleep itself produces changes in your schedule that might be stressful. If you eat your moderate meals frequently when you feel hungry, you are likely to experience less stressful change than when you eat them at pre-set lunch hours. Free running behaviors, by definition, free your organism to adapt behaviors to body's internal needs. As such, these can be considered anti-stress factors. It refers equally to sleep, eating habits, exercise, and other physiological needs

Free running sleep algorithm

1. Start with a meticulous log in which you will record the hours in which you go to sleep and wake up in the morning. If you take a nap during the day, put it in the log as well (even if the nap takes as little as 1-3 minutes). The log will help you predict the optimum sleeping hours and improve the quality of sleep. Once your self-research phase is over, you will accumulate sufficient experience to need the log no longer; however, you will need it at the beginning to better understand your rhythms. You can use [SleepChart](#) to simplify the logging procedure and help you read your [circadian](#) preferences.
2. Go to sleep only then when you are truly tired. You should be able to sense that your [sleep latency](#) is likely to be less than 5-10 minutes. If you do not feel confident you will fall asleep within 10-20 minutes, do not go to sleep! If this requires you to stay up until early in the morning, so be it!
3. Be sure nothing disrupts your sleep! Do not use an alarm clock! If possible, sleep without a bed partner (at least in the self-research period). Keep yourself well isolated from sources of noise and from rapid changes in lighting.
4. Avoid stress during the day, esp. in the evening hours. This is particularly important in the self-research period while you are still unsure how your optimum sleep patterns look. Stress hormones have a powerful impact on the timing of sleep. Stressful thoughts are also likely to keep you up at the time when you shall be falling asleep.
5. After a couple of days, try to figure out the length of your [circadian](#) cycle. If you arrive at a number that is greater than 24 hours, your free running sleep will result in going to sleep later on each successive day. This will ultimately make you sleep during the day at times. This is why you may need a vacation to give free running sleep an honest test. Days longer than 24 hours are pretty normal, and you can stabilize your pattern with properly timed signals such as light and exercise. This can be very difficult if you are a [DSPS](#) type.
6. Once you know how much time you spend awake on average, make a daily calculation of the expected hour at which you will go to sleep (I use the term **expected bedtime** and **expected retirement hour** to denote times of going to bed and times of falling asleep, which in free running sleep are almost the same). This calculation will help you predict the sleep onset. On some days you may feel sleepy before the expected bedtime. Do not fight sleepiness, go to sleep even if this falls 2-3 hours before your expected bedtime. Similarly, if you do not feel sleepy at the expected bedtime, stay up, keep busy and go to sleep later, even if this falls 2-4 hours after your expected bedtime.

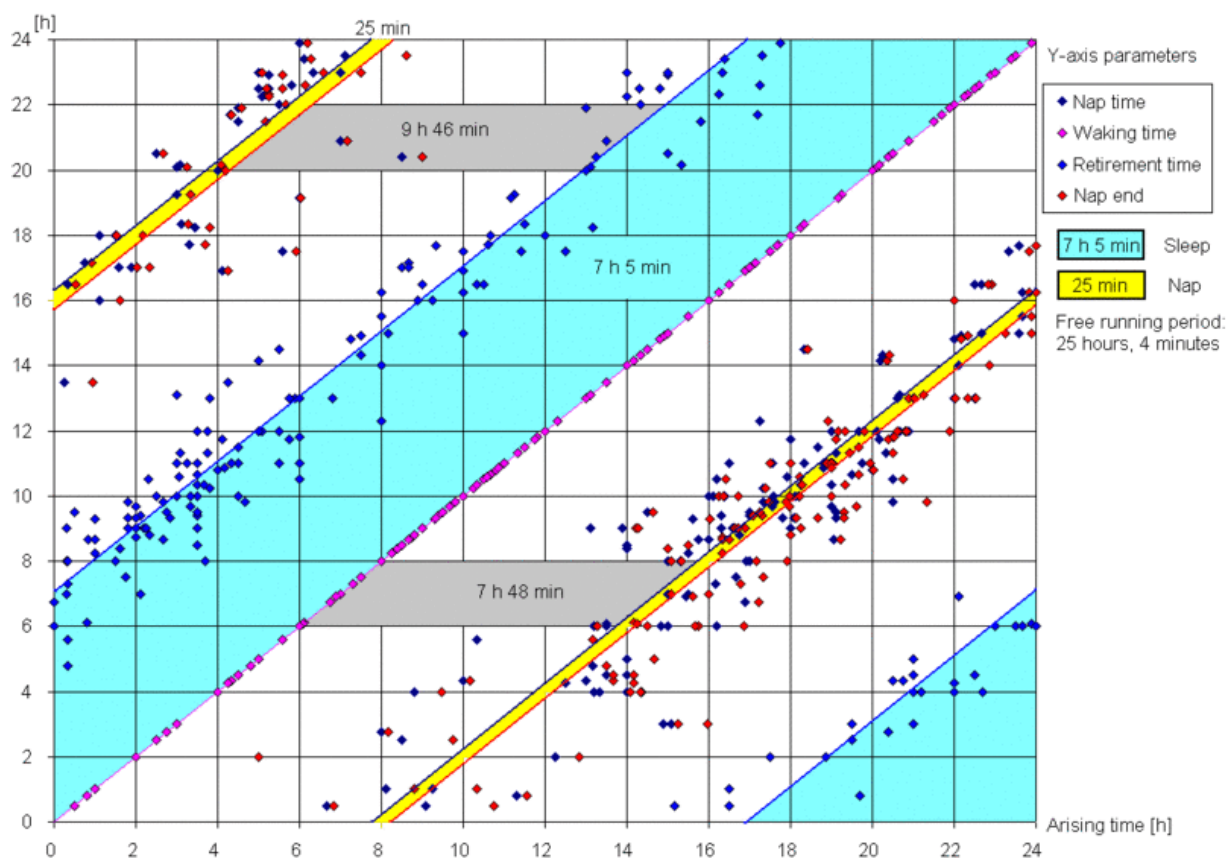
Cardinal mistakes in free running sleep

- do not go to sleep before you are sleepy enough - this may result in falling asleep for 10-30 minutes, and then waking up for 2-4 hours. Ultimately you can experience an artificial shift forward in the entire cycle!
- unless for natural reasons (no sleepiness), do not go to sleep well after the expected bedtime. This will result in missing the period of maximum [circadian](#) sleepiness. Your sleep will be shorter and less refreshing. Your measurements will be less regular and you will find it harder to predict the optimum timing of sleep in following days
- do not take a nap later than 7-8 hours from waking. Late naps are likely to affect the expected bedtime and disrupt your cycle. If you feel sleepy in the evening, you will have to wait for the moment when you believe you will be able to sleep throughout the night

Sleep logging tips

In free running conditions, it should not be difficult to record the actual hours of sleep. In conditions of [entrainment](#)

failure, you may find it hard to fall asleep, or wake up slowly "in stages". In free running sleep, you should be able to quickly arrive to the point when you fall asleep in less than 10 minutes and wake up immediately (i.e. without a period of [sleep inertia](#)). In other words, you can remember the hour you go to bed, add 5-10 minutes and record it as the hour you fell asleep. As soon as you open your eyes in the morning, you should record the waking hour. Usually you should not have any doubts if you have already awakened for good (as opposed to temporarily), and you will usually not fall asleep again (as it may be a frequent case in non-free running sleep). The graph below shows an exemplary free running sleep log in a graphic form:



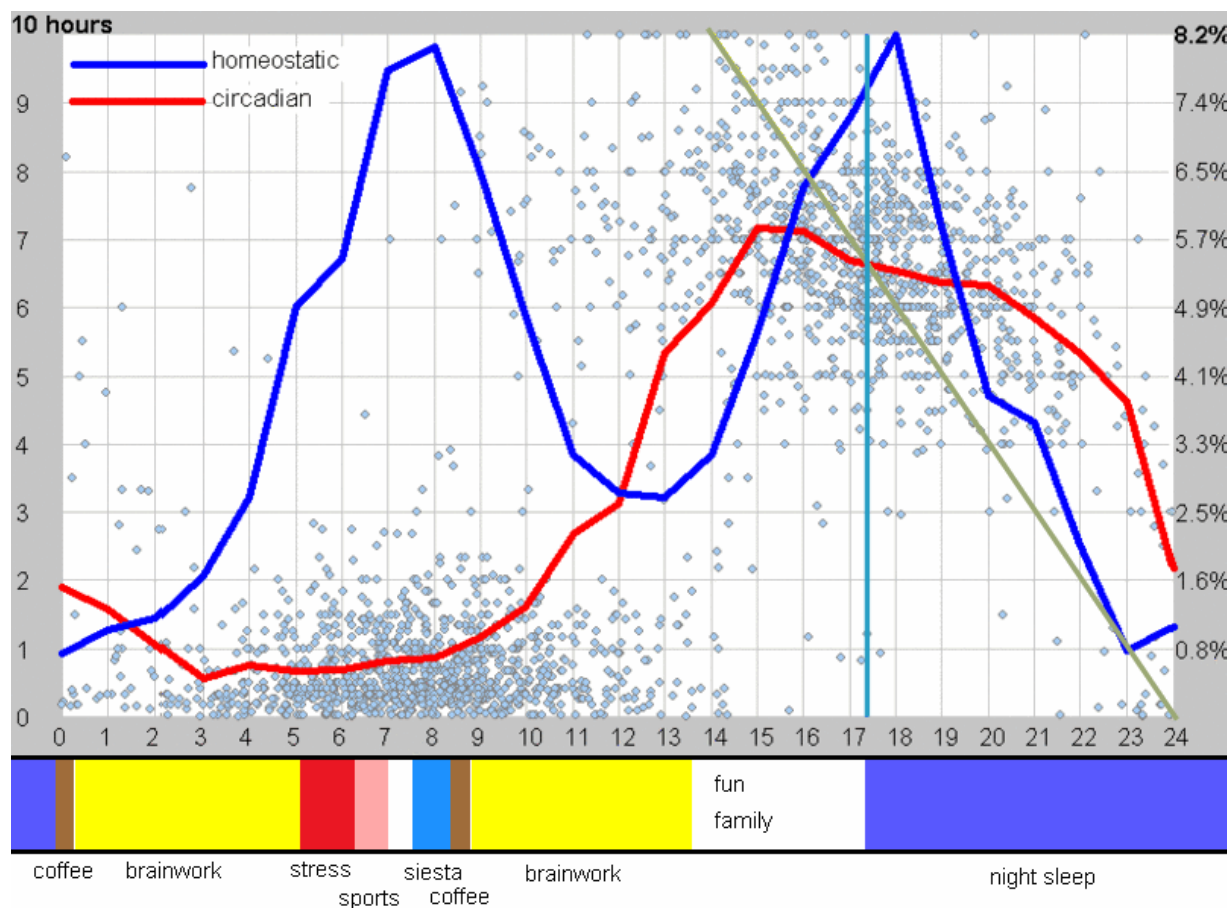
An exemplary 5-month free running sleep cycle graph. In the picture, the average time of night sleep is 7 h 5 min, time before the midday nap is 7 h 48 min, the average nap takes 25 minutes and the time before the nap and the night sleep is 9 h 46 min. The whole cycle adds up to 25 hours and 4 minutes. Note that the distance between the nap and the night sleep in the graph is less than 9 h 46 minutes due to the fact that the blue retirement-line refers to the previous day sleep as compared with the red nap-line. Consequently, the nap-to-sleep band is horizontally shortened by 64 minutes, i.e. exactly as much as the daily phase shift in the cycle.

If you have collected your own free-running sleep data with [SleepChart](#), I would be very grateful for your submissions that will be useful in further research (sending data from SleepChart takes just a single click).

Optimizing the timing of brainwork

Circadian graph and brainwork

The following exemplary [circadian](#) graph was generated with [SleepChart](#) using a log of free-running sleep:



The horizontal axis expresses the number of hours from awakening (note that the free running rhythm period is often longer than 24 hours). Light blue dots are actual sleep episode measurements with timing on the horizontal, and the length on the left vertical axis. Homeostatic sleepiness can roughly be expressed as the **ability to initiate sleep**. Percent of the initiated sleep episodes is painted as a thick blue line (right-side calibrations of the vertical axis). Homeostatic sleep propensity increases in proportion to mental effort and can be partially cleared by caffeine, stress, etc. Circadian sleepiness can roughly be expressed as **the ability to maintain sleep**. Average length of initiated sleep episodes is painted as a thick red line (left-side calibrations of the vertical axis). Mid-day slump in alertness is also circadian, but is biologically different and results in short sleep that does not register as red sleep maintenance peak. Sleep maintenance circadian component correlates with (but is not equal to): (1) negatively with: temperature, [ACTH](#), [cortisol](#), [catecholamines](#), and (2) positively with: [melatonin](#) and [REM sleep](#) propensity. For more details see: [Circadian graph](#) and [Biphasic nature of human sleep](#).

Best brainwork time

Optimum timing of brainwork requires both low homeostatic sleepiness and low circadian sleepiness. There are two quality alertness blocks during the day: first after the awakening and second after the siesta period. Both are marked as yellow blocks in the graph (above). For best learning and best creative results use these yellow blocks for brainwork. Caffeine can only be used to enhance alertness early in this optimum window. Later use will affect sleep (caffeine half-life is about six hours). Optimum timing of exercise may vary depending on your exercise goals and the optimum timing of zeitgebers (e.g. early morning for [DSPS](#) people and evening for [ASPS](#) people). In this example, the stress block is followed by the exercise block to counterbalance the hormonal and neural effects of stress before the siesta. Unmarked white areas can be used for the lunch (before siesta) and fun time unrelated to work in the evening at a time when the ascending circadian sleepiness makes creative work ineffective. That white evening protective zone should be free from stress, [alcohol](#), [caffeine](#), etc. Recommended activities might include fun, games, relaxation, TV, reading, family, DIY, housework, etc. For inveterate workaholics, less challenging and stress-free jobs might also work ok. **The best litmus test for a well designed day is that all activities should be fun!** Brainwork is fun only if your brain is ready. Sleep is fun if you are ready. Rest and entertainment feel in place only after a productive day. Even a bit of stress can be fun if it is properly dosed and timed. You do not need to be an adrenaline junkie to enjoy your stress and exercise slots. There is little exaggeration in saying that **a good understanding of the circadian cycle is the key to a happy and productive day!**

Balanced 24 hour cycle

The slanting green line separates the graph into the areas of phase advanced (right) and phase delays (left). The line is determined by points in the graph where the waking time (horizontal axis) added to the sleep time (left vertical axis) equals to 24.0 hours. The place where the green breakeven line crosses the red sleep length line determines the optimum balanced sleep cycle of 24 hours. In the presented example, 17.35 hours of waking, added to the expected 6.65 hours of sleep time complete a balanced full 24 hours sleep-wake cycle. The greater the angle between the green and red lines, the harder it is to balance sleep and fit it into the 24h cycle of the rotating earth. In the example, adding waking hours does not shorten sleep much enough to make the balance easy. This implies that a religious adherence to a 17.35 day may be necessary to balance the cycle. However, this shortened waking day may increase **sleep latency** and increase the probability of premature awakening, which can also tip the balance towards the phase delay. The vertical aqua line shows where the expected sleep time added to the waking time equals to 24 hours (crossover with the green line representing a perfect 24-hour day). In [DSPS](#) or [ASPS](#) that 24h balance may be hard to accomplish. For example, without medical intervention, only a large protective zone in the evening, early nap (or no nap), and intense morning exercise can help balance the day in [DSPS](#).

Important! This graph is based on data that is true solely for a free running sleep condition. If you use an alarm clock to regulate the timing of your sleep, this measurements and recommendations may not apply! In addition, timing and the amplitude of changes differ vastly between individuals!

Sleeping against your natural rhythm

If you sleep against your natural rhythm you will often experience tiredness or drowsiness that can be resolved by adjusting the sleeping hours. In healthy individuals, the daytime alertness is primarily determined by:

1. [circadian phase and homeostatic sleepiness](#)
2. total sleep time the night before
3. [amount of slow-wave sleep the night before](#)
4. regular adherence to the sleep-wake schedule in preceding days
5. sleep deficits accumulated in the preceding days (e.g. [REM deficit](#), SWA deficit, etc.)

All those factors are closely associated with the sleep phase. [Free running sleep](#) provides the best way to maximize the alertness throughout a waking day. Free running sleep is likely to shift the minimum temperature point from the early morning closer towards the middle of the **subjective night**. You should notice [increased sleepiness before going to sleep](#) and no [sleep inertia](#) upon awakening! If you cannot free-run your sleep, it is very important to understand the relationship between your **homeostatic** and **circadian** sleep drives as compiled in the table below. In the course of the day, you should move in sync between the yellow areas of the table, i.e. [from perfect alertness to maximum sleepiness, and then back to perfect alertness](#). The gray areas illustrate when your sleep falls out of sync:

	High circadian sleepiness	Low circadian sleepiness
High homeostatic sleepiness	Peak of the night: You are very drowsy and fall into refreshing sleep with latency of less than five minutes	Insomnia: You are tossing and turning in bed. You are very tired but you cannot fall asleep. Your temperature, blood pressure and pulse are raised. Your thoughts are racing
Low homeostatic sleepiness	Hypersomnia: You are drowsy throughout the day despite long sleep hours. Napping does not help. You show minimum energy levels. Your muscles are weak and atonic Solution: Adjust your sleep phase to your circadian (e.g. try to go to sleep 3-6 hours later)	Solution: Wait for the arrival of the circadian phase. Delay going to sleep by 3-6 hours Peak of the day: You are alert, energetic, and full of new ideas

Kill the alarm clock!

Alarm clock epidemic

Few upwardly mobile people in the modern rat-race society can live without an alarm clock. With a shot of strong coffee and round-the-clock stress, most people learn to live and survive with an alarm clock. Half of the population

wakes up with an alarm, 9% are woken by a partner, 4% by pets, 3% by children, etc. That leaves a minority that wake up naturally. Increasingly, time becomes the most precious commodity in society where achievement is often associated with speed and perfect time-management. However, alarm clocks introduce harmful side effects: stress, sleep debt, and worst of all, disruption of the natural physiological sleep function. At worst, those factors will result in physical damage to the brain (e.g. such sensitive structures as the hippocampus, your memory switchboard, may literally [lose neurons as a result of disrupted sleep](#)).

The art of time-management makes it possible to live at a high speed with an alarm clock at your side, and still be free from [stress](#). However, the societal damage inflicted by alarm clocks and [sleep deprivation](#) is unforgivable. An alarm clock that interrupts your sleep damages your memories, your ability to learn, your creativity, your mood and temper, your relationships with other people, your ability to focus, and your overall intellectual performance!

Dr Robert Stickgold has showed that people, who learn a skill during the day, do not show significant improvement until they get a sound 7-8 hours of properly structured sleep^[3]. There was a noticeable correlation between the degree of improvement and the quality of sleep received. My own work with [SleepChart](#) also shows that the [use of alarm clocks can dramatically reduce memory recall and consolidation](#). Forgetting is so painless that we rarely notice its effects. In a natural way, forgetting will proceed even if you get as much sleep as you need, and it is difficult to point to specific memories lost as a result of not sleeping enough. Moreover, [sleep deprivation may leave your memories intact while their storage will be sub-optimum](#). The difference may be impossible to spot without measurement. We are more likely to notice sleepiness, reduced mental agility, or bad mood.

Disrespect for sleep has reached biblical proportions. This is most noticeable in the US, and other highly industrialized nations. *Men's Health's* Dan Vergano writing for *ABC News* in "*No More Rude Awakenings*" suggests a seven-day system for fighting sleepiness: "*The secret is to fuel that arousal system so it can **beat the pants off the sleep system**. By creating the kind of feel-good expectations that trigger hormones to wake the brain, you'll override the need to sleep and be able to jump out of bed like a man on fire*". The article suggests a "fresh" mind method that capitalizes on the fact that stress hormones help keep you alert. However, there is a simple and the only rational remedy for "*rude awakenings*": get enough sleep! Jumping *like a man on fire* is not likely to have a positive effect on your creative potential!

You may often notice that waking up with an alarm clock gives you a quick start into a day. You may then come to believe that using the alarm clock might help you keep alert later during the day. This is not the case. The alarm signal simply scares your brain into wakefulness disrupting the carefully planned process of [neural optimization](#) that occurs in sleep. As a result, you get an immediate injection of [adrenaline](#) and your levels of [ACTH](#) and [cortisol](#) also increase. This is cortisol that peaks at awakening in natural sleeping rhythm that provides you with the fresh-mind impression. With passing time, this cheaply gained alertness will wear thin unless you continue abusing your physiology with more "remedies". You may use more scare tactics for keeping yourself alert, abuse caffeine, or even get a more profound effect with [modafinil](#), [cocaine](#), or [amphetamines](#). Alertness should be achieved with the help of sufficient sleep, not despite the lack of sleep! Apart from your reduced ability to learn new things, all unnatural anti-drowsiness methods will produce a great deal of side effects that can be pretty damaging to your health in the long run.

All efforts to overcome sleepiness by means other than sleep itself can be likened to a chase of the first high in the use of psychoactive substances. If you drink buckets of coffee, do pushups, pour cold water over your head, or slap your face, you only dip into the last reserves of your alertness hormones that only worsen the effects of deprivation after the effects of the stimulation wear off, which is usually a matter of minutes. Rarely can you get a boost lasting more than an hour, and the more you perk up, the lower you fall in the aftermath.

Insomnia trap

If your life without an alarm clock may seem like an impossibility, you will probably need to use all methods in the book to be sure you get enough sleep and minimize the damage. If you need to wake up early at the cost of your brain, avoid the [insomnia trap](#)! Insomnia trap is a vicious circle of:

1. going to sleep too early to get more sleep,
2. failing to fall asleep in time (or worse, waking up prematurely),
3. feeling even more tired on the next day, and
4. going to sleep even earlier on the next day to catch up with the lost sleep.

It is better to go to sleep at a natural hour (i.e. a bit later), wake up early, suffer a degree of sleep deprivation, and hope for a phase reset that will make it possible to continue on the [designer schedule](#). For a solution to the insomnia trap see [Curing DSPS and insomnia](#).

If you cannot reset your phase and still feel tired when getting up early on a regular basis, consider choosing a job that

is acceptable for your body, not the other way around. Your long-term health and well-being is at stake. If you absolutely cannot live without an alarm clock, you can at least start from changing your mindset about the importance of sleep and ensure you do not impose wrong habits on your children. Perhaps the young ones will be lucky enough to work in a flex-time system that will make it possible to get sufficient amount of undisturbed sleep. At least, do not set a bad example!

Wake up the President

President Bill Clinton was woken up twice by telephone during the night of April 22, 2000 before the infamous I.N.S. raid on the home of Miami relatives of the young Cuban exile Elian Gonzales. He was probably the most often disrupted and sleep deprived president in history. Only after a heart surgery did Clinton take diet, sleep and (real) exercise seriously. Those interrupted nights would definitely influence his performance and the quality of his decisions! Has anybody thought of a rule: *Do not wake up the president*? A rule that could only be revoked in a true national emergency? President G. W. Bush (b. 1946) was woken up when an American spy plane landed in China in 2001. He was also woken up after a suicide bombing in Jerusalem in 2002. George H. W. Bush (b. 1924) and Hilary Clinton made "waking up in the middle of the night" part of their presidential campaign and prowess. It seems that only Ronald Reagan had pretty strong rules for protecting his own sleep. He also famously napped during some cabinet meetings. He slept through a couple of international events without an apparent negative impact on his somewhat delayed decision-making. Critics would say he slept through the entire [Iran-Contra affair](#). Was Reagan so protective of sleep because he understood the role of sleep better, or perhaps he was just a bit lazier than other presidents? I don't know. However, he sure set a good example.

Alarm clock monsters

Andrea K. wrote to me with skepticism: *"Take the alarm clock away from a typical person and they won't just wake up on their own at their desired time and they will miss work, school, or whatever. An alarm clock can't be that bad for you because of the simple fact that most people use it and I never noticed any problem with them :) Everyone in my family has been using one since they were children, and no one suddenly went crazy or began to mutate into a monster (yet)!"* As I wrote earlier, when you use an alarm early in the morning in order to get to work or to school, you cut off the later stages of sleep. If the intrusion into natural sleep is not large (e.g. from minutes to an hour), the damage may be limited. Alarm clock will do far more damage if it cuts deep into the middle of the night sleep. You can compare the use of alarm clocks to smoking or eating hot dogs. The harm is not great enough to be instantly noticeable. It took the public many years to largely accept that "smoking is bad" or "fast food is bad". It is hard to quantify the degree of damage. However, as we move to knowledge society where our intellectual performance becomes increasingly important, the effects of **sleep deprivation** will come under closer scrutiny and alarm clocks are bound to gradually fall out of favor. Unlike hot dogs, they are already universally hated by their users. Most people are able to somewhat adapt their sleep to their schedules if their routines are regular enough. When those people need to resort to the use of the alarm clock, they cut less of their sleep and the damage is proportionally smaller. Nevertheless, we should always strive at eliminating alarm clocks altogether. Most of all, we should protect our kids from suffering interrupted sleep!

Sleep inertia

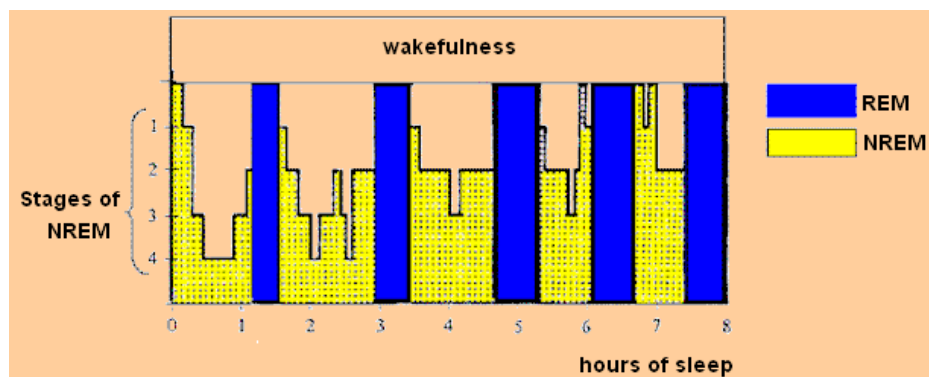
What is sleep inertia?

Sleep inertia is the feeling of grogginess that may follow sleep. There are different types of sleep inertia and there is a monstrous confusion in terminology, as well as a great deal of confusion between different types of sleep inertia in scientific literature. An example of a confusing definition of sleep inertia: *"Sleep inertia refers to the feeling of grogginess most people experience after awakening"*. A more appropriate definition would say *"Sleep inertia refers to the feeling of grogginess that is a result of interrupted sleep or other violations of sleep hygiene"*. Most of all, sleep inertia is not an inevitable part of sleep in humans. In healthy individuals, **sleep inertia is a direct result of errors in the art of sleeping**. With a religious adherence to the principles of sleep hygiene, you need not ever experience sleep inertia and its negative consequences for learning, attention, health, etc.

All research into sleep inertia should clearly distinguish between its different types:

- **interrupted deep sleep** - in the exemplary **hypnogram**, we can see Stage 4 **NREM** setting in after some 30 min. of sleep. Waking up a sleeping subject at this stage is particularly difficult. When woken from deep sleep, we experience an overwhelming need to get back to sleep. The feeling can be compared to being hit on the head with a heavy object. The brain is in a state entirely unsuitable for processing waking information. This is the torture that many polyphasic sleepers impose on themselves by trying to interrupt "naps" taken in their **subjective night**

phase.



- **interrupted REM sleep** - in the **hypnogram**, REM sleep is marked in blue and its occurrence increases towards the end of night sleep. Interrupting fully-blown REM sleep is equally unpleasant. Yet the neurohormonal state of the brain is entirely different than that when the deep sleep is interrupted. One of the easily recognizable hallmarks is muscle weakness. Due to the function of REM, the motor system is turned off in this phase. If you were to test your strength on a hand gripper, you might score less than your kids. Interrupted REM is also frequently associated with dream **recall**. As soon as the brain returns to its typical waking mode, REM dream memories dissipate very fast. If you do not write down your dream instantly, it may be unrecoverable from memory as soon as 5 min. later.
- **waking in a wrong phase** - even natural waking can result in sleep inertia. If you wake up naturally in the period of your **subjective night** sleep, you may feel pretty groggy for a while. The main cause of premature waking is an early bedtime. Sleeping in an early phase is pretty widespread. Many people need to wake up early against their body clock. They will often use various remedies to fall asleep early (from **alcohol** to **sleeping pills**). As a result, they will fall asleep early, wake up early, and seemingly get "sufficient" sleep while still feeling tired and unrefreshed. This is because they wake up while their body is still, in **circadian** terms, in the period of the **subjective night**. Early bedtime will often result in **insomnia**. However, when sleep is initiated successfully, the sleep control system can launch an equivalent of night sleep ahead of time. Such sleep may run its course and even last a bit longer. However, its structure will differ, and the morning **circadian** sleep propensity will still not be fully cleared on waking. As a result, morning grogginess will result as a combination of **circadian** sleepiness and various sleep deficits caused by a change in sleep structure (e.g. REM deficit). Inertia caused by early waking is far easier to combat than interrupted NREM or REM sleep as it largely dissipates with the expiration of the **circadian** sleep propensity. However, minor sleep variable deficits may last for the course of the day. For some people, sleeping in a wrong phase is so much of a daily reality that they tend to forget what a crisply alert mind is, and, as in the mis-definition quoted above, they tend to think this is the "*type of sleep inertia most people experience*", as if it was part of normal human physiology. They might dismiss it by saying "*I am just perpetually tired. It is just me*". Technically, the definition of sleep inertia should also be extended to the brain state caused by a major delay in bedtime. That brain state is similar to the inertia caused by early waking. It may feel more natural as it combines both components of sleep propensity: **homeostatic** and **circadian** sleepiness. Instead of feeling like inertia, it will feel like severe sleepiness that might verge onto nausea. That type of inertia is particularly dangerous for drivers as it only gets worse in time and may results in moments of microsleep when portions of the brain cortex simply enter the sleep mode with the appearance of theta waves in the EEG.

Does sleep inertia show a circadian rhythm?

This question does not have a straight answer. Whatever you read on the subject, make sure you deconvolve the all-encompassing term "sleep inertia" and ask the same question for each of the types of sleep inertia. If you interrupt deep sleep, it will always feel bad. The degree of that feeling will likely depend on the depth of sleep, your **homeostatic** status and, to a lesser degree, your **circadian** status (only because deep sleep is largely homeostatic). However, if you interrupt REM sleep, it is more likely to have a more profound effect at the times of the **circadian REM** peak. Finally, the wrong-phase inertia is purely **circadian**. It will hit you only in the periods of your subjective night, and it will dissipate on its own at time of your subjective day.

How can I recover from sleep inertia?

You can google out dozens of remedies against sleep inertia (**example**), and you might be amazed that there is a big wide hole in reasoning behind all that "Internet advice", which often fails to notice that: **well-timed sleep is the best remedy against all forms of sleep inertia!**

For **interrupted sleep inertia**, NREM or REM, the simple remedy is: **go back to sleep**. The more powerful the inertia,

the greater your chances of quickly falling back asleep. Remedies like [coffee](#) or [exercise](#) might make you feel better (or not), but they can do their own damage. If your profession calls for waking up in the middle of the night, remember that you are doing the service at the cost of your own health and longevity.

Wrong-phase inertia is a bit harder to combat. In many cases you won't be able to fall asleep. Even worse, trying to sleep can sometimes make things worse. The best solution is to suffer through the discomfort, avoid napping till your next [subjective night](#) period, and go to sleep in the right phase. Most of the time, sufficiently long wakefulness and hitting the right phase will help you instantly synchronize all sleep variables. However, in some cases, [circadian](#) ripples may drag for days, esp. if you are not too fluent in computing your correct sleep phase. If you do lots of shift-work or intercontinental flying, it is very easy to be confused about when your [subjective night](#) time occurs. In such cases, you could use [SleepChart Freeware](#) to get some visual support that makes a guess easier.

Can sleep impair learning?

Amazingly, the confusion into the types of sleep inertia has been responsible for yet another myth: sleep before learning increases forgetting! Well-timed sleep will not cause sleep inertia and will not contribute to a decline in learning. Just the opposite, it is 20-60 min. after natural waking when the learning results are best. Naturally, this is only true in free running sleep. All too often, alarm clocks are used to interrupt the night sleep and the early morning is pretty uncondusive for learning.

Why naps cause sleep inertia?

Naps will cause sleep inertia only if they are taken:

1. too late, or
2. in conditions of severe sleep deprivation, or
3. in conditions of [REM sleep deficit](#).

All those three conditions can fool the sleep control systems into thinking that the nap is the opportune time for launching a full-night sleep episode. If an attempt to launch full-blown sleep takes place long before the main [circadian](#) low (nighttime [acrophase](#)), you may wake up prematurely with the sense that you got an incomplete and unrefreshing nighttime sleep. Such sleep will leave you groggy and will make it harder to initiate proper sleep during the [subjective night](#). To avoid sleep inertia associated with napping then, avoid [sleep deprivation](#) in the first place, and read about the [optimum time window for napping](#).

Long sleep and sleep inertia

Many people believe that long sleep causes sleep inertia, headaches, etc. The root cause of problems that follow long sleep is prior [sleep deprivation](#) or sleeping in a wrong phase. Unusually long sleep is simply not possible in a healthy individual on a free running schedule. It is usually a severe [sleep deprivation](#) that makes it possible to fall asleep well ahead of the optimum [circadian](#) bedtime. The unusually long sleep will then carry through the subjective evening and the entire subjective night, adding up to some highly unusual sleep totals (12-18 hours). Such sleep is often followed by a state that is reminiscent of sleep inertia (the "worn-out" syndrome). No wonder it is easy to build a wrong association between long sleep and sleep inertia. It is very difficult to persist in a long-sleep routine, since the sleep-regulating mechanism will quickly bring the length of sleep to a more typical range. On one hand, the "worn-out" syndrome might seem to persist if the sleep period is wrongly adjusted to the [circadian](#) cycle. On the other hand, the "worn-out" observation is usually produced by those who cannot get enough sleep during the week and then sleep long on the weekend. In the latter case, follow-up observation is often impossible due to the next week's obligations. This deepens the wrong conviction that too much sleep is harmful. **Healthy individuals cannot get "too much sleep"**! Their brain will simply produce natural waking up at the right time. [Drs Jim Horne and Daniel Kripke may claim otherwise](#). Perhaps they never tried to nod off at a peak alertness window?

Health effects of shift-work and jetlag

Nearly 20% of the population in the industrialized nations is involved in shift-work! Surveys show that only 10% of the shift-working population have no complaints about the negative impact of their sleep schedules on their health and life^[12]. With well-designed shiftwork, those numbers could look much better. This would not, naturally, change the fact that all forms of sleep regulation are risky and potentially unhealthy. Research shows that shift-workers suffer from various gastrointestinal and cardiovascular problems. Cardiovascular changes might be mediated by inflammatory markers such as [C-reactive protein](#). Many have problems with achieving refreshing sleep. After many days of chronic sleep restriction, a significant degree of cognitive decline accumulates. This decline leads to levels that

in the end approach those found in severe acute total [sleep deprivation](#). Substance abuse among shift-workers is also much higher than average. Seemingly minor problems such as headache, inattention, decline in libido, fatigue, irritability, etc. all add up to pretty miserable life for a vast majority of workers on a poorly designed shift schedules. The set of problems affecting shift-workers is pretty familiar to researchers studying jetlag. Separate medical terms have been coined for the two related sets of symptoms: shift work disorder (SWD) and jet lag disorder (JLD). The most dramatic finding in reference to jetlag was the loss of cells in the hippocampus in flight attendants who were employed for longer periods in jobs involving intercontinental flights (Cho 2001^[13]; Cho et al. 2000^[14]). We can surmise that the exactly same health issues (times ten) would affect [polyphasic sleep](#) adepts if they could only last on their schedule long enough.

In addition to the direct effects of sleep phase misalignment, there is also a degree of [sleep deprivation](#) in shift-work and jetlag. Sufficient sleep is important for proper glucose metabolism and prevention of obesity and [type II diabetes](#). Sleep restriction decreases the levels of [leptin](#) and has an opposite effect on [ghrelin](#). Those two appetite hormones, as a result, make sleep deprived individual feel hungrier than well-rested individuals and shift upwards the set point of body fat weight in the caloric balance homeostat. Restricting sleep to 5 hours per night causes some 20% change in the levels of these appetite control hormones. This change corresponds to some extra 1000 kcal in free running feeding, or over 3 kg of fat per month in energy terms. Sleep restriction can easily halve [insulin sensitivity](#) leading to [type 2 diabetes](#). It also significantly increases the risk of [hypertension](#), [stroke](#), [heart attack](#) or [kidney failure](#) (Van Cauter et al. 2007^[15]). Other hormonal changes include increase in thyroid hormone levels (Allan and Czeisler 1994^[16]), [prolactin](#), [LH](#), and [estradiol](#) (Baumgartner et al. 1993^[17]). Finally, the root cause of many [phase shift](#) problems is a complex impact of shift-work and jetlag on the [circadian](#) changes in the level of the stress hormone [cortisol](#). The net effect of the impact of cortisol level changes is the hypercatabolic state that effectively results in the body "eating itself up" in the long run. This way, when neglecting your body clock, you can become obese and biologically "wasted" at the same time.

In 2007, the International Agency for Research on Cancer issued a statement saying "*Shiftwork that involves [circadian](#) disruption is probably carcinogenic to humans*". Using the term "*carcinogenic*" is probably slightly misleading as the actual cause of increased cancer in shift-workers is probably related to the decline in the immune function and the body's natural ability to fight off mutating cancer cells. However, the statement is important as it seals the fate of shift-work and jetlag, which should ultimately fall into the category of long-term health risk factors that cause wide ranging and serious systemic health problems.

Poorly designed shift-work, jet lag, and sleep deprivation are all serious systemic health risks that affect your well-being and longevity.

For more about the tiny and delicate structure of the body clock, see the section devoted to the [suprachiasmatic nucleus](#).

Properly designed shift work

I often qualify shift-work as a health risk with the designation "poorly designed". This is because it is possible to design schedules for a group of people where the [circadian](#) disruption is minimum. Using [chronotherapy](#) it is possible to gradually phase in employees into working through the night. The chief principle of such a therapy is that phase shifts should not exceed one hour per day and should, with few exceptions, be forward shifts (i.e. shifts where the days are longer than 24 hours, not shorter). All therapies that depart that principle and involve leisure time, napping, bright light, [melatonin](#), [sleeping pills](#), [modafinil](#), etc. are a pure waste of time as they keep fighting the inevitable: a misalignment between the work time and the [subjective night](#) period. This misalignment can only be remedied by a gradual properly timed phase-shift-based adjustment.

Even though many shift workers will disagree with me (mostly for psychological and convenience reasons), I insist that it should be easier and healthier to maintain a night shift for a longer period (e.g. a month) than to do regular cycling between night and day without the [body clock](#) having any chance for adjustment. Some cancer researchers also oppose long periods on night shifts due to the documented decline in [melatonin](#) that is believed to have cancer protective properties^{[18][19]}. However, those need to be weighted up against an even more serious problem of the [circadian](#) disruption.

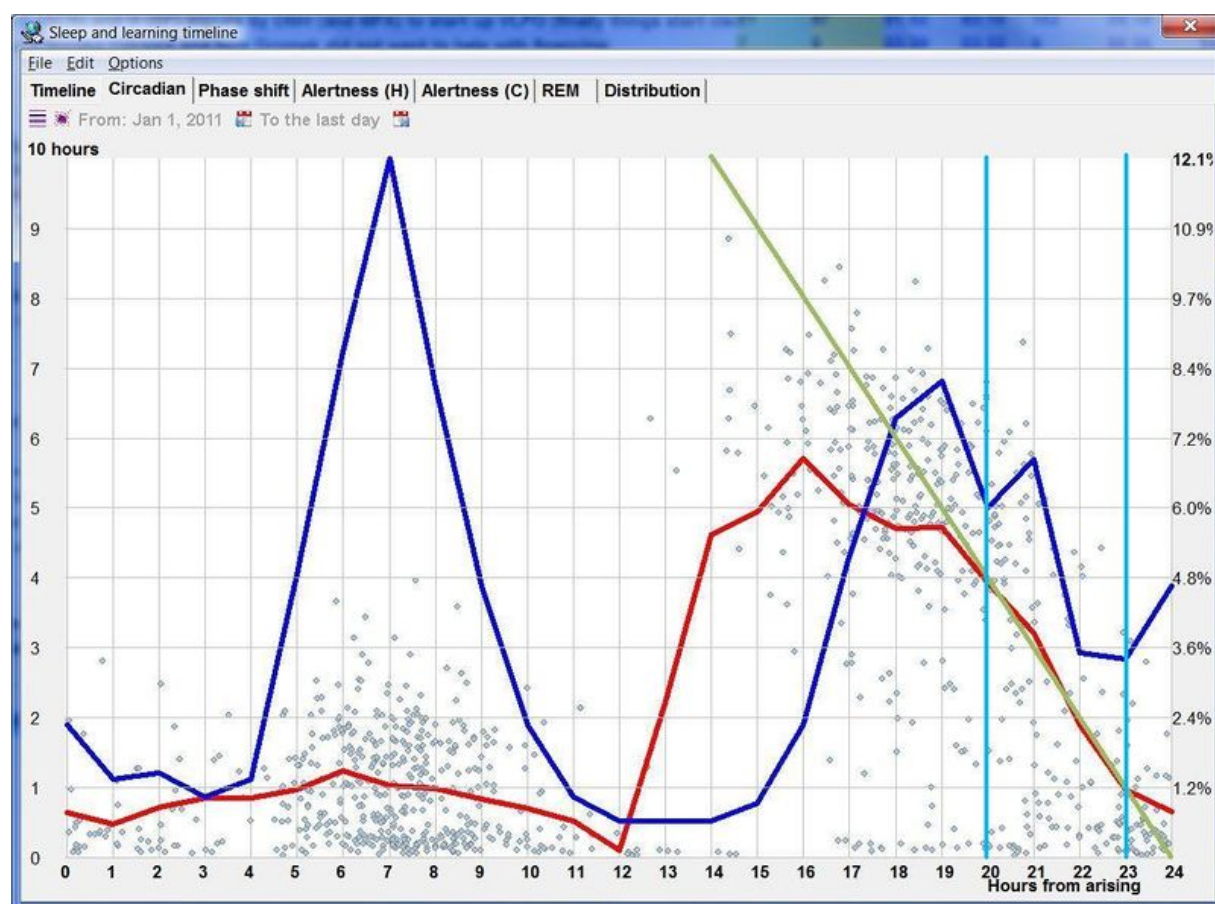
Excessive sleeping

One of the most persistent myths about sleep is that our body is programmed to get as much sleep as possible. Even some [reputable researchers](#) subscribe to this idea! They compare sleep to overeating. Some note how long Inuit sleep

in winter. Others note that people allowed to sleep freely often binge heavily and clock up an indecent number of sleeping hours. As if conservation of energy was the main function of sleep. As if all animals were made as lazy as they are perpetually hungry.

Some scientists even contemplate sleep restriction analogous to calorie restriction. It is conceivable that sleep restriction might be helpful in some rare cases in sick people (e.g. "wake up to get your medicine"). However, its analogy to calorie restriction is as weak as the reverse proposal: wake restriction. The myth was probably born from epidemiological studies that show that people who sleep 7 hours per night live longer than those who sleep 9 hours per night. However, the suggestion to restrict sleep to live longer is as smart as an effort to shrink or stretch people just because those who are very short or very tall do not live as long as an average man in the street.

We can't demonstrate any evolutionary advantage to getting more sleep than neurally necessary. The harmful myth of excessive sleeping might make you think that free-running sleep will make you sleep longer in the same way as free access to the kitchen will make you overeat. Considering the known functions of sleep, there is no specific benefit to sleeping beyond the standard 6-8 hours. Sleep is a neurophysiological consumer of benefits accumulated in waking (such as learning, exercise, etc.). Its healthy **homeostatic** and **circadian** control roughly ensures the optimum proportion of sleep to waking. People who binge on sleep in free-running conditions usually come from a period of long-lasting **sleep deprivation** or initiate sleep too early in reference to their **circadian** phase. Their total sleep time quickly drops to their natural average after a couple of days on a free schedule. A study showed that to get over 8 hours of uninterrupted sleep, the sleep should be initiated some 6 hours before the temperature nadir (shortly after the alertness **acrophase**) (Dijk and Lockley 2002^[20]). The same can be seen in **SleepChart** data submissions. For example, in the presented graph, the maximum length of sleep is obtained when sleep is initiated 3 hours ahead of the most favored bedtime (merely an hour after the evening "forbidden sleep zone"). Those observations have put paid to the idea that we have a tendency to sleep excessively.



Circadian graph that shows that "excessive sleeping" occurs when sleep is initiated too early. In the graph, sleep initiated in the 16th hour is longer than average, while the sleep-wake cycle does not add up to 24 hours (unbalanced cycle with phase advance). In contrast, sleep initiated in the preferred 19th hour is nearly an hour shorter and produces a perfectly balanced 24-hour sleep-wake cycle.

If your main concern is time, you can survive on less sleep and get more time at the cost of your mental acuity. If your main concern is the brain power, you should live by the motto: **Maximum efficiency of sleep is accomplished when sleeping without artificial sleep regulation** (i.e. without alarm clocks, pills, designer schedules, substances, etc.).

Free-running sleep schedule will make you sleep less on average. It will make you sleep much less than on any artificial sleep schedule that forces you to catch up with the accumulated sleep debt. Irregular schedule is bound to produce deficits because you can accomplish irregular sleep only by interfering with it. To read more about excessive sleeping see: [Jim Horne and Daniel Kripke](#).

Sleep habits

In this section, I would like to demonstrate that people can differ vastly in their sleeping habits, and some of the differences have an important underlying biological cause. Scientists use the term **chronotype** to differentiate between different sleeping time and duration preferences that characterize different individuals. One person's **chronotype** might make him a short sleeper. Another's **chronotype** will make him an owl. Yet another's **chronotype** will make his doctor diagnose a sleep phase disorder. Despite a seeming variety, a small set of underlying variables should make it rather easy for you to figure out your own **chronotype**. Your **chronotype** may determine your suitability for certain professions. Luckily, you do not need to determine your **chronotype** before you choose your major or your job. Many people naturally gravitate towards activities and professions that match their natural sleep habits. A physician or a fireman needs to tolerate shift work and interrupted sleep. Milkmen get up early, while gym or disco owners need to stay up late, while a writer may be of any **chronotype** as he/she can adapt his/her writing hours to his/her sleep patterns. To illustrate individual sleep patterns I use a freeware application called [SleepChart](#) that you can download [here](#) to visually chart your own sleep (Wozniak et al. 2003^[21]). If you collect a few months of data, I would be very happy to receive your data file for analysis and future research. Sending **SleepChart** data requires a single click in the program.

Body clock

The cycle of sleep and waking is regulated by the body clock. Body clock is located in the brain and is primarily based in the suprachiasmatic nucleus (see the chapter devoted to the [SCN](#)). The clock has a period of about 24 hours. During a single 24 hour day we have a period of 5-10 hours when we are very sleepy. This is the time when we normally sleep. During the remaining 14-19 hours we are usually awake or take a nap at **siesta** time. As mentioned earlier, only a small portion of the waking time is suitable for top-quality intellectual effort (see: [Optimizing the timing of brainwork](#)). The period of maximum alertness may last as little as 2-4 hours. We should plan our day in such a way so that sleep comes at the time of maximum sleepiness, while activities that demand maximum focus or creativity fall into the hours of maximum alertness. It is very difficult and usually very unhealthy to force the body and the body clock to change the timing of waking activities and sleep. It is far easier to do the opposite: adapt one's life to the natural cycle governed by the body clock. That adaptation will depend on the unique properties of one's own body clock. In the following sections I will try to show different types of sleep habits determined by the properties of the body clock that characterize a given individual.

Components of sleep in phase disorders

There are two main mechanisms that regulate sleepiness (see: [Two components of sleep](#)). One is the **body clock**, and the other is the "wake-meter". Body clock produces increased sleepiness every 24 hours. The wake-meter increases sleepiness with prolonged wakefulness (i.e. the longer we do not sleep, the sleepier we are). In sleep literature, these two mechanisms are called the **circadian** and **homeostatic** components of sleep propensity.

Sleep control components:

- **circadian clock** - **circadian** clock produces sleepiness in 24 hour cycles
- **homeostatic control** - wake-meter measures the period in which we stay awake and triggers sleepiness after we stay up for long enough

In people affected by [DSPS](#) or [ASPS](#), there may exist a combination of several factors that make it harder to get good sleep in normal hours:

- **Circadian** clock runs in periods far different from 24 hours. For example, in DSPS people, the **circadian** clock may be set to 25-26 hours.
- **Circadian** clock is not sensitive to time resetting factors (termed *zeitgebers*). Normal people reset their clock in the morning by light and activity. In addition, darkness and inactivity in the evening provide further clues for the clock. Normal people with normal lifestyles can easily synchronize their sleep with the day-night cycle.
- Homeostatic wake-meter has an unusual time constant. Sensitive wake-meters will make people get tired very quickly after awakening. Insensitive wake-meter may make people tend to stay up for long. [Caffeine](#) abuse could

contribute to a fast decline in alertness via [adenosine](#) receptor downregulation.

- Lifestyle has a dramatic effect on the behavior of the [circadian](#) and [homeostatic](#) sleep regulation mechanisms. The same individual will show a different sleep pattern depending on such factors as: using artificial lighting, [exercise](#), level of [stress](#), timing of exciting activities, [napping](#), [diet](#), climate, changes in ambient temperature, health status, etc.

Lark-owl misconception

Research shows that 15% of people would classify themselves as "morning type" or lark. Another 20% would call themselves "evening type" or owl. The remaining 65% are indifferent or "mid-range". What is your type? You can find many lark-or-owl tests on the net. However, I have not yet seen even one that would be well-designed to truly answer the question of your genetic predispositions. In particular, the same person on a work-week schedule may be classified as a different [chronotype](#) than when he or she is on a [free running schedule](#).

Few people know that they can easily adapt to a completely different schedule by means of chronotherapy (e.g. by shifting their sleeping hours by 30-45 minutes per day). If you ask a typical owl to go to sleep 30-45 minutes later each day, the owl will keep shifting its bedtime to later hours. Initially, it will sleep during the day. That sleep will shift gradually to even later hours until the owl finds itself going to sleep in the very early evening just to get up before the larks! Surprisingly, even the most committed owl can then comfortably stick to the early waking hours for quite long! There is little natural preference as to the sleeping time of the day!

However, there is a factor that drives people into believing they are of a given sleep-time preference type. This is the length of the [circadian](#) cycle and their ability to entrain it to 24 hours. As mentioned earlier, typical [circadian](#) clock period lasts longer than 24 hours. Those people whose cycle is particularly long tend to go to sleep later each day. They push the limit of morning hours up to the point when their compulsory wake-up time results in unbearable sleepiness. In other words, people with long cycles will tend to work during the night and sleep in the morning as long as it is only possible.

Larks and owls do not differ in their preferred timing of sleep in reference to daytime! The difference comes from the length of the [circadian](#) cycle, sensitivity to zeitgebers, and lifestyle. You can easily make a lark work comfortably late into the night and make an owl get up at 3 am. This can be done by chronotherapy (cycle adjustment)! Moreover, owls can keep getting up at dawn if they adopt an ancient [farmer's lifestyle](#) (e.g. by giving up electricity).

A smaller proportion of people will experience short [circadian](#) periods and experience extreme sleepiness in the early evening. This is the lark type. Life forces larks to go to sleep slightly later than their natural preference (family, work, light, etc.). This keeps larks in line with time and they will often claim that the quiet of the morning, the singing of birds or the beauty of the sunrise keeps them getting up early. Yet it is still possible to forcibly push a lark to gradually shift sleeping hours and behave like an owl!

In a modern society, only a small fraction of people can boast a perfectly steady and regular natural sleep pattern. Not only are these the healthiest people around, they are also creatures of habit in reference to their sleep and waking rituals. They obey their rituals religiously, avoid alarm clocks, avoid evening entertainment, avoid medication that affects sleep, etc. Unlike those well-regulated individuals, owls shifted to a morning schedule will gradually tend to advance to their standard late-night rhythm. Similarly, larks will quickly shift back to getting up with the birds.

Some correlation studies showed that owls (as defined by the timing of melatonin release) exhibit slightly higher IQs than larks (Roberts and Kyllonen 1999^[22]).

Charting sleep with SleepChart

Understanding the control mechanisms that produce sleep and wakefulness is extremely helpful in understanding sleep habits. It is particularly useful in individuals suffering from a number of sleep disorders, esp. [insomnia](#) and phase-shift disorders. Simple measurements of [circadian](#) variables and simple tools of chronotherapy may bring sound sleep to those who often struggled for years with [insomnia](#), unsatisfying sleep, or sleep in wrong hours. Better understanding of chronobiology could also help extinguish dangerous practices such as [poorly planned shift-work](#), disrespect for health consequences of the jet lag, cumulative [sleep deprivation](#) and the Internet fad of [Uberman sleep](#).

To illustrate various sleep habits I use charts from a freeware program [SleepChart](#). You can download [SleepChart here](#) and begin your own analyses today. All you need to do in the program is to click the beginning and the end of the sleep block in the graph. See the bottom of the [SleepChart](#) window for exact time corresponding with the position of the

mouse pointer. If you set a wrong block, select it with a click and press *Del*.

Using [SleepChart](#) data, I will try to explain the main reason for which healthy people may not be getting refreshing sleep: **sleep phase problems**.

SleepChart attempts to approximate the circadian [acrophase](#) that correlates with maximum sleepiness, low body temperature, low [ACTH](#), high [melatonin](#), etc. The underlying assumption is that when you log your sleep with SleepChart, you do not attempt to artificially play with the sleep hours. Each intervention in the sleep schedule makes the tools used in [SleepChart](#) work with lesser accuracy. Here are the most important interventions that should be avoided:

1. waking up with an alarm clock,
2. combating sleepiness in the evening (e.g. in order to delay sleep), and
3. controlling sleep with substances (e.g. [alcohol](#), [sleeping pills](#), etc.).

On those rare occasions when you delay sleep or use an alarm clock, you can disqualify the sleep episode with the appropriate markings. However, all attempts to modify the sleep schedule will partly fool the algorithm and your reading will be inaccurate or plain wrong. It is also very important that you do not attempt to follow the [circadian](#) approximation when determining your optimum sleeping hours! You should always give priority to your natural body signals, i.e. sleepiness. Following [SleepChart](#) approximations can result in a positive feedback of error. In other words, errors in the graph may be amplified by your attempts to follow the graph. This can disrupt the sleep cycle. At worst, you could even self-diagnose yourself with [DSPS](#) without actually suffering from the disorder! Your only and sole "go to sleep" criterion should be rapidly increasing sleepiness. You may use the graph to approximate the moment in which the readiness for sleep will occur so that you could "cool down" in time. You can also find [SleepChart](#) helpful in chronotherapy for [ASPS](#) or [DSPS](#) to make it easier to schedule your appointments without conflicting with your natural sleep rhythm.

Courtesy of the numerous contributors who sent in their [SleepChart](#) data, we can draw a number of interesting conclusions. The most compelling one is probably the confirmation of the hypothesis that we might be facing an epidemic of [Delayed Sleep Phase Syndrome \(DSPS\)](#) in younger generations, esp. among students and people employed in high-tech jobs. The epidemic is a result of an ever-growing discrepancy between the environment in which humans and their primate ancestors evolved over the last several million years, and the environment in which we live today with electric lighting, Internet, computers, TV, rat race, and 24-hour society. The increasing gap between lifestyles and biology leads many to seek radical solutions and take on drastic measures. A quick survey of those who attempted to adapt to an [Uberman sleep schedule](#) reveals an interesting truth. Although the idea to squeeze in more waking hours into a day is very appealing, most of the "experimenters" began their interest in [polyphasic sleep](#) as a result of troubles with achieving refreshing sleep!

Some people reacted with skepticism to the concept of using [SleepChart](#) as a sleeping prop: *"it is just far too complicated and Ockham's razor needs to do a bit of shaving! Sleep is as natural as breathing air or drinking water and if you have to set up complicated charts and experiments, and utterly eccentric sleep-activity patterns just so as to get some decent shut-eye, then you must have a problem - but one more of a psychological than a physiological nature"*. It is true that sleep will occur naturally in a natural setting. The trouble begins when we interfere with nature using [caffeine](#), [alcohol](#), [nicotine](#), artificial lighting, 24/7 society, night-time entertainment, etc. [SleepChart](#) may seem complex, but it might still be the easiest way to predict the optimum timing of sleep in free-running conditions for people who may have problems with sleeping. [SleepChart](#) will only ask you when you go to sleep and when you wake up (naturally). All computational complexity is hidden in the background. The approximation procedure needs no further input from the user and it predicts the [circadian acrophase](#) as well as the optimum bedtime. [SleepChart](#) can even disentangle [homeostatic and circadian components of sleep](#). Understanding these can also be helpful in planning healthy sleep.

I agree that the need to resort to tools such as [SleepChart](#) is a sign of troubled times. However, [SleepChart](#) has a proven record of helping people understand their seemingly irregular sleep patterns and organizing their sleep. Falling asleep might be natural, but there are many factors that mask sleepiness or magnify it. For people on very irregular sleep schedules this can pose an insurmountable obstacle!

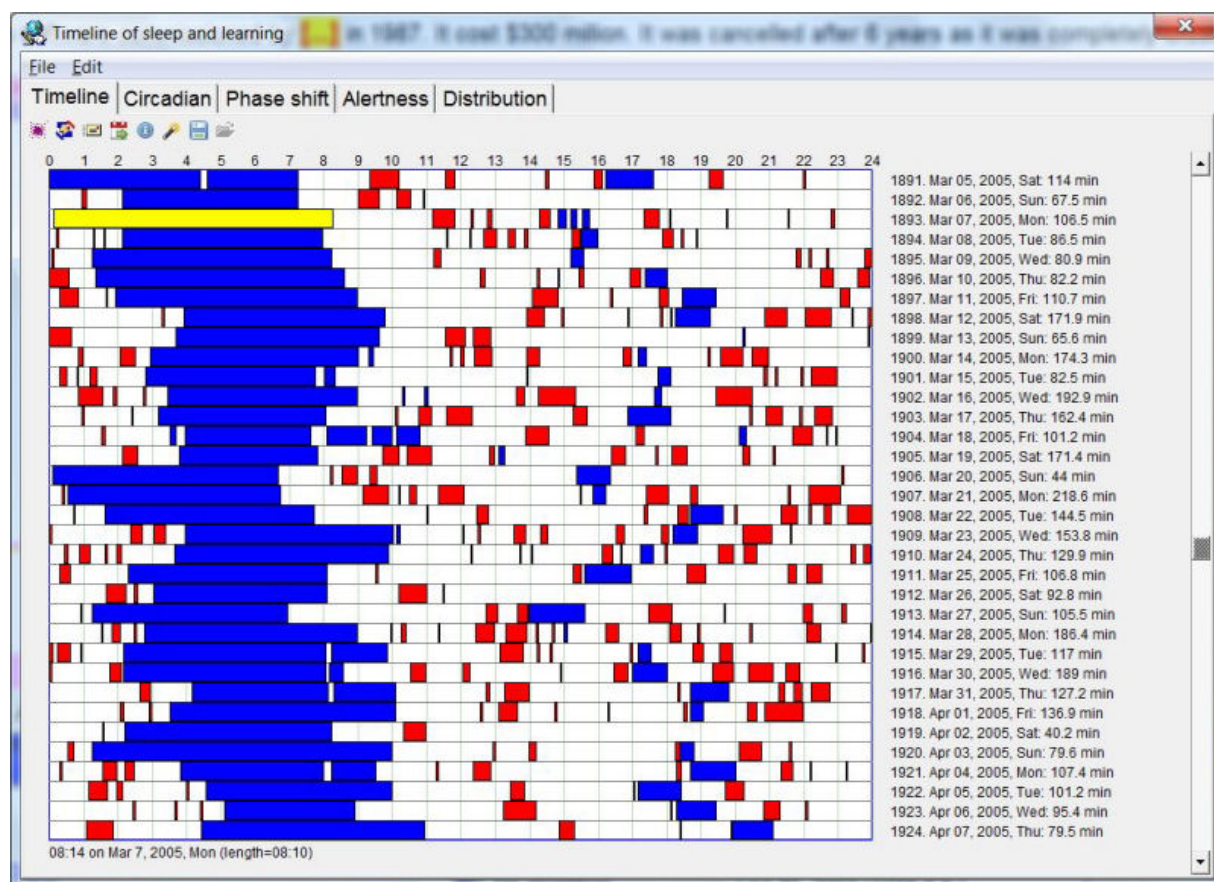
People with sleep problems are often little understood by the naturals: *"If you work solidly 8 hours a day, have 3 decent meals, have a proper family life, and treat other people as human beings, then in the evening you go to bed happily knocked out and wake up next morning happily refreshed. Surely this is as it always has been for most people throughout history and surely this is how it will always remain"*. This attitude towards sleep problems is not much different from telling a clinically depressed person: *"Pull yourself together"*, or expect a heroin addict to go cold turkey and instantly return to normal life. A tortured insomniac will only get more upset with himself or herself if (s)he is told that sleepless nights come from *"unsolid work"*, *"indecent meals"*, *"improper family life"* or treating others *"inhumanely"*. The

trouble stems from the clash of biology with modern lifestyle. With the arrival of artificial lighting sleep disorder statistics skyrocketed. These were only made worse by television, computer games and the Internet. With the advent of mobile telephony and instant messaging, [insomnia](#) and sleep phase disorders seem to reach epidemic proportions. Fewer people are able to leave work behind, cope with stress, or give up evening activities. Without a major change in lifestyle or a breakthrough in [circadian](#) control methods, people affected with lifestyle-related sleep disorders are faced with a choice between a daily [sleep deprivation](#) misery and radical solutions such as [throwing away the alarm clock](#). Certainly, we can expect science to come up with answers to the problem. Until that happens though, waking up "happily refreshed" remains a privilege of a shrinking subset of the population in industrialized nations.

SleepChart in SuperMemo

To make it possible to analyze the connection between sleep and learning, [SleepChart](#) has been integrated with [SuperMemo](#) speed-learning software. Instead of explaining [SleepChart](#) itself, I will shortly describe its functionality in [SuperMemo](#). Keep in mind that some of the functions related to memory are not included in the [freeware version](#) due to the fact that it does not have access to your learning data.

SleepChart was included in [SuperMemo](#) a few years ago upon the understanding that **sleep is vital for learning**. To sleep well and to learn well, one needs to understand his or her own [circadian](#) rhythm. [SleepChart](#) in [SuperMemo](#) was designed with the view to assisting in that task. It can help you optimize the timing of sleep as well as to optimize the timing of your learning. Moreover, you can submit your sleep and learning data for analysis and have your own contribution in our research over the impact of sleep on memory. You can access [SleepChart](#) in [SuperMemo](#) with: (1) **Tools : Sleep Chart** on the [Main menu](#), (2) [SuperMemo commander](#), or (3) by just pressing **F12**.



Sleep blocks are marked in blue. Learning blocks are marked in red. Total learning time on individual days is displayed on the right. Selected sleep block is displayed in yellow. The length of that block is displayed at the bottom.

In [SuperMemo](#), the learning timeline is generated automatically. Each time you make repetitions with [SuperMemo](#), the learning block is added to the timeline (displayed in red on the graph). On the other hand, your sleep data must be logged in manually (displayed in blue). At minimum skill level, you can use [SleepChart](#) for a basic visual inspection of your favorite learning and sleep hours. However, more advanced functions such as optimizing the time for learning or the time for sleep require advanced analysis and understanding of [circadian](#) rhythms. If you start logging your sleep data today, you will be able to use future, more advanced versions of [SuperMemo](#) to study and understand your sleep and learning.

Sleep timeline in SleepChart

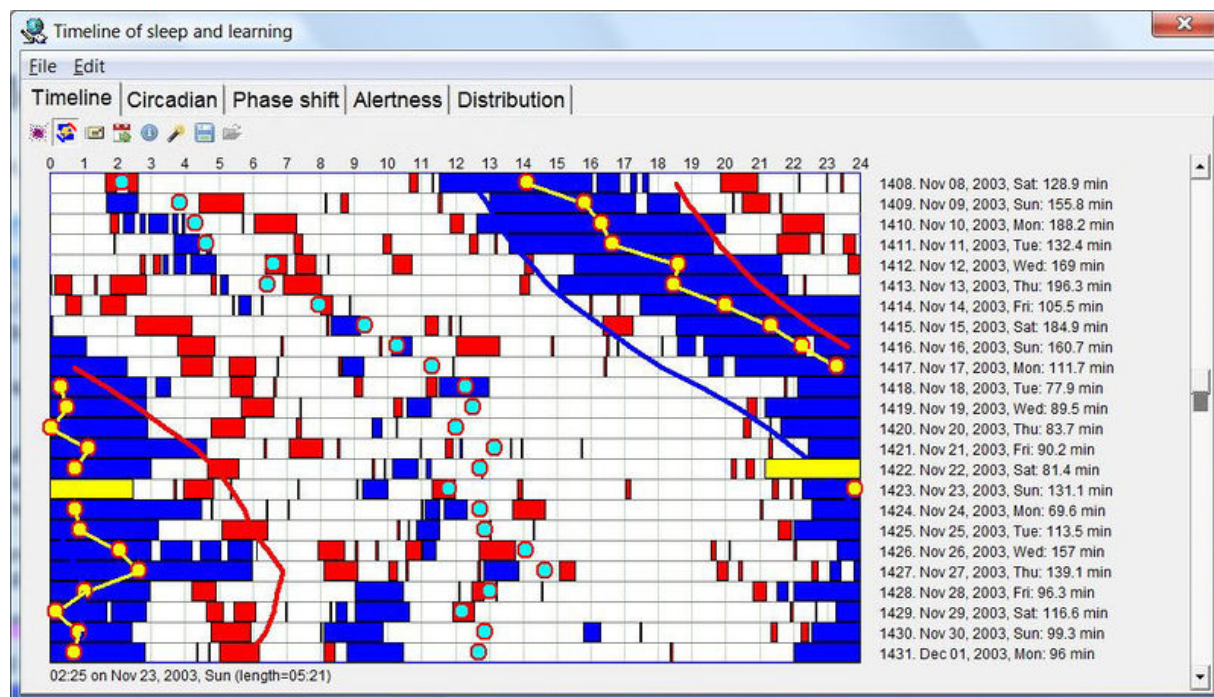
The timeline of sleep in [SleepChart](#) must be logged manually. To log a block of sleep, click the beginning of the block (sleep start) and then click the end of the block (sleep end). You can also start from clicking the end of sleep first. Sleep blocks above 22 hours are disallowed. Sleep blocks cannot overlap with repetitions timeline (you cannot learn with [SuperMemo](#) and be asleep at the same time). If you have already collected your sleep data in [SleepChart Freeware](#), you can import this data to [SuperMemo](#) with **File : Import : SleepChart file** (you can also import data from a spreadsheet). If you import files from [SleepChart](#) Freeware, you can test for sleep and learning overlaps with **File : Verify : Block overlaps**. Protection from block overlaps is an important advantage of using [SleepChart](#) in [SuperMemo](#) as opposed to a standalone SleepChart, in which it was very easy to fall out of phase in logging data (e.g. by failing to fill out a single day and noticing that only a month later). You can mark blocks of forcefully delayed sleep, as well as mark blocks cut short with an alarm clock or other factors. Please note that you can get best analytical results if you do not artificially regulate sleep (e.g. with an alarm clock, sleeping pills, etc.). Applied models will not fully account for artificial intervention. Last but not least, natural sleep is what you should aim for in learning as well as for the sake of maximum health and well-being.

Sleep and learning timeline in SuperMemo

Combining sleep timeline with repetition data taken from [SuperMemo](#) opens an array of new research and optimization options.

Various sleep statistics pertaining to individual days can be displayed on the right. Sleep blocks can be consolidated with the **Consolidate** button on the toolbar. For example, if you woke up for 5-10 min. in the night, consolidation will make [SuperMemo](#) treat the entire night sleep episode as a single entity. Short nocturnal awakenings are a norm, even if we are not aware of them, and have little impact on learning. Sleep block consolidation often unmasks important properties of sleep (e.g. see [Preference for night sleep](#)). It helps treat successive sleep episodes as an expression of a single period of high sleep propensity.

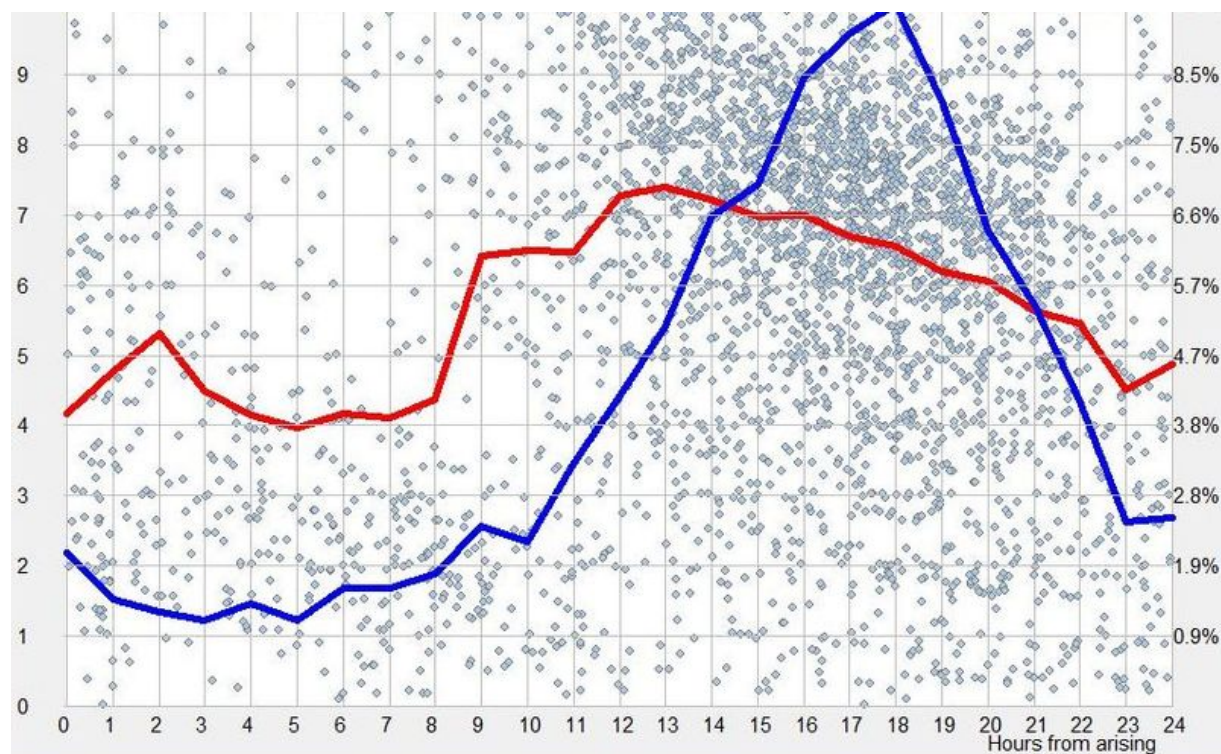
In addition to sleep statistics, optimum bedtime can also be estimated in [SleepChart](#). Two independent models are used to predict middle-of-the-night points as well as the expected optimum retirement and awakening times. Those approximations may be helpful in optimizing sleep in people who work shifts or sleep in irregular hours for various reasons. For example, after a week of irregular sleep, it may be difficult to determine the optimum retirement hour that is likely to produce best quality sleep. Going to sleep too early might result in premature awakening (which may often ruin the night sleep entirely). Going to sleep too late may result in short night sleep, sleep deprivation, and reduced alertness on the following day. Predicting optimum sleep time on the basis of sleep history is inexact science, and the two models used may produce different outcomes. **Important!** Your natural instinct should always take precedence over mathematical models. Moreover, best results in sleep optimization are accomplished in free-running sleep. If you use an alarm clock, or force yourself awake through the night, or take sleeping pills, the models may not adequately account for the chaotic change that is occurring in your sleep control systems.



Blue and red continuous lines are predictions of optimum sleep time using the **SleepChart** model (based on sleep statistics). Yellow continuous line shows the prediction of the maximum of **circadian** sleepiness (circadian middle-of-the-night peak) using a phase response curve model. Note that theoretically, yellow line should roughly fall into the middle between blue and red lines. However, when a disruption of the sleep pattern is severe, those lines might diverge testifying to the fact that it is very hard to build models that fully match the chaotic behavior of the sleep control system subjected to a major perturbation. **Aqua dots** point to the predicted daytime dip in alertness (i.e. the time when a nap might be most productive).

Circadian graph

The **circadian** graph in **SleepChart** can help you better understand your sleep patterns, as well as to visualize the degree of cycle instability (i.e. how difficult it is for your sleep-wake cycle to fit into 24 hours). You will need a few months of data before the graph becomes meaningful. In addition, **subjective night** approximation lines in the sleep log are subject to substantial **hysteresis**. If your lifestyle changes dramatically (e.g. as a result of a therapy), you may need a few weeks for the approximation lines to align properly with data. The **circadian** graph may then be more difficult to interpret. In such cases, you can use **From the first day** and **To the last day** options to demarcate the period of interest. This will limit the analysis to a selected period characterized by a selected lifestyle.



Exemplary circadian graph of a monophasic sleeper

Sleep initiation

Blue line shows the preferred time to fall asleep. It corresponds with sleep propensity derived from the number of sleep blocks falling into a given hour of the waking day, where zero on the horizontal axis refers to the hour of waking up. Percentage of sleep episodes initiated at any given time is displayed on the right vertical axis. The blue line roughly expresses your "tiredness of wakefulness". It also expresses your ability to fall asleep. Your own optimum bedtime hour is your personal characteristic as it differs between people. For most people the optimum bedtime falls into the range of 16-20 hours from waking. In the example, the most favored bed time occurs in the 18th hour of waking.

Sleep maintenance

Red line shows the average length of sleep. This line is a rough reflection of the ability to maintain sleep, i.e. the longest sleep episodes occur during the **subjective night**. The average length of sleep is displayed on the left vertical axis. The graph will tell you that even if you are able to initiate sleep during the day, it will never last long. In most cases of regular sleepers, only after 11-14 hours of waking does the length of initiated sleep start increasing. Note that the sleep length graph is slightly phase shifted in reference to the preferred sleep initiation time due to the fact that long sleep is mostly achieved by initiating sleep early.

Optimizing bedtime

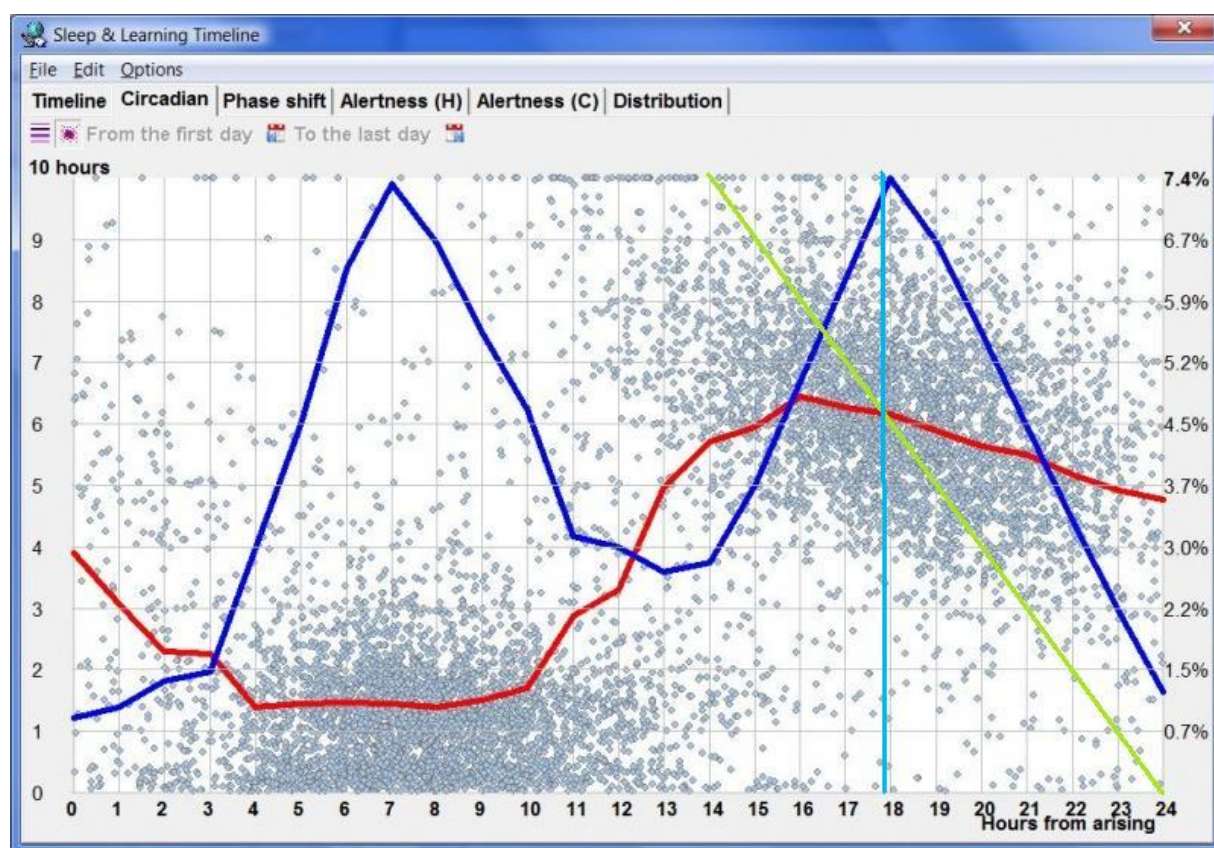
If you are trying to determine your optimum bedtime, find the evening peak in the blue curve and choose nearby points that produce sufficiently long sleep (red curve high enough). In addition, pay attention to the fact that your wake and sleep time should add up to 24 hours, otherwise you will experience phase shifts.

Some people take naps during the day. Others don't. In nappers, the blue curve should also point to the maximum mid-day alertness dip. Short nap time may actually be a sign of good nap timing as long as the nap is not taken too early in reference to the blue curve (see: [Best nap timing](#)). Non-nappers will also experience a peak of sleepiness around the 7th hour even though their blue curve will not show as a prominent bulge.

If the graph shows that your optimum nap time falls into the 8th hour, and you wake up at 6 am, you should take a break at around 14:00 (2 pm) and look for a secluded place for a few minutes of rest. You could also plan your lunch at around 13:00-13:30 to complete a perfect setting for a [siesta](#).

Example 1: Unstable circadian cycle

In the exemplary [circadian](#) graph below, on average, the best night time sleep is obtained when it is initiated after 18 hours from the morning awakening (assuming the graph was created without any artificial form of sleep control such as an alarm clock, delaying sleep, etc.). The blue line shows that the 18th hour is the preferred time to initiate sleep, while the length of sleep (red line) is long enough to add up to a 24 hour sleep-wake cycle.



As blue peaks are of the same height, we can conclude that the graph represents a religious napper, whose optimum [siesta](#) time occurs 7 hours from awakening. In this case, for an awakening at 8 am, the [siesta](#) should begin at 3 pm, and the night sleep around 2 am. For both blue peaks, 7.4% of all sleep episodes being at the optimum hour, while the remaining 85% are suboptimum.

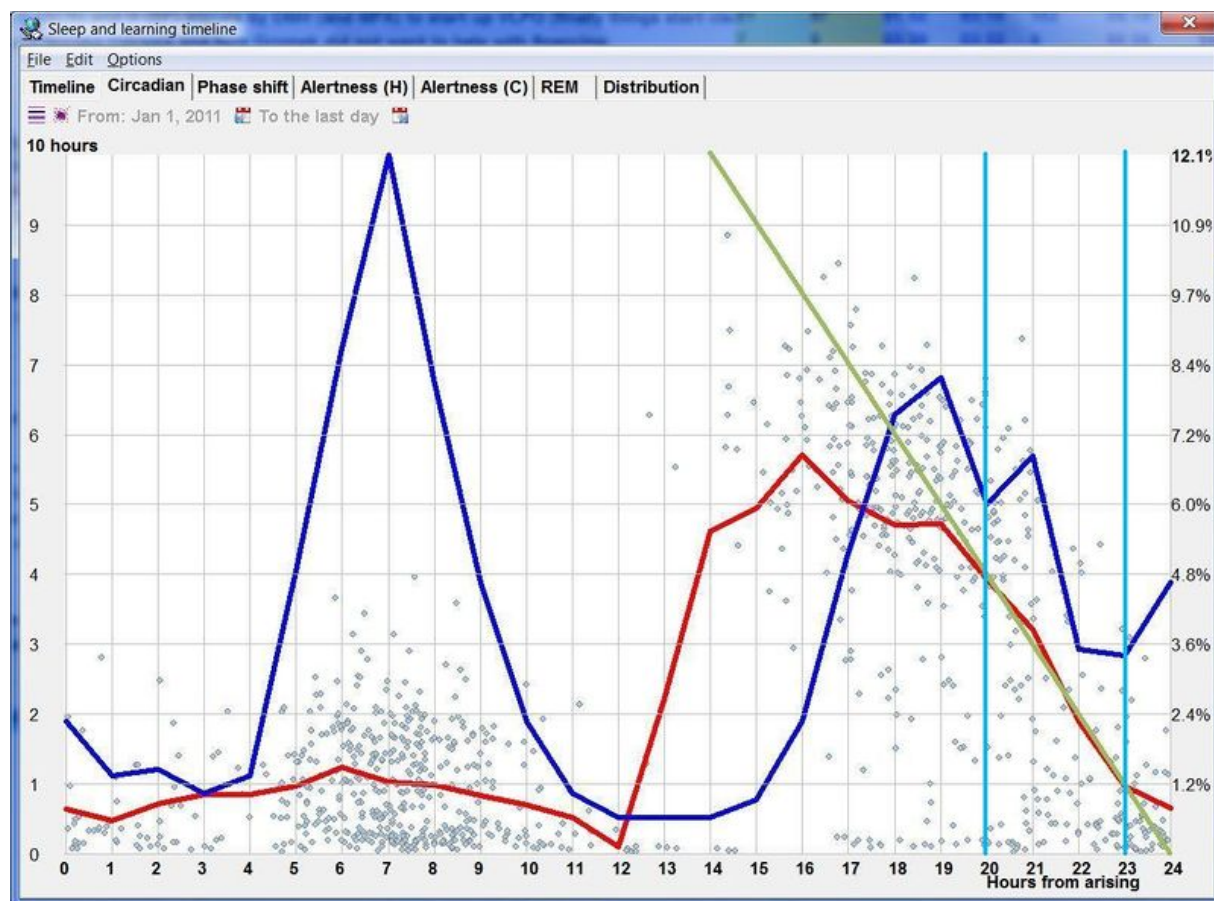
Maximum length of sleep can be achieved at the 16th hour, however, this does not indicate this is the optimum hour of going to sleep. If sleep is initiated too early, it may or may not catch on the full [circadian](#) low of the [subjective night](#). In other words, there is a risk of a premature awakening after just a couple of minutes of sleep. Such an awakening makes it harder to fall asleep again. This is one of chief causes of [insomnia](#). The difficulty in re-initiating sleep is due to a very rapid loss of [homeostatic](#) sleep propensity during sleep. In addition, sleep initiated before the full [circadian](#) low does not seem to be of more value than slightly shorter sleep initiated a bit later (e.g. as reflected by the subjective feeling of being refreshed in the morning, or as measured polysomnographically). The blue homeostatic line indicates that the sleep is more likely to be initiated effectively at the 18th hour, while its average length is then 6 hours. If your

graph is generated without attempts to artificially regulate sleep, the second peak in the **homeostatic** curve will often indicate the optimum bedtime. The graph also indicates that if the sleep is delayed by an hour, it will be shortened by 10-30 minutes. It is possible, that even this little shortening will affect the performance during the day. If the sleep is advanced by an hour, it may be 10-30 minutes longer but its quality is not likely to increase proportionally.

The graph can also show how **the length of the circadian period can be determined by the bedtime hour**. The green line shows the set of breakeven points for a stable 24 hours sleep-wake cycle where the sleep and wake times add up to 24 hours. All the **circadian** graph points that lie to the right of the green line cause a phase delay, while points on the other side will cause a phase advance. Aqua blue line shows where the 24-hour-cycle green line crosses the red sleep length line. Due to the fact that the angle between green and red lines is large, this sleep pattern is pretty unstable. This means that going to sleep before the 18th hour will result in a cycle that is less than 24 hours long, while going to sleep after the 18th hour may lengthen the cycle and result in **phase shift** delays. For example, early bedtime (around the 15th hour) will result in a day that lasts 21 hours (15 hours on the horizontal axis corresponds with the average sleep length of 6 hours read from the red curve). Later bedtime (around the 18th hour) will result in a perfect 24 hours day, while a very long waking day (e.g. 20 hours) will produce a day lasting 25.5 hours. Naturally, all manipulations in the length of the day would better be avoided as early bedtime increases the chances of **insomnia**, while a very late bedtime increases the chances of sleep deprivation, and **REM sleep deficit**. Understanding one's sleep preferences can be very helpful for planning shift-work or combating jetlag in long-haul flights.

Example 2: Stable circadian cycle

The second graph shows a sleep pattern that is much more stable than the one from the first example above.



The graph shows a **habitual napper** who shows a preference for a waking day of 19 hours. As opposed to the graph shown earlier, the zone of stable sleep-wake cycle, demarcated by vertical aqua lines is much wider due to the fact that red and green lines are nearly parallel. This means that if the sleep is initiated after the 20th hour of waking, the night sleep will be shortened to fit the 24h cycle. Naturally, even if delayed sleep does not cause a phase shift, it will always result in lesser sleep quality due to stage compression. Such sleep will result in sleep deficits. Days lasting less than 20 hours may result in a phase advance. Despite running free, the longest average sleep period (initiated at around the 16th hour) isn't even 6 hours long. This illustrates that **excessive sleeping** is not a problem in free running sleep. In the graph, the optimum **siesta** time again falls in the 7th hour and is executed religiously (over 14% of sleep episodes executed "on the dot").

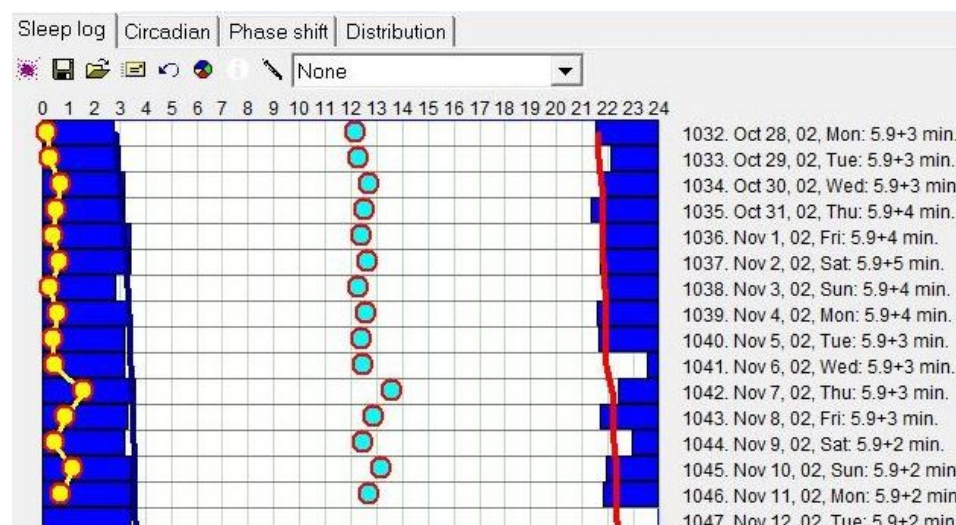
Phase shift disorders

As shown in both graphs above, with sufficient discipline, people with phase disorders should be able to accomplish 24 hour free running rhythm independent of the desired waking hour. In practice, due to various perturbations in lifestyle (exams, stress, socializing, etc.) as well as due to the stress of the need to wake up early, adherence to the optimum 24h sleep schedule may be very hard to achieve for people with severe **phase shift** problems. For those who need to wake up at a specific early hour, **free running sleep** may become unobtainable without the use of an alarm clock, **melatonin**, or other unwelcome measures.

24-hour sleep cycle

Perfect 24-hour cycle

Let us now consider an ideally synchronized 24-hour cycle. In the picture below, an octogenarian female wakes up naturally everyday around 3:00-3:30 am. She sleeps 5.4-5.5 hours per day, wakes up refreshed and is active throughout the day.



There is no synchronization with daylight as the waking hour falls into the period of darkness. The cycle is synchronized by evening activities, not daylight. The subject keeps in her mind a "must go to sleep" hour estimation that helps synchronize body clock with the time of day. This "psychological imprint" is illustrated by a smooth change in the sleeping rhythm after the end of the daylight saving time on Sunday October 27, 2002 (the graph disregards DST so that the waking hour before the change is set at 2:00-2:30 am).

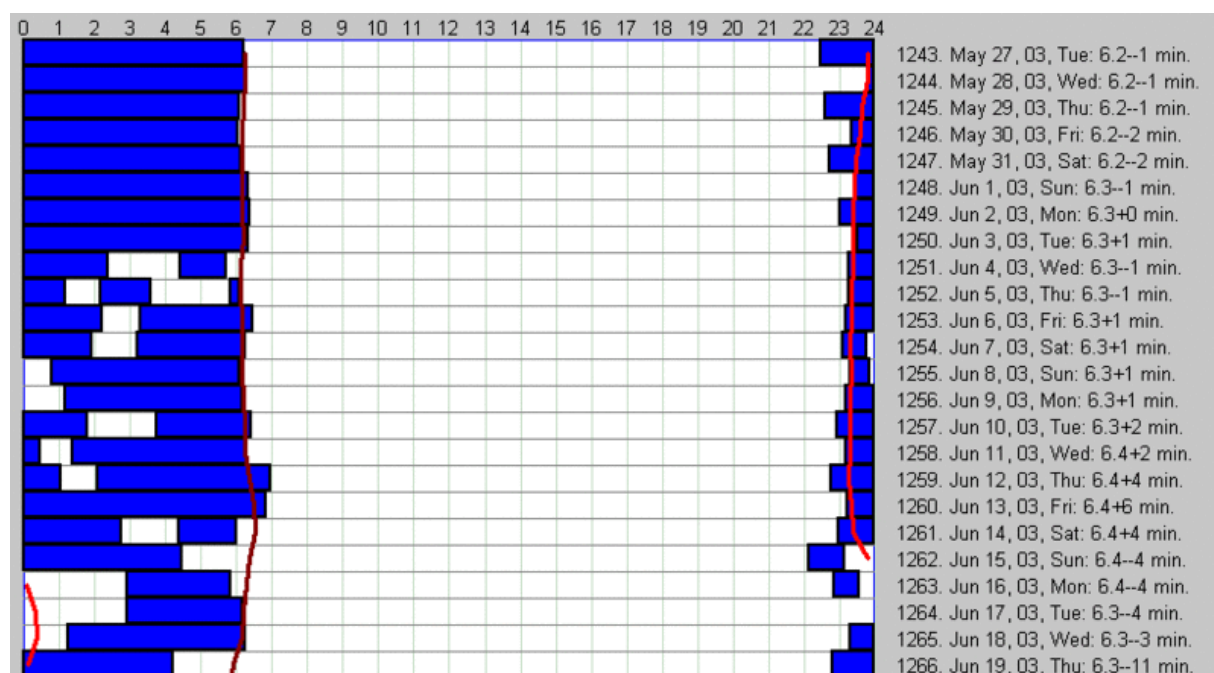
Even though aging is said to increase nocturnal awakening, perhaps due to the cell loss in sleep control centers, this subject reported no awakening in the study period.

Circadian graph shows a single favored bedtime in the 19th waking hour. As the average nighttime sleep episode is 5 hours long, the sleep-wake cycle lasts exactly 24 hours, and daily fluctuations in bedtime are minimal. As the green breakeven line and the red circadian line are nearly parallel in the span of 3 hours, this sleep pattern is very stable, and all delays in bedtime occur at the cost of sleep time without causing a phase delay.



Sleep and stress

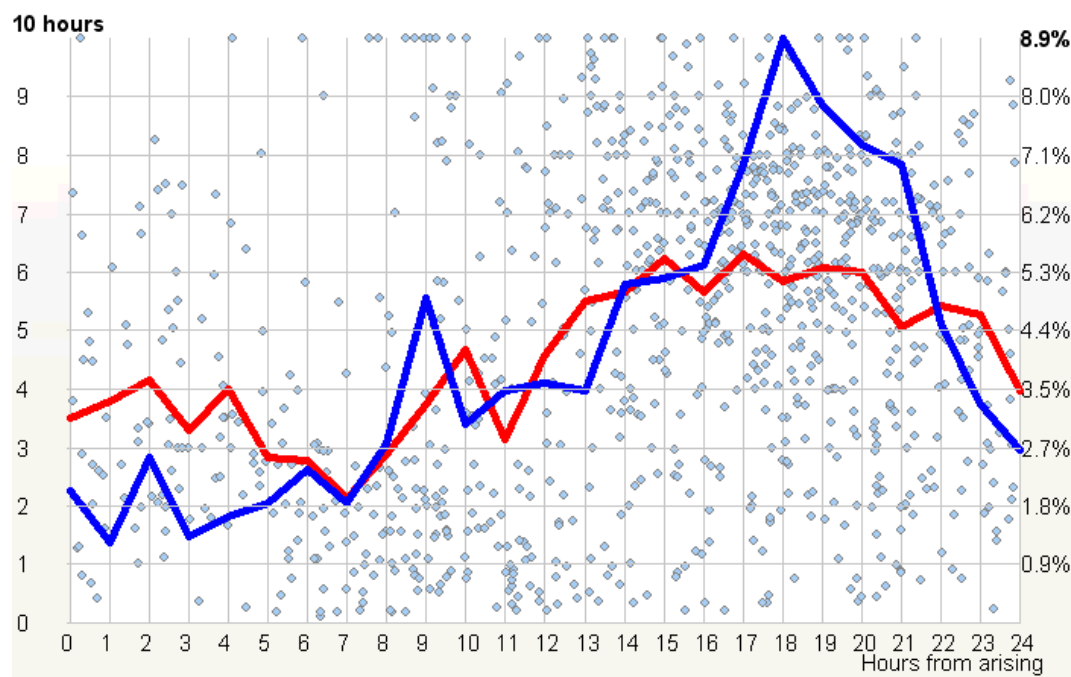
Stress can ruin the fabric of sleep. The following [SleepChart](#) graph demonstrates the impact of stress on a well-balanced 24 hour sleep pattern:



In the presented example, a middle-aged self-employed male wakes up naturally everyday around 6:00-6:20. However, on Jun 3, 2003, a severe family problem threw the rhythm into chaos as evidenced by frequent nocturnal awakenings. The rhythm returned to the norm one month later as soon as the family conflict was resolved.

Monophasic sleep

Monophasic sleep graphs will often show a small siesta-time sleep propensity peak due to the fact that even the purest monophasic sleeper hits crisis days in which a postprandial nap brings a welcome relief. Due to their "crisis nature", such naps may last longer than in a [habitual napper](#). The mid-day peak is particularly visible in irregular sleepers who show less discipline in sheltering their natural regular sleeping hours.

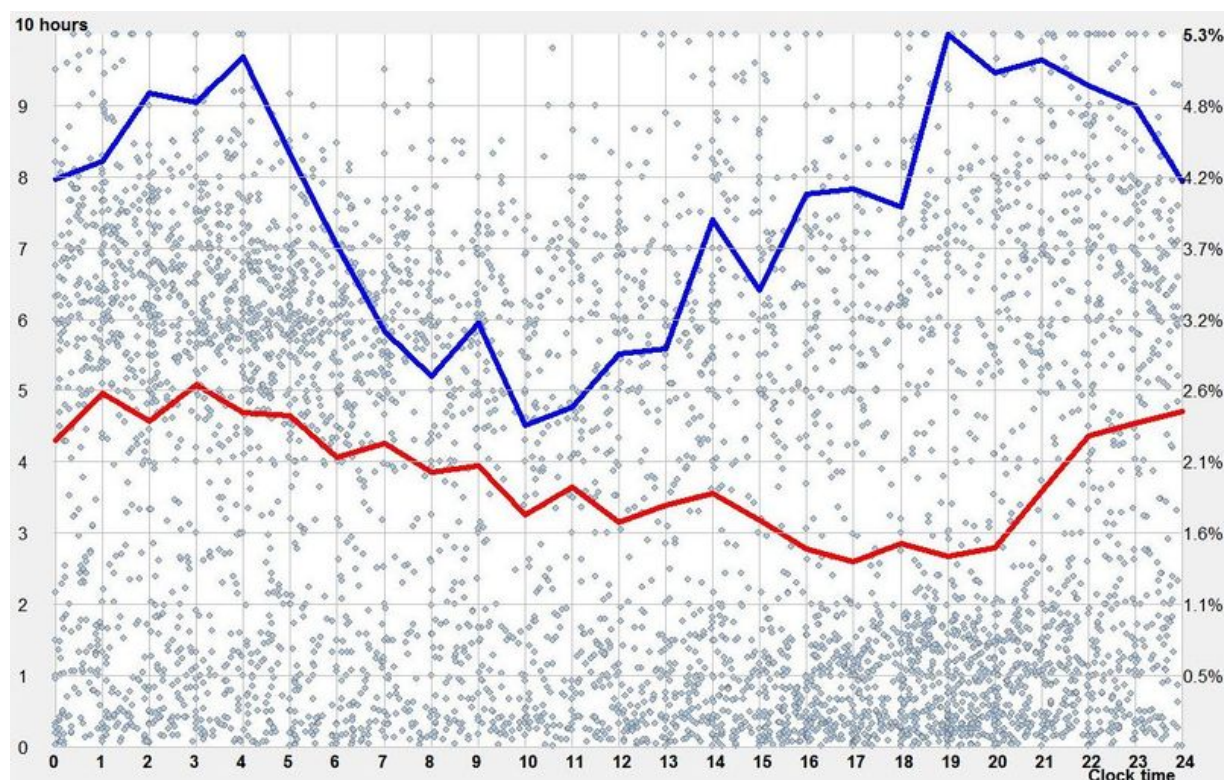


Preference for night sleep

Independent of the innate [circadian](#) cycle, light has a powerful impact on sleep. In particular, its [phase-shifting capacity](#) will always ensure that humans naturally gravitate towards sleeping at nighttime. Only the advent of lifestyle that involves electricity and 24h work cycles triggered the present epidemic of sleep disorders, which indirectly contributed to the appeal of concepts like ["Uberman sleep"](#).

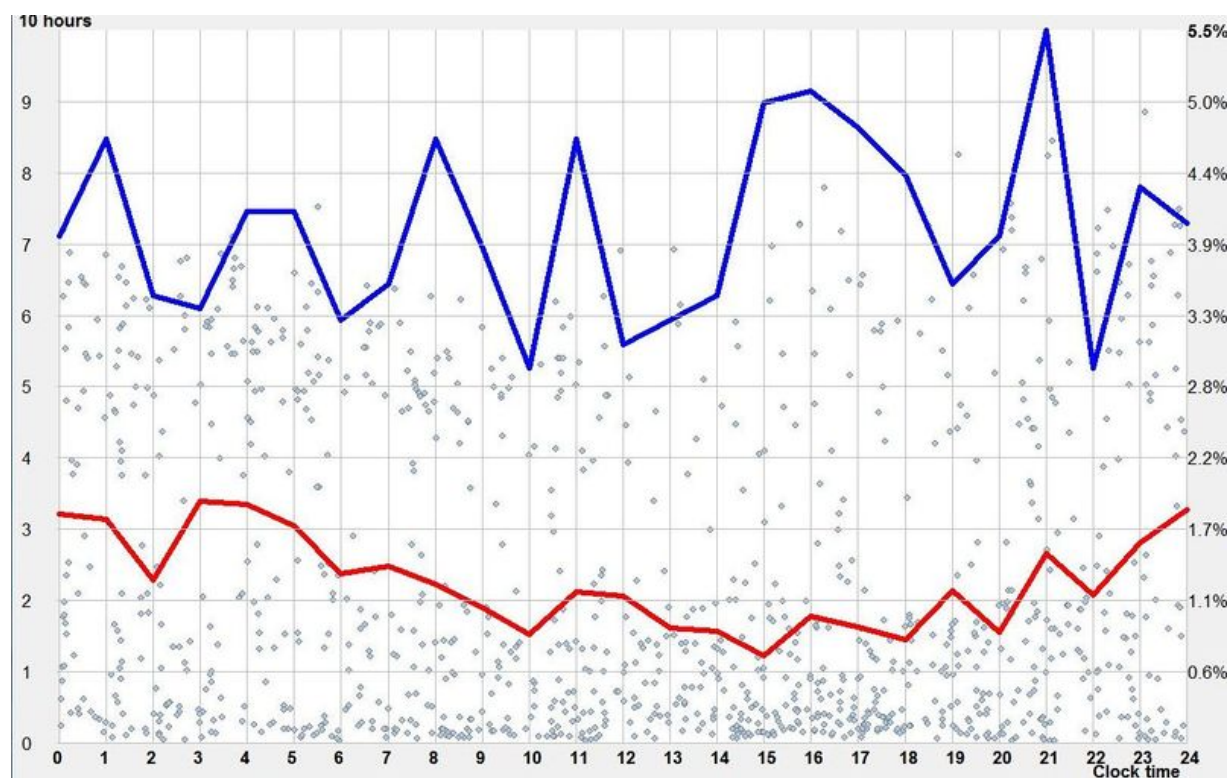
The preference for sleeping in the night can best be seen in irregular sleepers, esp. those who suffer from [phase shift](#) disorders and run their sleep free, or those who are on a free running schedule and [phase shift](#) "by choice" (i.e. by not trying to fit any particular sleeping hours). In those cases, using the [circadian](#) graph in SleepChart, we can see the impact of nighttime on the ability to initiate and maintain sleep.

In the presented [circadian](#) graph, we see a clear preference for night sleep in free running sleep. The graph shows that sleep initiation (blue line) is easier at nighttime between 7 pm and 4 am, while the length of sleep (red line) is greatest if the sleep is initiated between 10 pm and 5 am.



The graph can also be interpreted as a phase space. It shows how difficult it is to achieve ["wasteful" 8 hours of sleep](#) in an efficient free running sleep pattern. It can also be used to demonstrate that no trajectory in the phase space will lead to an entrained [polyphasic sleep](#). When alarm clock and/or sleep delay are introduced into the system, sleep control may become chaotic. However, in free running mode, it quickly stabilizes around a roughly [biphasic rhythm](#), often with a degree of phase-shift dependent on the lifestyle. The timing of phase-shifting, excitatory and inhibitory stimuli, even if they are repetitive and regular, may still lead to a degree of chaos in the system. This occurs if the period of the stimulus cycle is different from the period of the entrained [circadian](#) rhythm.

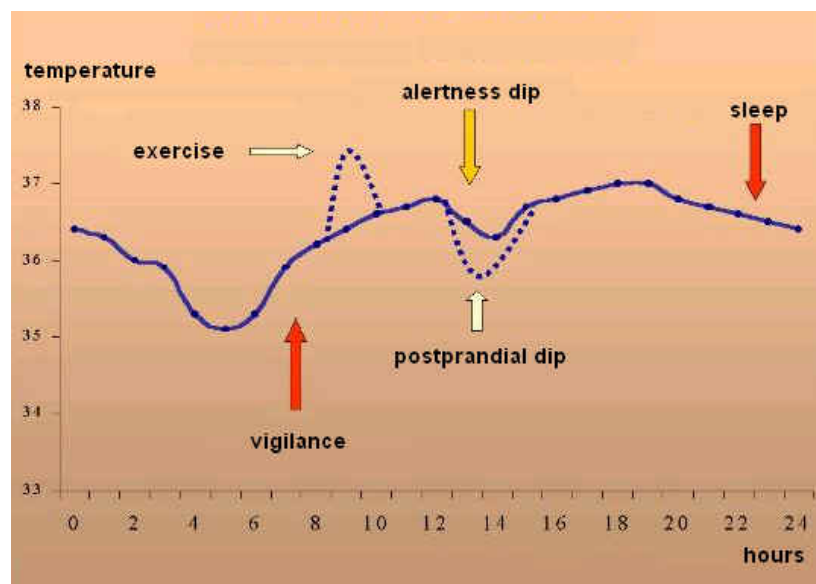
In contrast to the first graph, the second example can be used to argue that artificial lighting can virtually eliminate the impact of natural light on the cycle in a well-disciplined sleeper with a more regular cycle and better adherence to free running sleep rules.



The question remains open to whether the nighttime sleep preference isn't to a large degree caused by social [entrainment](#). Despite the fact that we live in a 24/7 society, there is still more fun to be had during the day or in the evening than during the night when still the larger portion of the population is asleep. A big clue comes from the fact that despite little difference in sleep initiation preference throughout the day, sleep initiated in the evening or in the night (8 pm - 6 am) is still likely to last up to twice as long as sleep initiated at 3 pm.

Biphasic nature of human sleep

Most researchers agree that human adult [circadian](#) cycle is biphasic. In addition to sleep, one of the outward expressions of the [circadian](#) cycle is the changes in core body temperature.

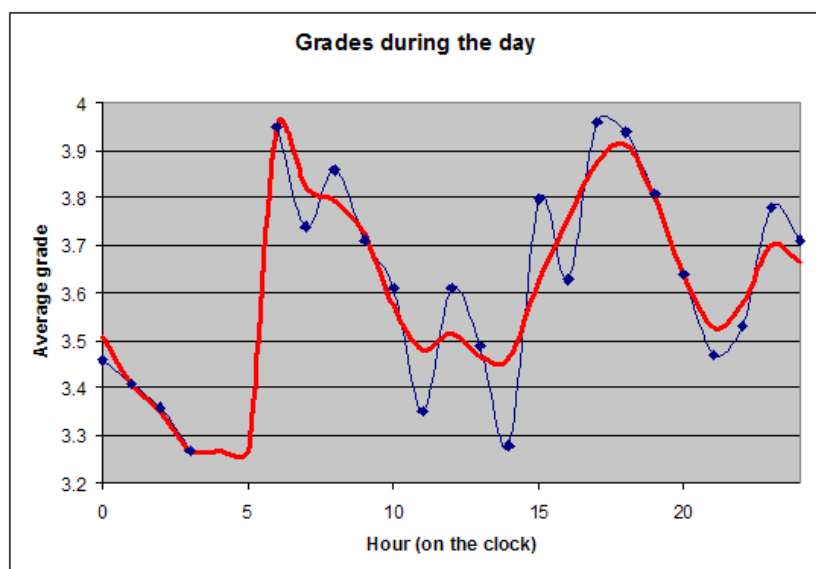


Temperature changes in the course of the day in degrees centigrade (courtesy of: Dr Luiz Menna-Barreto, State University of Campinas, Brazil)

SuperMemo and [SleepChart](#) provide an excellent tool to verify the claim of the biphasic nature of human sleep-wake cycles. I have collected data from monophasic and biphasic sleepers that illustrate our biphasic nature.

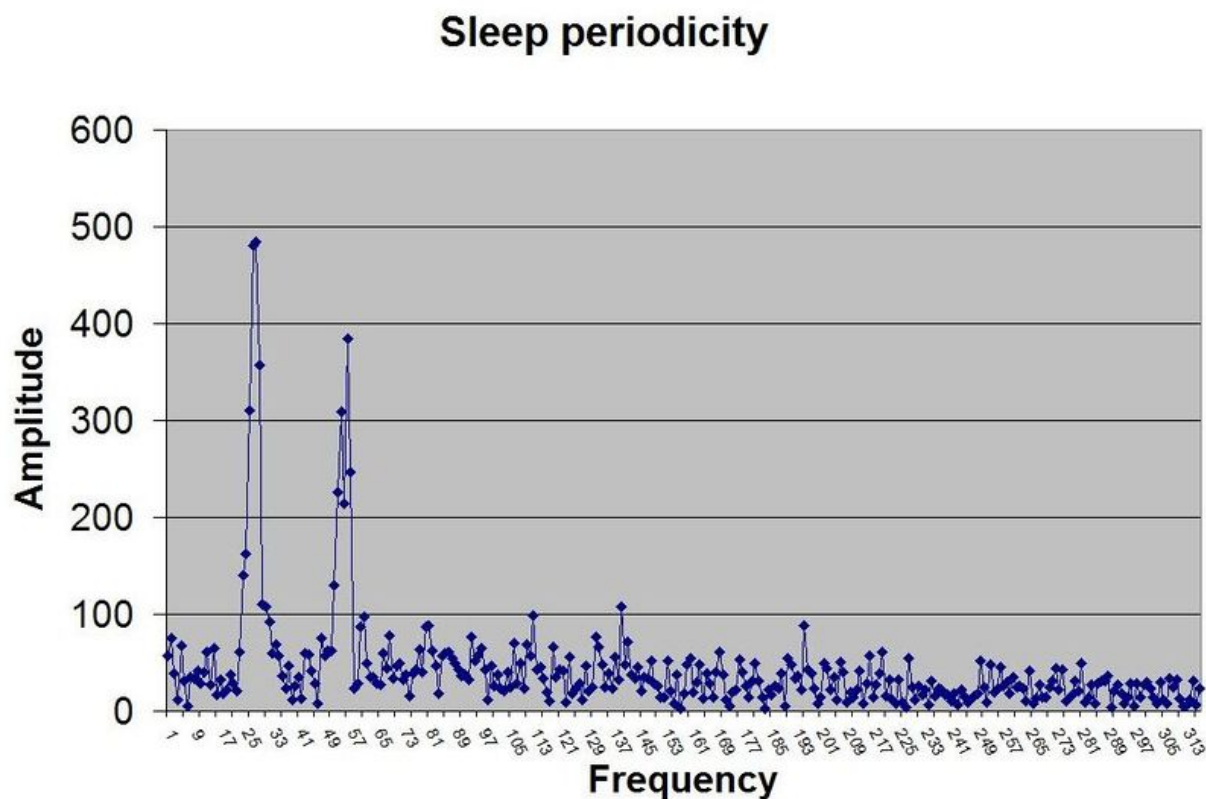
Biphasic learning

SuperMemo alone makes it possible to see the biphasic character of the learning performance throughout the day by charting grades vs. the clock time without the need to include sleep log data. In the presented example, a monophasic sleeper, a busy father of two, shows the best learning performance in the early morning around 6 am, i.e. shortly after his natural waking time. There is a big dip in the average grade scored when learning in hours 11 am to 1 pm (on the clock). There is a second surge in the quality of learning at around 5-6 pm:



Biphasic sleep periodogram

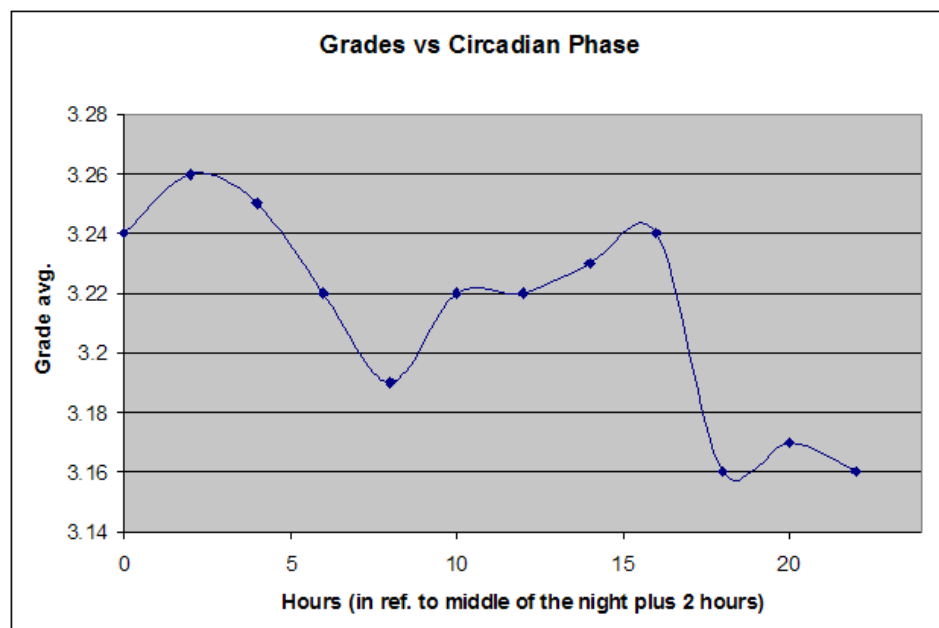
SleepChart alone can also be used to demonstrate sleep biphasicity. Free running sleep logs can be subject to [Fourier analysis](#) to reveal the nature of sleep periodicity. An exemplary periodogram is shown in the graph:



Exemplary periodogram of human free running sleep reveals a biphasic nature of sleep periodicity. Two basic sleep frequencies dominate this particular sleep log. These roughly correspond to 12 and 24 hour cycles.

Biphasic learning and sleep

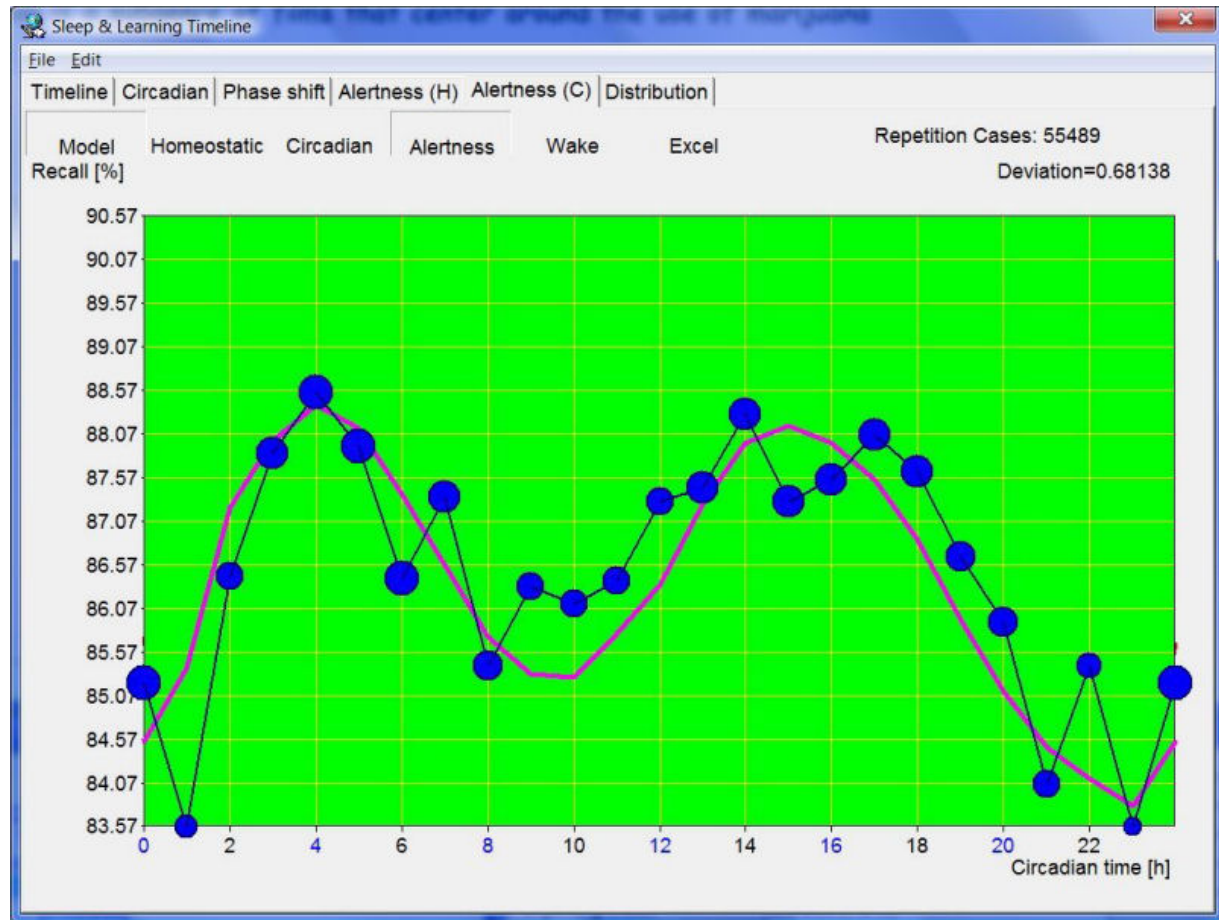
If we employ both [SleepChart](#) and SuperMemo, we can also see how waking performance changes in reference to sleep phase. The biphasic grades graph from [SuperMemo](#) ([as shown earlier](#)) can be corrected for the [circadian](#) phase that can be pretty independent of the actual clock time, esp. in free running sleep. In the presented example, a biphasic sleeper, middle-aged male with irregular sleep patterns, shows the best learning performance in the early morning (roughly around the estimated end of the subjective night):



There is a big dip in the average grade scored some 7 hours from the morning peak. There is a second surge in the quality of learning in the evening. Finally, there is a steep decline in the quality of learning shortly before sleep.

Biphasic graphs in SuperMemo

The newest version of **SuperMemo** makes it possible to correlate **recall** with the circadian phase as estimated by **SleepChart** (which has been integrated with the program). In the presented example, a biphasic 45-year-old male shows two major peaks in alertness and learning quality during the day:



The first peak occurs in the hours 3-4 from the estimated natural waking time, i.e. not the actual waking time, which may be different. The second, slightly longer peak spans hours 12-18. There is a pronounced depression in free **recall** at the 8th hour of the subjective day period (i.e. wake time estimated from the **circadian** data, not the actual waking period). The red line shows the estimated overall alertness derived from SleepChart's [two component model](#). In this case, the estimated alertness nearly perfectly matches the **recall** measured during an actual learning process.

Monophasic sleep with biphasic learning

The height of the two alertness peaks may differ in a monophasic sleeper, who will also show the same depression in **recall** around the 8th hour of the subjective waking day. However, characteristically, a monophasic sleeper may not get the same performance boost in the evening as biphasic sleepers due to the effects of the [homeostatic sleep drive component](#). Even a few minute nap can result in a major boost in alertness. This has already been noticed by a prominent napping expert Dr David Dinges in his comprehensive surveys comparing habitual nappers with non-nappers (Dinges 1989^[23]).

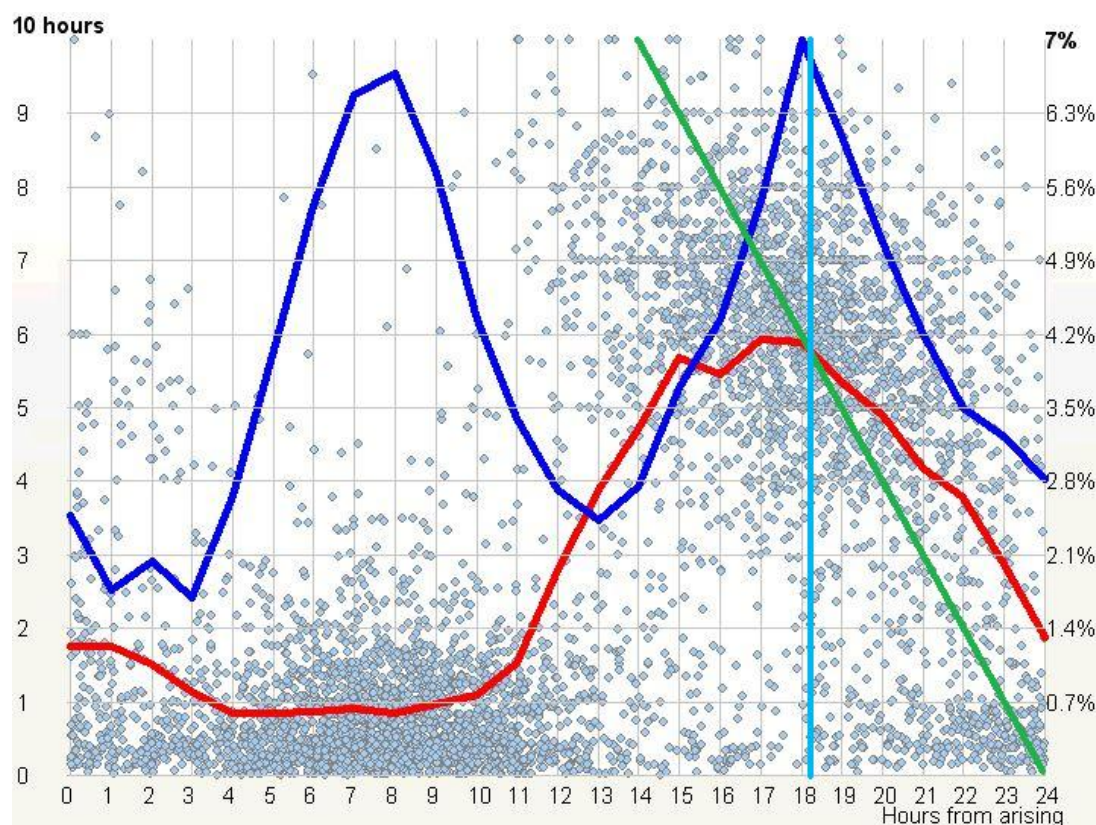
To illustrate the difference between biphasic and monophasic sleepers, see an analogous **recall** graph in which a monophasic 15-year-old non-napper shows the best performance in the morning hours with a sharp dip at the 8th hour of wakefulness coinciding with a subjective decline in cognitive function:



After a temporary dip, there is a sharp recovery, and a gradual decline in performance in the second half of the day. That decline is strongly accelerated by a homeostatic mechanism. The yellow line shows the estimated **circadian** component of alertness. In this case, the **circadian** benefits are muffled by the **homeostatic** decline in alertness, which is not shown in the graph. This is why the hypothetical **circadian** alertness and the actual alertness match only in the first half of the day.

Biphasic **circadian** graph

There is a biphasic twist to the two-process model of sleep propensity. In free running sleep, where sleep is a true expression of sleep propensity, it is possible to visualize both the **homeostatic** and the **circadian** components of sleep in a circadian graph:



In a habitual napper, the **circadian** biphasic nature is paradoxically expressed by the two-peak sleep propensity curve instead of the **circadian** curve. The reason for this role reversal is the physiological difference between the two circadian peaks in sleep propensity. In a habitual napper, sleep is initiated as easily at **siesta** time as it is initiated at night. However, the length of sleep at **siesta** time is very short (usually 15-80 min).

In the presented graph, the blue line corresponds with the ability to initiate sleep at any given **circadian** time. On the horizontal axis, it aligns well with the alertness graphs displayed in **SuperMemo** (as shown in earlier paragraphs). It aligns well with both the learning data, as well as with the two-process sleep model implemented in **SleepChart**.

The red line corresponds with the ability to maintain sleep. It reveals what is not visible in the alertness graph shown earlier: **siesta** naps cannot last long and will always be subject to an early natural termination (low red line under the first blue peak). In contrast, the period of **subjective night** is the only time of day when sleep can and should last longest (usually no less than 4-5 hours). The red peak is also the reason why **polyphasic sleep** adepts crave for "core sleep", wake up groggy, and need heavy alarm artillery to wake up in this critical **subjective night** period.

David Dinges, in his surveys noticed, that napping more than once within a day was extremely rare. Most nappers took naps lasting 15-120 min. Naps will be shorter if they are taken before the **siesta** peak. If they are taken after the peak, they will usually last longer, and may even integrate with the night sleep in cases of particularly large delay, or where there is a sleep deprivation, **REM-sleep deficit**, or any other form of "sleep debt".

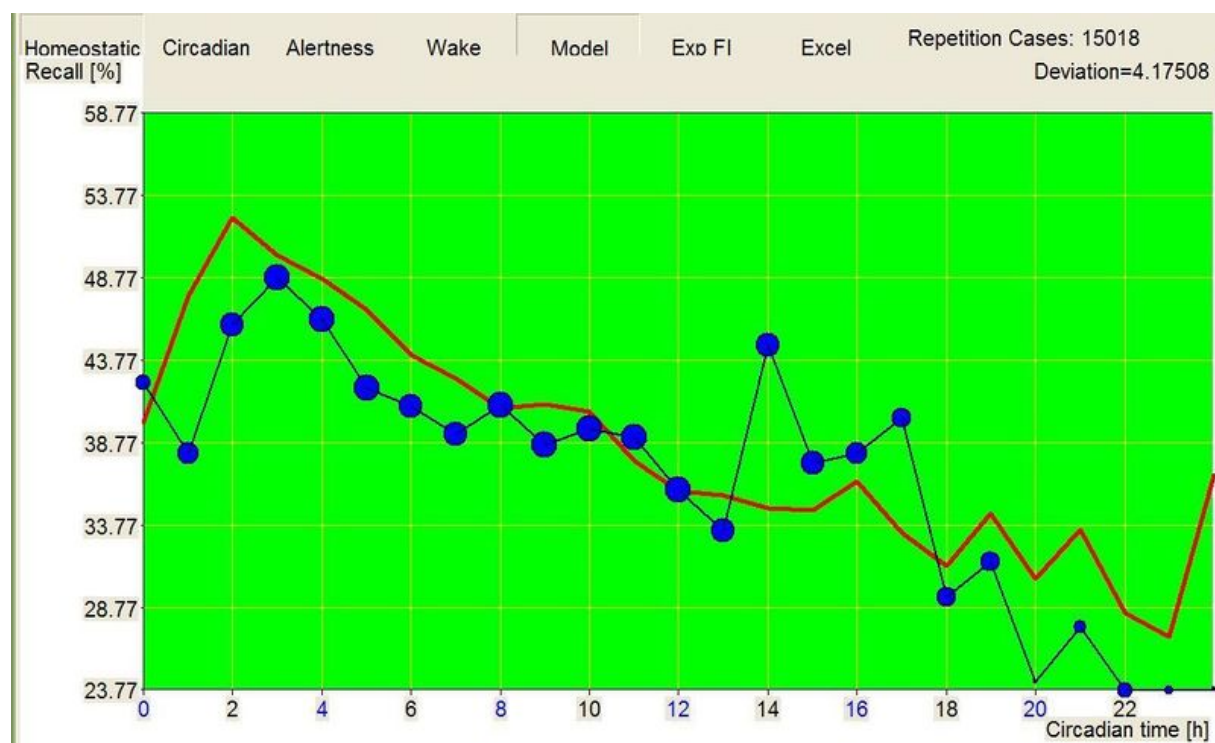
Dinges noticed that both appetitive (habitual) and replacement (compensatory) nappers tended to time their naps 7-8 hours from waking (see: **Best timing of naps**). Even though napping habits may differ, the **circadian** timing of the **siesta** trough seems to be pretty similar across the population (Dinges 1992^[24])

It is important to note again that the evening boost in alertness is magnified by a nap, but shows up also in non-nappers and can easily be deconvoluted in the two-processes model into its **homeostatic** and circadian components (as shown in the next two examples).

Two components of biphasic sleep propensity

The last two graphs show the impact of the circadian and homeostatic components on alertness.

In the first example, a free running female 29-year-old non-napper shows an alertness dip in 8-9 hours since waking. The red homeostatic estimate shows no dip and a steady decline over the waking day:



The yellow circadian estimate shows the expected position of the dip and the evening crest that explains a boost in the evening learning performance:



Both the evening **recall** boost and the evening **circadian** estimate align pretty well showing once again that the overall alertness depends on both **homeostatic** and circadian components of the sleep control system.

Biphasic performance in sleep deprivation

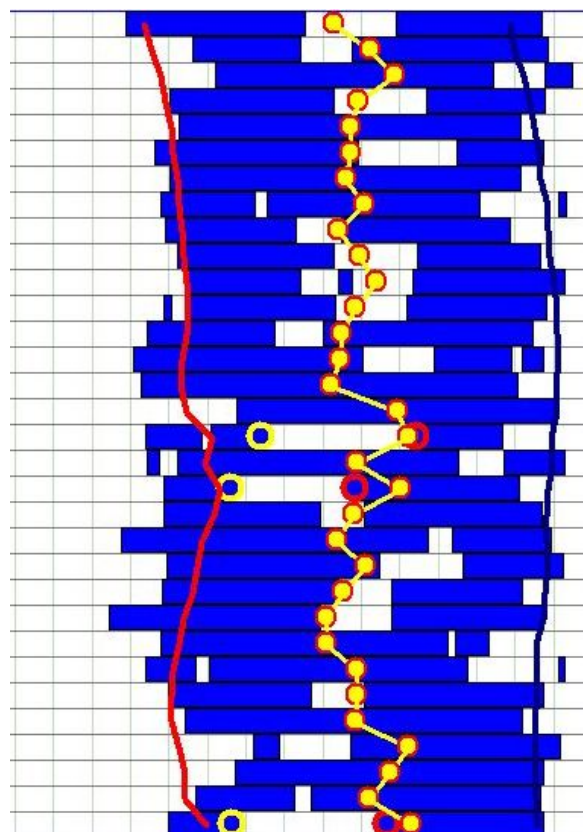
Mid-day slump is as prominent in conditions of severe as well as mild **sleep deprivation**. This [graph](#) shows a mid-day alertness slump in a 26 hour **sleep deprivation** study (Czeisler et al. 2006^[25]). The timing of the slump (hours 10-12 of waking period) indicates that the preceding sleep episode was positioned suboptimally (hence the need to interrupt sleep for the study). Natural awaking would probably take place 1-2 hours after a forced awakening in lab conditions. The graph also shows that **sleep inertia** caused by forced awakening from Stage 2 **NREM** or **REM** sleep causes a much greater cognitive decline than 26 hours of **sleep deprivation**.

Summary: Napping is good!

1. Humans are biphasic in nature and show a **circadian** boost in learning in subjective evening hours.
2. Non-nappers show a mid-day dip in performance and might also benefit from a **siesta**.

Segmented sleep

In 1992, Dr Thomas Wehr published the results of his interesting experiment on sleep in periods of prolonged darkness (e.g. as seen in Inuit during the arctic winter)(Wehr 1992^[26]). He divided the experimental day into 10 hours of daylight (photoperiod) and 14 hours of darkness (scotoperiod). This type of artificially controlled environment resulted in **segmented sleep** that was often composed of two 4-5 hour segments separated by an hour of wakefulness. Wehr found that the onset of sleep was associated with an increase in melatonin, which is released in the periods of darkness (in both diurnal and nocturnal animals). He also noticed that the release period of nocturnal melatonin lasts longer in shorter photoperiods (Wehr et al. 1993^[27]).



Fragment of a segmented sleep log produced in conditions of 10 hour photoperiod.

Interpretation of segmented sleep

When the results of the experiment were publicized, insomniacs rejoiced: *Perhaps this is normal? Perhaps this is how we all should sleep?* Those who tend to wake up in the night and spend an hour or so reading, watching TV or plundering the fridge, no longer had to feel abnormal. Indeed, the best criterion that should separate healthy sleep from unhealthy patterns is the refreshing power of sleep. Nocturnal awakenings should not matter as long as they did not contribute to morning misery.

A historian, [Dr Roger Ekirch](#) noticed that this prolonged two-part sleep is frequently mentioned in historical records that predate the advent of electricity: "Until the close of the early modern era, Western Europeans on most evenings experienced two major intervals of sleep bridged by up to an hour or more of quiet wakefulness. [...] The initial interval of slumber was usually referred to as "first sleep," or, less often, "first nap" or "dead sleep." (Ekirch 2001 [\[28\]](#)).

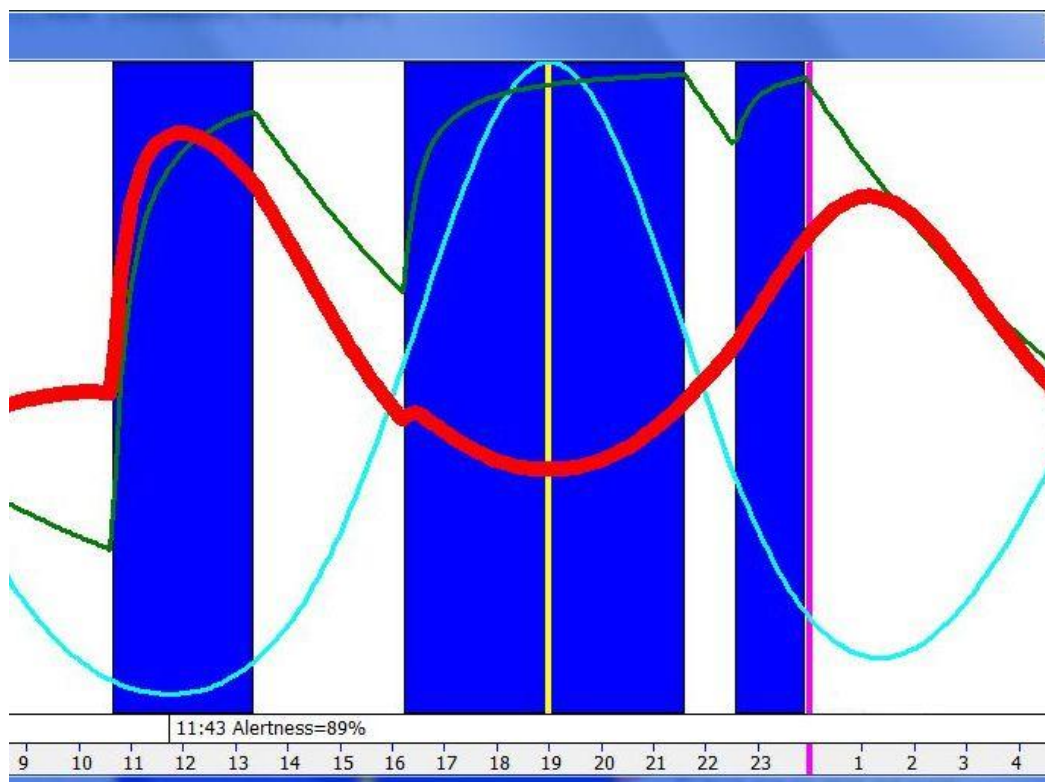
Sleep researchers speculated that this is perhaps how healthy sleep should look like and that our sleep control models with a single nighttime [circadian](#) peak are wrong. Evolutionists speculated that this could be an adaptation to nighttime sex, or breastfeeding, or periods of extra vigilance. [Dr Horne](#) likes to refer to segmented sleep as an example of the human propensity to [excessive sleeping](#).

Segmented sleep and Borbely model

I happen to disagree with most of the interpretations put forward thus far except those that stand in agreement with the mainstream sleep research. We need to observe that most of human and pre-human evolution took place in tropical areas with far shorter nights than those that characterize winters in the north, and, mathematically speaking, there should be no preference for waking up in the middle of the night for 1-2 hour as opposed to entering shallow sleep or waking at the end of each full NREM-REM cycle. The segmented sleep observed in Wehr's experiment can easily be accounted for with [Borbély model](#) of sleep. Even though [Borbely](#) model provides very specific mathematical conditions needed for initiating sleep, we must remember that it is only an approximation of reality that does not necessarily account for the level of lighting or external arousing stimuli. In periods of prolonged darkness and silence, lesser overall sleep propensity will be needed to initiate sleep. I will try to illustrate my claim using SleepChart's two-component model and some real life examples.

Segmented sleep and two-component model

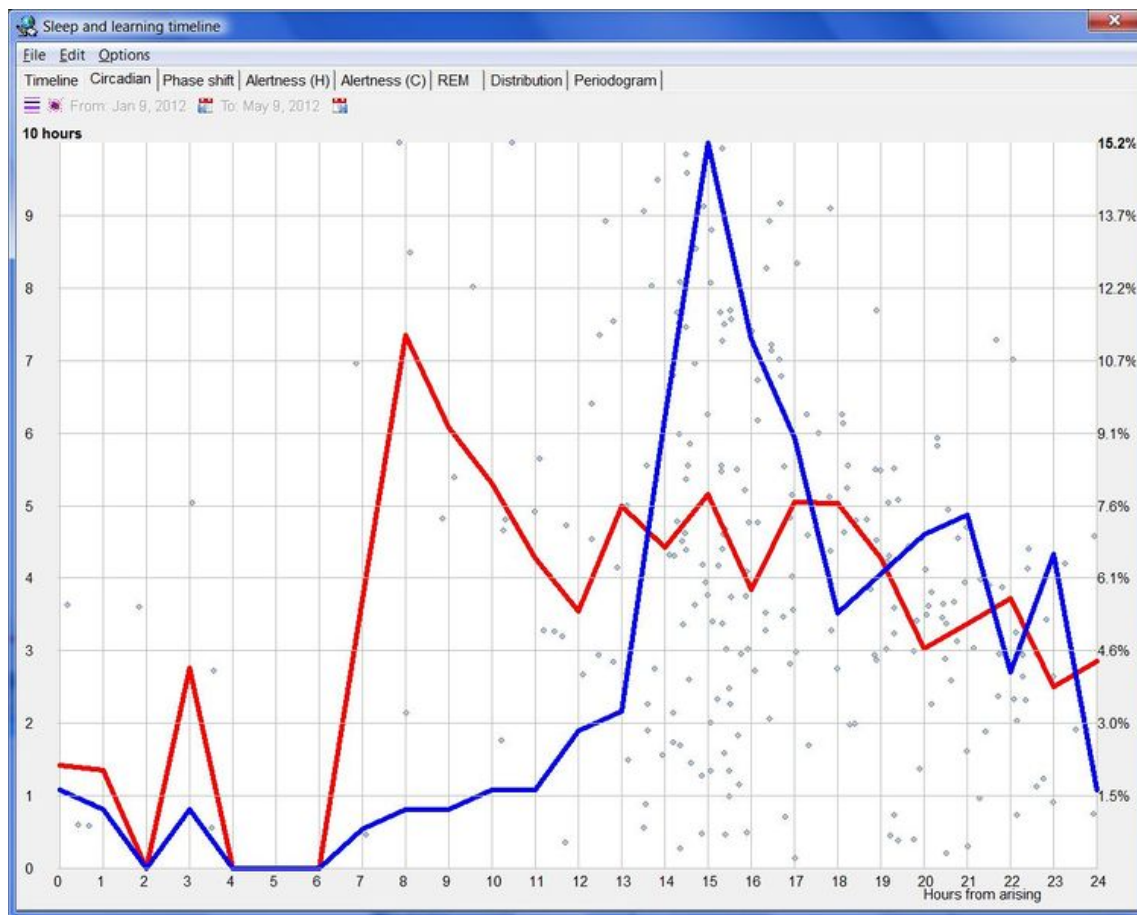
When Wehr's data are processed using [SleepChart's two-component model](#), we see that sleep is characteristically initiated at periods of relatively low sleep propensity:



Wehr's segmented sleep as interpreted with the help of the two-component model of sleep employed in [SleepChart](#).

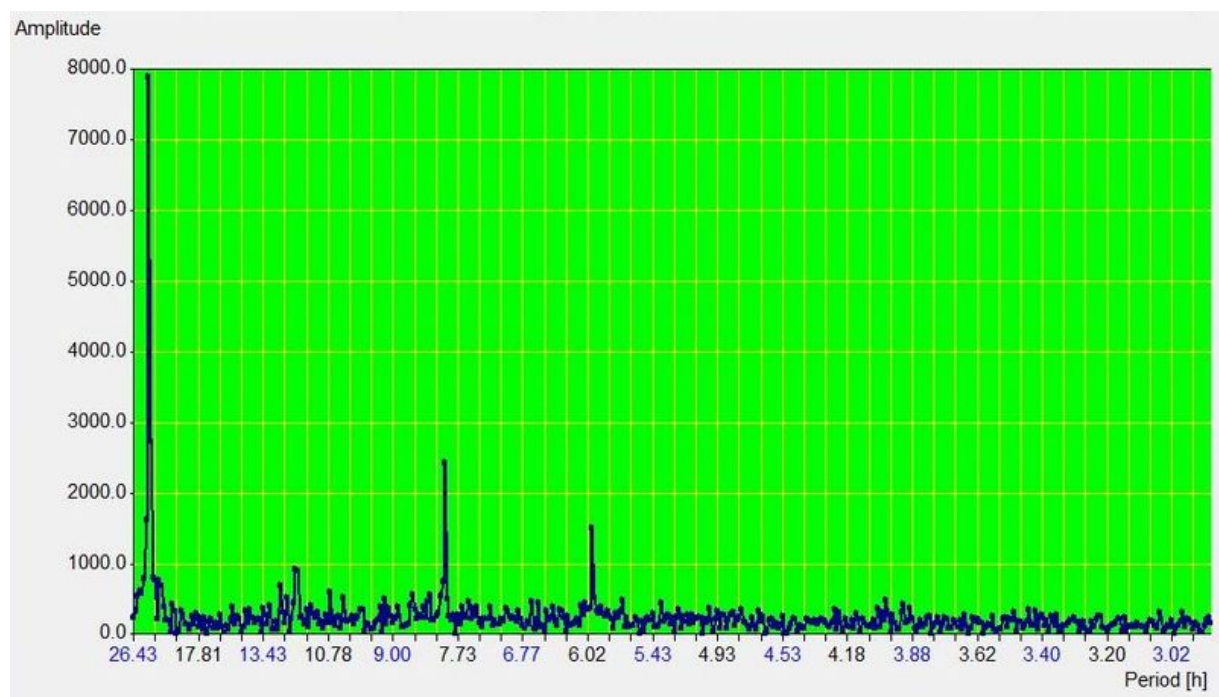
In real life, the two-component model indicates that sleep is initiated when alertness levels drop to 33-40%. In segmented sleep, alertness at sleep onset is much higher: 40-50%.

Circadian graph shows that the favorite sleep initiation hour is the 15th from arising and it results in 5 hours of sleep on average. As waking comes close to the [circadian acrophase](#), wakefulness cannot last long due to a rapidly ascending [circadian](#) sleepiness. The second bout of sleep then follows in the 21st hour and lasts 3 hours on average. Thus the sleep is segmented into a 5 hour long pre-sleep and 3 hour long "correction".



Circadian graph based on Wehr's data.

Sleep periodogram shows a typical frequency peak at period 24h, and two atypical peaks at 8 and 6 hours (instead of the usual 12h *siesta* peak).



Periodogram based on Wehr's data.

Examples of segmented sleep

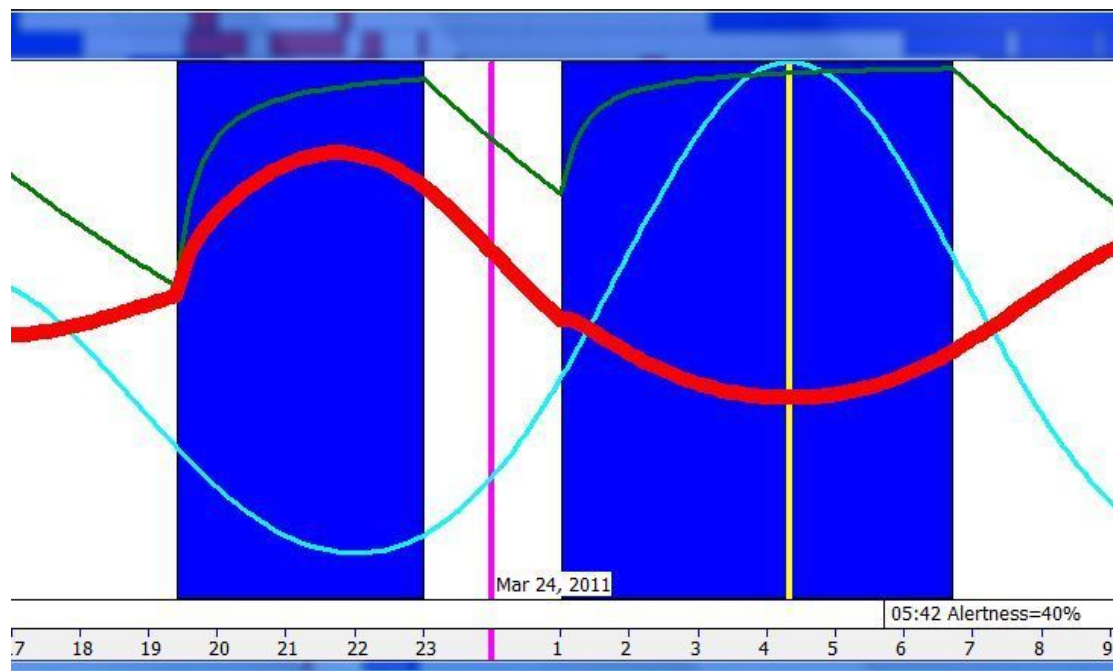
I scanned years of sleep logs in search for natural segmented sleep examples. I did not find that many. Without doubt, I can blame the modern lifestyle that rarely permits a leisurely early bedtime. Below I list three very different

examples from real-life logs. Several characteristics seem to be associated with segmented sleep:

- this sleep often results in high alertness, e.g. as testified by the absence of daytime napping
- as predicted, this sleep is easier to find in winter periods
- intense exercise may be a factor that helps induce segmented sleep (perhaps due to earlier bedtimes)
- as in Wehr's data, SleepChart's two-component model of sleep propensity shows a very rapid decline in sleep propensity early in segmented sleep due to the fact that the sleep is initiated very early in reference to the **circadian acrophase**

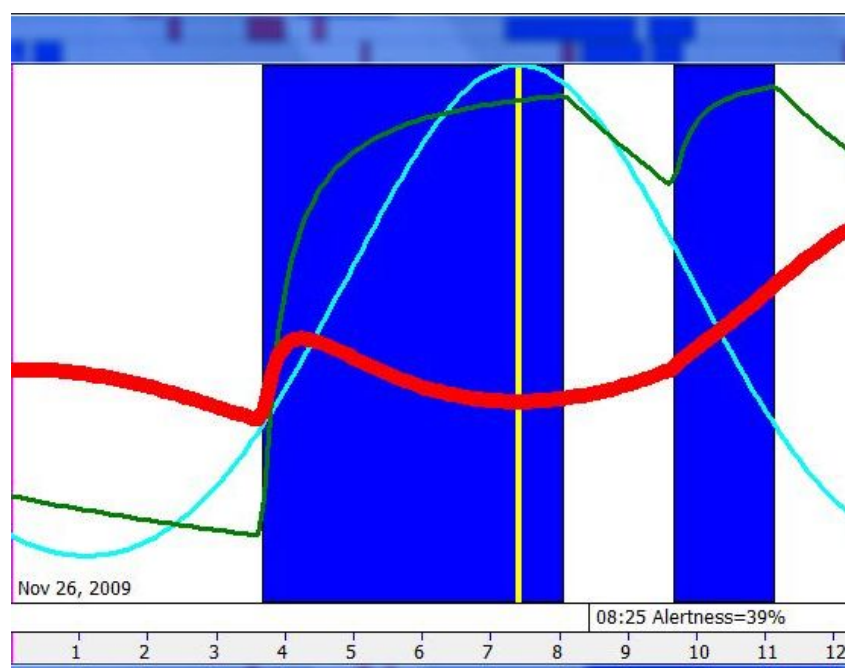
Example: Premature bedtime

Typical long darkness premature bedtime segmented sleep. Sleep initiated too early, again with a very marked decline in sleep propensity resulting in a nocturnal awakening:



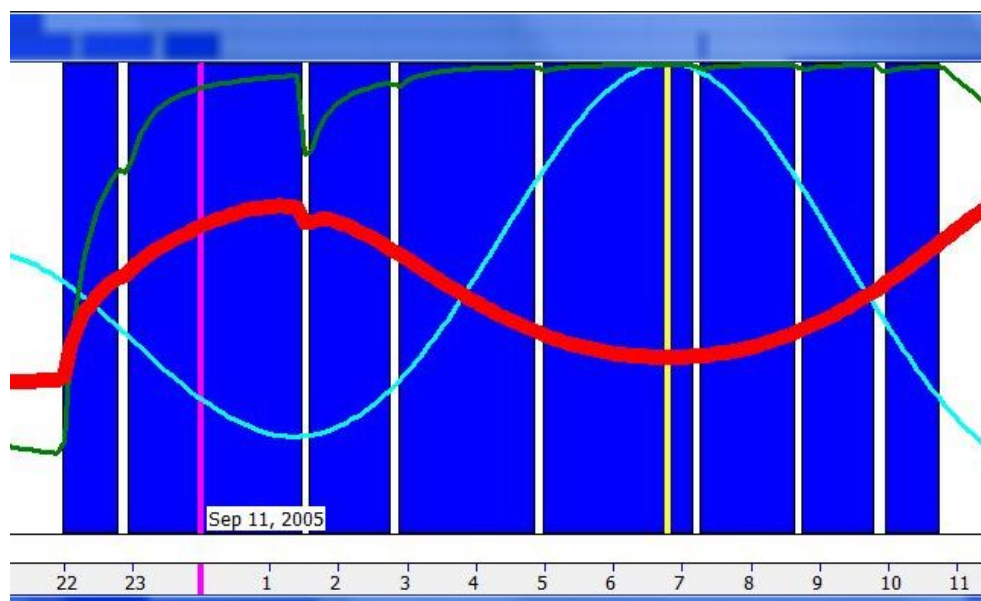
Example: Nocturnal awakening caused by stress

Premature awakening caused by stress. Segmented night with a "correction":



Example: Intense exercise

Prolonged sleep induced by intense exercise with increased demand for sleep. Over 12 hours of segmented sleep are initiated early with multiple harmless awakenings, fast decline in sleep propensity (inverse of the red line) in the first 3-4 hours of sleep that results in shallow prolonged sleep:



Application of segmented sleep

This type of sleep results in very refreshing nights, however, it would be pretty hard to implement in agreement with the modern lifestyle. Certainly, it would not optimize the time use. I can only guess that matching sleep well with the **circadian acrophase** should also increase the efficiency of sleep. This should be verifiable with **SuperMemo** data, however, as of the moment of writing, I have not done the necessary computation. Considering the nice effect of this ancient sleep on mood and alertness, I would love to subject myself to an experiment with 14 hours of darkness, however, 10 hour working day would be pretty hard to stomach even in a short term. I also doubt I would be able to extinguish the thoughts of the day and initiate sleep early. Even the mere fact of collecting exciting data for the experiment would keep me up with my thoughts racing. I might try this in retirement when my vital powers decline sufficiently enough to make it truly enjoyable.

Delayed Sleep Phase Syndrome (DSPS)

When a tendency to go to sleep later each day is strongly pronounced, it may become a serious problem. People with a particularly long **circadian** cycle or with an insufficient sensitivity to zeitgebers are classified as suffering from Delayed Sleep Phase Syndrome (DSPS for short). Sometimes the abbreviation DSPD is used where *syndrome* is replaced with *disorder*. The terms *non 24-hour sleep/wake syndrome* (N24, N-24, Non-24) or *hypnnychthemeral syndrome* (with a few spelling variants) are occasionally used to refer to the most severe cases. I will consistently stick with the label DSPS to emphasize that these are all variants of the same problem expressed differently in different circumstances. This quarrels with the established definitions used by other authors, which I will disrespectfully ignore due to the fact that the established terminology leads to a harmful confusion and the sense of disabling inevitability.

In DSPS, an individual finds it difficult to fall asleep late in the night, and sleeps well into the afternoon if not awakened. DSPS has only been characterized in 1982, but increasing data indicates that various degrees of DSPS occur with epidemic frequency, esp. among high school and university students. DSPS individuals often like to keep on learning late into the night, go to sleep very late (for example, 4-6 am), and find it very hard to wake up early on a regular basis. For example, regular getting up at 7 am is a pure torture for individuals affected with DSPS. They often fail to keep jobs that require them to perform early in the morning. Very often, they tend to split the day sleep into two components. For example, DSPS students often get a short sleep in the night, wake up early with an alarm clock, go to school where they are semi-conscious and perform poorly, get a solid nap after school and only late in the evening they regain vigor and their full mental powers. DSPS students feel best after midnight when everyone else is asleep and they can focus on learning or other activities (reading, Internet, watching TV, computer games, etc.).

The main factors contributing to DSPS:

- increased period of the body clock (well above 25 hours)
- reduced or increased sensitivity to factors that reset or advance body clock (e.g. light, activity, stress, exercise,

etc.)

- electric lighting, 24-hour economy and the resulting "want to do more" lifestyle

A normal individual has a body clock running with a period slightly longer than 24 hours. The clock is reset in the morning with activity and bright light. Thus a normal individual easily adjusts to the standard day-night cycle. However, DSPS individuals may have their clocks running periods long enough to find it hard to fit to 24 hours. They also push their clocks ahead by activity late in the evening (the process opposite to the morning reset synchronization). DSPS individuals, when given a chance to sleep when they want, will tend to go to sleep later and later. They will also wake up later and later. DSPS people do not have problems with sleep if they sleep in their favorite hours. Most mild DSPS cases can be remedied by changes in lifestyle, but rarely are those changes painless to individuals affected by the condition. If this description fits your problem, you may diagnose the degree of your DSPS with [SleepChart freeware](#).

DSPS in teenagers

Research shows that DSPS is very frequent in adolescence (Carskadon 1995^[29]). Teenagers with DSPS will often find it difficult to adapt to normal school time. They will experience maximum daytime sleepiness at 10 am (in the middle of the school day) and a peak in alertness right after the school. For many teenagers with a natural tendency to go to sleep late, school becomes a torture and a true waste of time! Educators have already taken on this subject; however, students dozing off during classes are still a norm! Sleepy students learn little, and may naturally [develop strong negative feelings for the school in general](#). This is a problem of colossal proportions! If you are a parent of a teenager who finds it difficult to wake up for school, you will need to act now! Otherwise young man's school years will be a period of monumentally wasted time! It won't be enough to demand an early hour for going to bed. If you ban the late evening Internet surfing, you will just swap a dose of evening education for an idle tossing and turning in bed. Actually, there is only one simple solution, let the kids get up at their natural time but... this may not be realistic in most cases. Your sleep therapist may not be able to help either. The whole school system might need to be changed to accommodate the prevalence of DSPS among adolescents. There have been positive results noted in schools that decided to start classes 1-2 hours later. However, long [circadian](#) cycles may result in students staying up yet later in the long-run. Researchers suggest schedule stabilization and gradual realignment. Those measures may still be largely ineffective. [Homeschooling](#) and [free running sleep](#) could be a great option for those kids.

Solution to the DSPS problem

[Free running sleep](#) is usually an instant solution to sleep problems in DSPS, however, it inevitably results in a "shifting" sleep pattern (see below). Other than free running sleep, the best known remedy is to:

1. cycle the sleep phase to alignment with the desired hour bracket and
2. battle to reset the cycle (see: [Curing DSPS and insomnia](#))

In other words, if possible, you could use your natural tendency to go to sleep 1-2 hours later, until you align with the desired sleep rhythm. At that point, the real battle begins by efforts to provide strong morning resetting stimuli (e.g. bright light, stress, exhaustive exercise, etc.). Those can be enhanced by evening measures such as [melatonin](#) and the avoidance of phase delaying factors such as light, stimulation, stress, Internet, etc. In general, you need to provide resetting stimuli in the morning, and avoid evening delay factors such as computers, TV, artificial lighting, etc. For most people, a degree of [sleep deprivation](#) is more acceptable than several futile inactive hours in the evening in a dark room.

Is DSPS a disease?

Probably, most of the cases of DSPS can be explained by a lack of compatibility between the genetically determined sleep control system and the lifestyle. For some people, the degree of the problem may be greater than for others (see: [Clock Genes](#) and mutations affecting the clock period (Golombek and Rosenstein 2010^[30])). Everyone can easily cure the disorder with a decision to drastically change one's habits (e.g. a return to a [farmer's lifestyle](#)). However, such a change is usually not feasible due to the type of employment or family life conditions. This means that DSPS sufferers are probably, for a while, sentenced to wage a constant battle with their body clock.

Officially, 0.2% of adults suffer from DSPS. Using numerous [SleepChart](#) data submissions, I see a true epidemic of DSPS. Moreover, there is a large hidden DSPS population. I have seen cases where people started showing DSPS sleep patterns as soon as they gave up an alarm clock after years on a normal schedule with a seemingly normal life contaminated somewhat with a degree of [sleep deprivation](#).

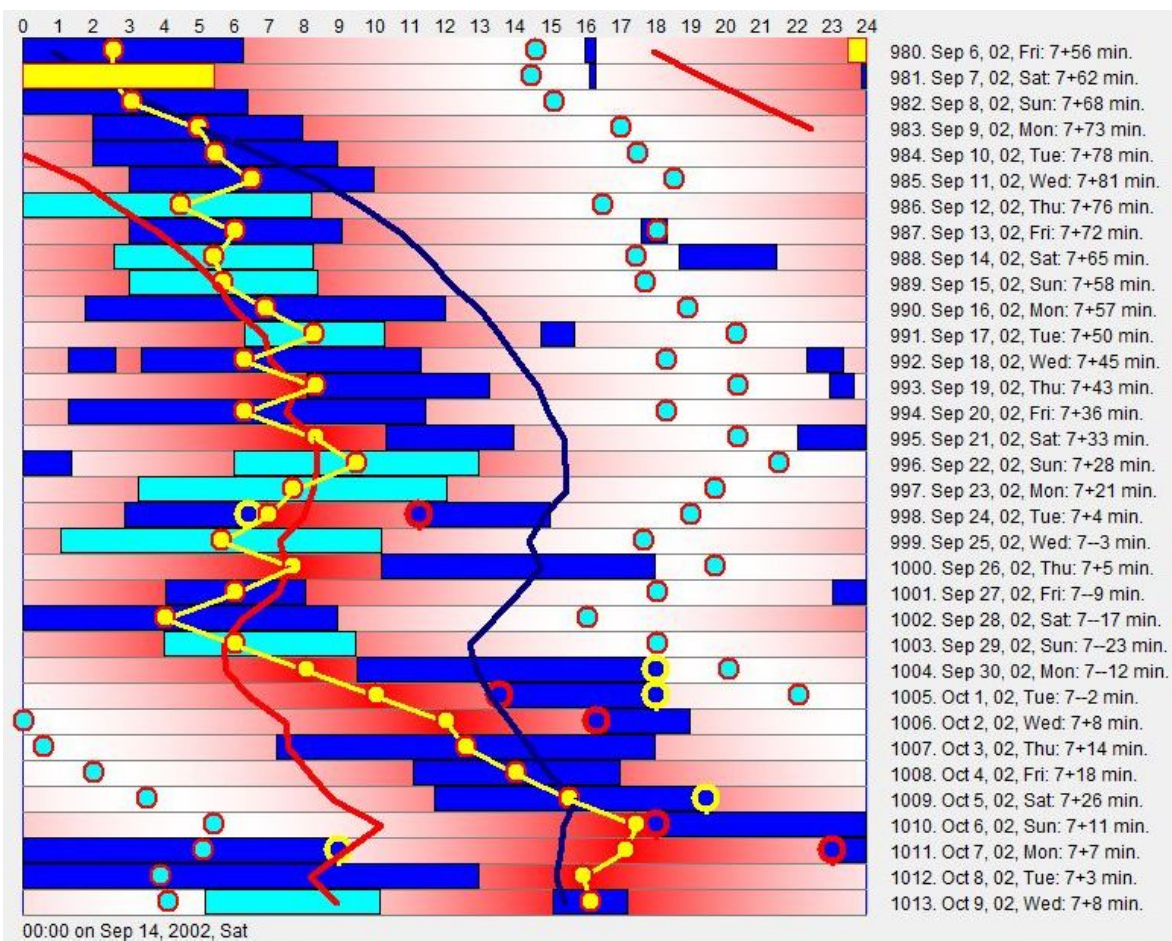
Admittedly, people who write to me are already a pre-selected population, but the numbers are really staggering. I am pretty sure that most of those DSPS cases are lifestyle related. As the term "syndrome" might suggest DSPS is a disease, I keep emphasizing that DSPS is rather a reflection of our modern electricity-based lifestyle than an actual disorder. Interestingly, I received very few [ASPS](#) submissions. It seems that it is DSPS people that hang out late in the night googling on their PC for solutions to their sleep problem. In the end, they arrive to [SleepChart](#) and the concept of [free running sleep](#) that can be their magic cure (if ever truly affordable).

DSPS epidemic can be considered a civilizational disorder in which the pressure of a modern lifestyle stands in disagreement with millions of years of evolution. In the long run, once we fully understand all biochemical and hormonal processes underlying sleep, it is possible that mild pharmacological intervention will make it possible to regulate the circadian cycle.

Asynchronous DSPS

Combating phase shift

People suffering from DSPS find it difficult to synchronize with the 24-hour clock. In the picture below, an adolescent female with a mild DSPS suffers disintegration of the sleeping rhythm due to the failed efforts to synchronize with "the rest of the world":

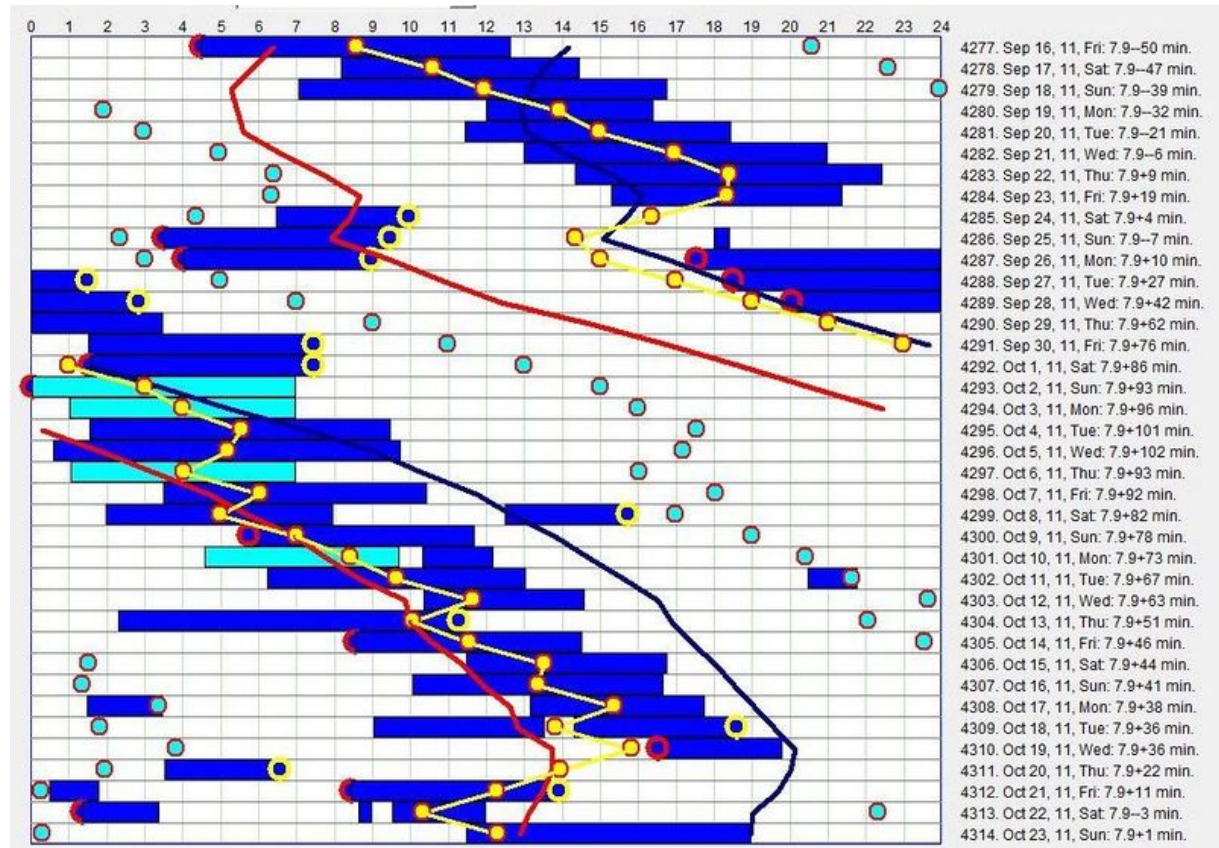


After the vacation period, she begins in early September well-synchronized with the "rest of the world". She wakes up between 6:30 and 10:00. However, her body clock experiences continuous shift in her [subjective night](#) period. Soon she wakes up at 12:00 and begins a struggle against the further shift. This results in the disintegration of the sleep cycle, short sleep periods below her preferred average (e.g. 4 hours) and frequent bouts of tiredness. [SleepChart](#) attempts to plot the extent of the [subjective night](#) (i.e. the hours of maximum natural sleepiness). The statistically predicted [subjective night](#) is bracketed between the red and blue lines. Circadian [acrophase](#) (middle-of-the-night) is plotted in yellow. [Circadian](#) sleep propensity is expressed by the shades of red. Sleep blocks terminated with an alarm clock are marked in aqua. Clearly, the greatest disruption in the sleep pattern occurs at the point where the "natural" rhythm departs furthest from the "desired" rhythm. Mild DSPS cases are able to force the body clock to remain more or less in the desired bracket at the cost of a constant struggle with sleepiness. In more severe cases, the [circadian](#) variables will run a 24 hour cycle and the individual will experience return to "good sleep" when free running variables align again with the "desired" sleep period.

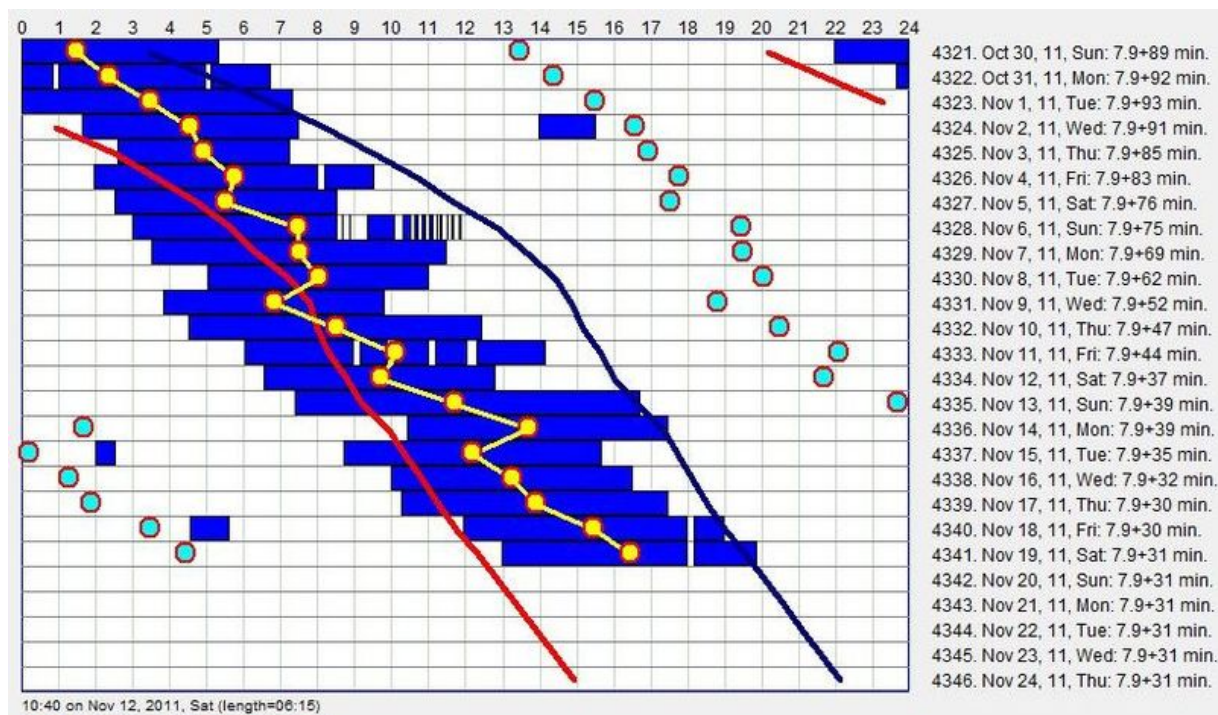
The average sleep length is 6.8 hours but total sleep changes widely from day to day. The average DSPS shift is difficult to determine due to the battle against the natural rhythm. However, it is likely that the shift is around 60 minutes as evidenced by the average progression of the circadian **acrophase** estimate (in yellow). Without the use of an alarm clock, the advancing sleep phase would likely complete a full 24h turnaround in 3-4 weeks.

Resynchronizing the cycle

In the next example, a middle-aged female with a severe case of DSPS experienced a similar struggle in stabilizing her sleep rhythm within socially acceptable limits:



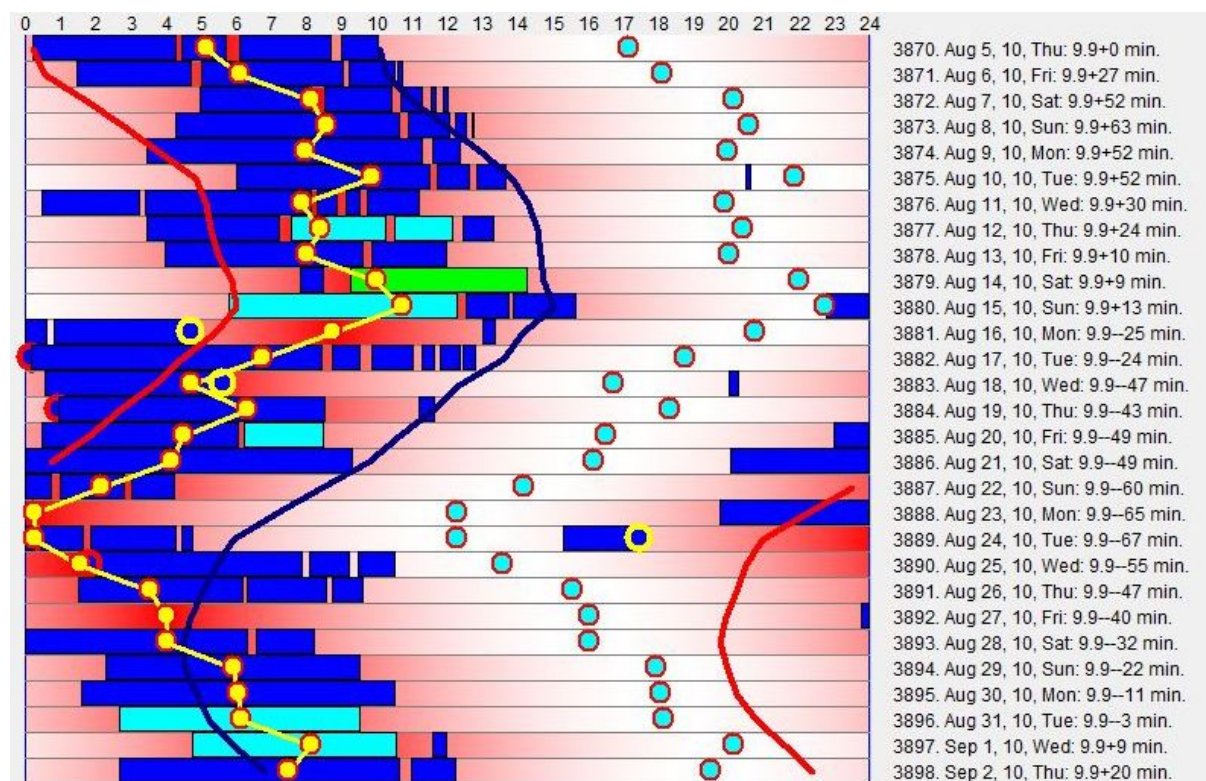
Subjective sleepiness was minimum when the body succumbed to the progression of the sleep phase (Sep 16 - Sep 23), daytime tiredness increased markedly at the time of the battle with the progression (Oct 2 - Oct 11) where light aqua blue sleep blocks were blocks artificially terminated with an alarm clock. Finally, daytime drowsiness peaked in the period of lost synchrony between sleep periods and the **circadian** phase (Oct 19 - Oct 22). The breakthrough came with the religious adherence to **free running sleep**. The next log shows the same female on a well-managed free running schedule:



A perfect alignment of sleep periods with the circadian **acrophase** (yellow line in the middle of the subjective night) resulted in tripled energy and a sense of well-being.

Social life in DSPS

Naturally, only people who are telecommuting, self-employed, or working from home office can afford to let their sleep run free in DSPS. Even then, the shifting sleep phase is a serious predicament. A legally blind DSPS sufferer from the Netherlands wrote about the pain of the shifting sleep pattern: *"I am free running my sleep. I had an appointment at 17:30. I expected to wake up around 15:00 as in the previous three days. Instead I woke up around 17:00 still a bit tired. I had to skip my morning routine (meditation, breakfast, SuperMemo, etc.). FRS works really well for me. But today sucked. It was really stressing having to run due to waking up later than expected"*. After a medical consultation, this subject was prescribed evening [melatonin](#) and was able to stabilize his cycle (for at least a few weeks at the moment of writing these words). The torturous battle of the same subject with phase shifts before running free and before administration of melatonin is shown in this graph:



This example illustrates the major dilemma of all more severe DSPS cases. [Free running sleep](#) will often produce a [phase shift](#). Anyone who tends to wake up very late is also highly likely to tend to wake up later each day in free running sleep. This is a hallmark symptom of the DSPS. DSPS, however severe, is never a health problem on its own if the sleep is run free. It is the scheduling problems that are most bothersome. The choice is between the two extremes:

1. either make one's life less dependent on meetings and appointments that can collide with your sleep schedule, or
2. study DSPS remedies that can stabilize your sleep-wake cycle.

If you happen to always wake up late, waking up always at the same time makes scheduling much easier. If you do not opt for one of the above extremes (free schedule vs. stabilization battle), you will risk collisions that will make life pretty hard. What is even more dangerous, if one disrupts a [circadian](#) rhythm on a free running schedule, there can be a loss of synchrony between various [circadian](#) variables. This will result in a situation in which for a day or even a few days one is not sure of the optimum bedtime. Even [SleepChart](#) may be unable to make a good prediction. This will inevitably result in poor quality sleep, and a few days of low productivity.

DSPS: genes or lifestyle?

Even though I keep repeating that the DSPS epidemic is a reflection of a modern lifestyle, genetic factors clearly play a role and the "creative personality" can also be at the root of the problem. Here is an interesting story of a writer mom whose parents and two kids do not show any signs of sleep problems, however, she suffers from a severe case of DSPS and so does her 20-year-old son:

My mother claims I have had sleep issues from the day I was born. In those days "rooming in" was new as most babies were kept in the nursery and it was the norm for both baby and mother to stay in the hospitals for a week after a normal birth. She enjoys telling the story of how the nurses forced her to have me "room in" with her during hospital stay because I was "keeping up all the other babies in the nursery all night long" because I refused to sleep during nighttime hours. She said that after she and my father brought me home, I was afforded one night in the room with them but I was up all night so I had to "cry it out" alone from then on because I simply would not sleep at night. When I was a few years old, one night, exasperated, my parents said, "Fine. If you want to stay up, you can sit here and watch Johnny Carson." Apparently I was happy to do so! I did, however, have very unhappy memories dating back to the beginnings of my [recall](#) of being put to bed at around 20:00 every night and lying up awake and with nothing to do for hours and hours in my darkened, boring room. Back in those days, there was no Internet, no cable TV, no video games, no cell phones, etc. I simply could not get myself to sleep at a decent hour ever in my entire life! I'd often sing myself to sleep and it would take hours to do so. Sometimes I would run out of songs to sing and have to repeat a few until I passed out."

Today, this self-employed female is experimenting with [free running sleep](#) and claims that, except for her social life that suffers as a result, the new schedule brought her back from the "hell of perpetual drowsiness".

Chronotherapy and its perils

Chronotherapy makes it easy to fit the [circadian](#) phase into a desired time bracket, e.g. after an intercontinental flight, in circadian disorders, or for the sake of shiftwork. For most people, shifting the cycle forward by inducing phase delays is easier. It is possible to go to sleep 40-70 min. later each day and to cycle throughout the day until the desired sleep phase is reached. Pushing one's circadian cycle should always be the last resort. All artificial forms of sleep control should be avoided if possible as they are not healthwise neutral. However, some reports in the literature suggest that chronotherapy may have serious long-term cycle synchronization consequences. Wehr reports (Wehr et al. 1992^[26]): "In 1983, one of us described a 28-year-old man with DSPS who underwent chronotherapy and found himself unable to stop his sleep period from rotating around the clock or restore his rhythm to a 24-hour schedule. Instead, *hypernyctohemeral syndrome* developed, with a persisting 25-hour sleep-wake cycle. This rare syndrome is extremely debilitating in that it is incompatible with most social and professional obligations".

I have personally witnessed numerous cases of phase delays upon switching to [free running sleep](#) in seemingly normal people, and have a different interpretation. People differ in the degree of difficulty in sustaining a balanced 24h cycle in free running sleep. That difficulty is well expressed in [circadian graphs](#) by the angle of the sleep maintenance curve in reference to the breakeven line that determine a balanced 24h cycle. Most adolescents will experience a degree of difficulty in maintaining the balance if they are allowed to engage in their hobbies and passions late into the night. Once they are allowed to do as they wish, they will often induce phase delays by a simple unwillingness to go to bed "in time". Even though the progressive 24.5 hour cycle may seem unsettling at first, resulting in sleeping in unusual hours, the convenience of running free with extended waking days may outweigh the negative side effects. For people suffering from DSPS, running free may provide an unusual degree of comfort that is difficult to forfeit. No wonder that many DSPS sufferers, who enjoy a progressively shifting [circadian](#) cycle in free

running sleep, often give up the battle to reset the cycle, or even discover that their natural **phase shift** is far larger than originally diagnosed.

As the medical and psychiatric terminology of severe cases of DSPS is very confusing, I need to yet attempt to explain cases of "irregular Non-24-hour sleep-wake syndrome", by which I mean a severe DSPS where sleep episodes do not fall into a regular pattern. I have presented some cases in the [Asynchronous DSPS](#) section. I have little doubt that most of such irregularities come from subject's own ignorance of his or her sleep preferences, as well as the rules of a healthy free running sleep regimen in circadian disorders. Once a sufferer is instructed on the rules of healthy free running sleep, perhaps with some assistance from SleepChart, the sleep pattern becomes regular.

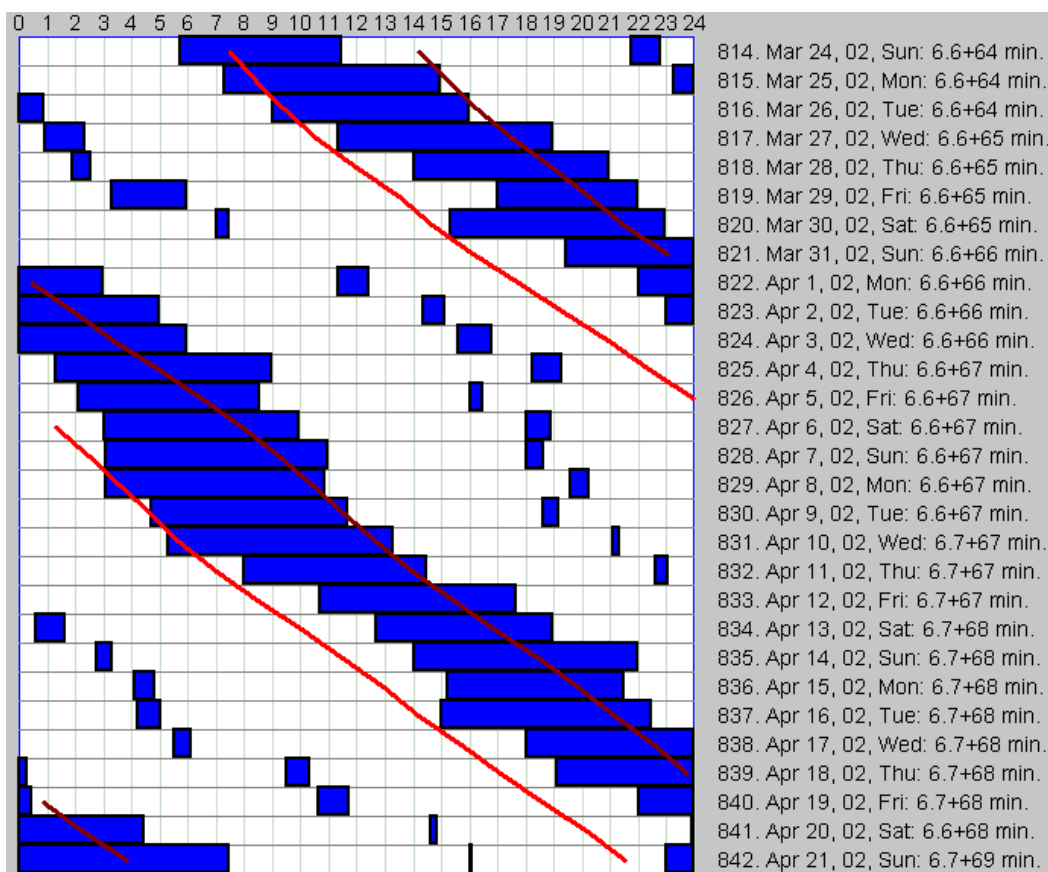
My personal stance on chronotherapy is therefore as follows:

Chronotherapy is the best approach to repositioning the phase of the **circadian cycle. It should always be the last resort as it is not neutral for the quality of sleep. However, long term consequences of occasional use of moderate chronotherapy are probably negligible.**

Synchronous DSPS

When a DSPS sufferer attempts [free running sleep](#), sleep phase delays are inevitable. There have been cases in literature that documented people living along such a shifting DSPS schedule for decades without major health side effects (Neubauer 2000^[31]). For an exemplary report see this [blog](#)^[32]. Some authors claim that a shifting schedule may increase the incidence of depression, alcoholism, or dependence on sedatives (as a result of attempts to induce sleep at the "appropriate" time).

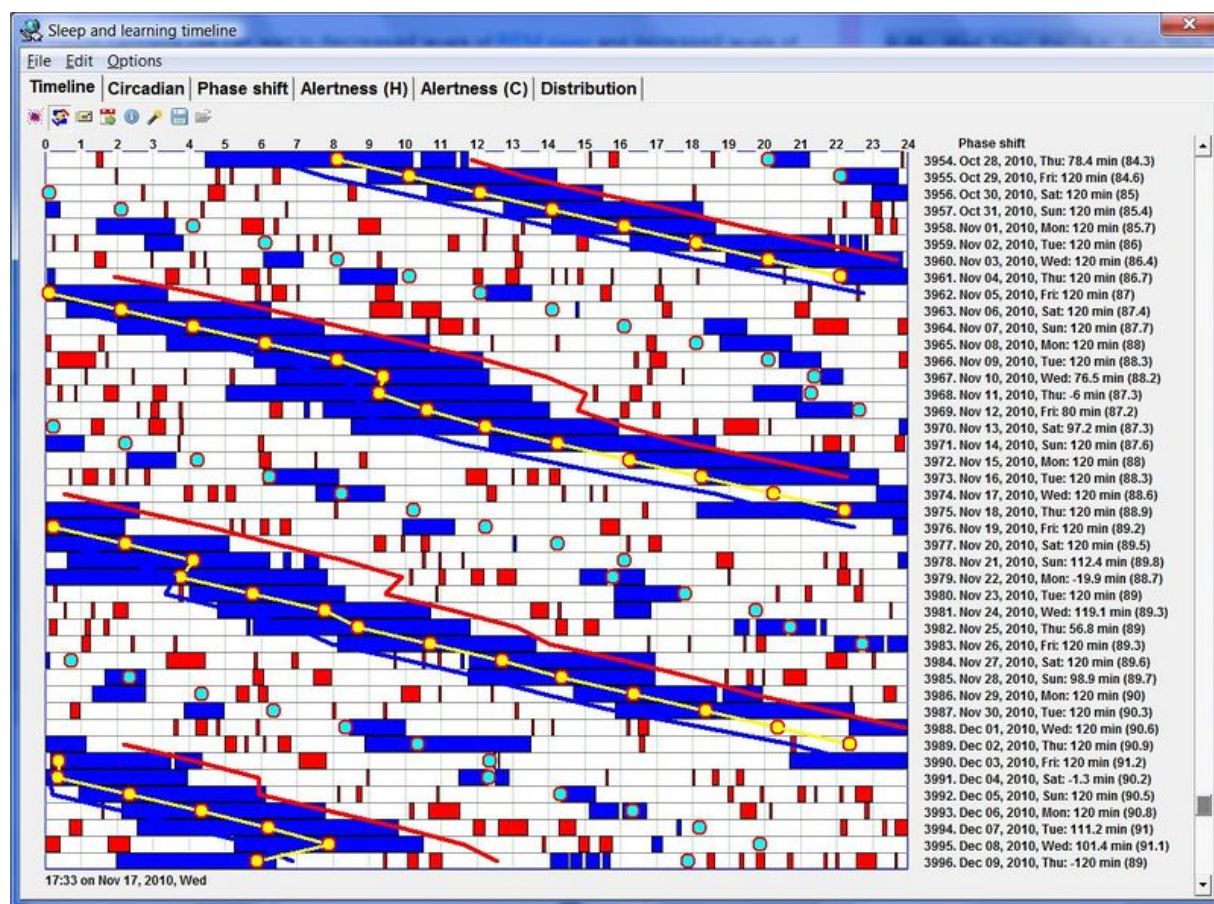
The following graph presents a sleep pattern of a free running middle-aged self-employed male:



A very clear and regular DSPS pattern visible in the graph with a daily **phase shift** of 64-68 minutes. Although sleeping in "unnatural" hours is certainly less beneficial healthwise than normal sleep, for a DSPS subject, free running sleep rhythm may be far less stressful and disruptive than any attempt to fit to "standard" lifestyle. A very reliable determinant of synchronous DSPS is the loss of the link between the sleep onset hour and sleep duration (see: [Preference for night sleep](#)). As the duration of sleep is determined by the **circadian** phase, well-synchronized sleep schedule shows little variability in the sleep length (6.6 hours in the presented graph). In particular, the sleep length is independent of the sleep onset hour. Whenever the subject makes any attempt at synchronization with daylight or daylight-related activities, the link between sleep length and the onset hour will be reconstituted. Mistakenly, DSPS

people are often called "owls" for their tendency to stay up late, while **ASPS** people are called "larks". The graph illustrates why this is a misnomer.

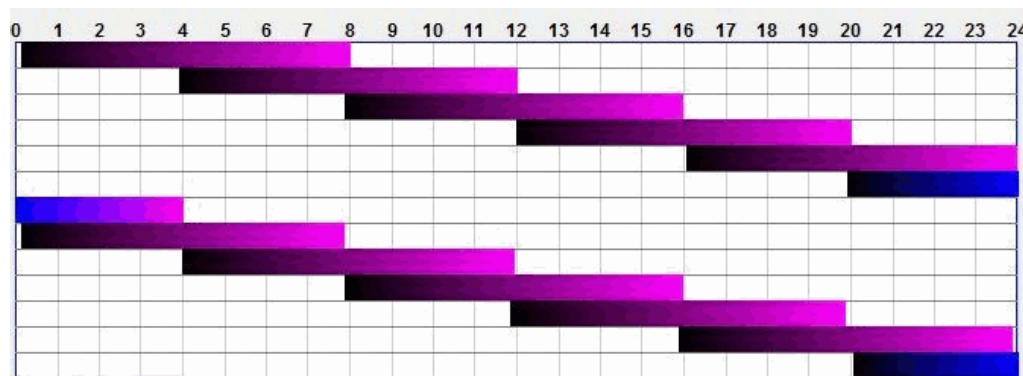
A similar graph shows a DSPS case with an even greater degree of **phase shift** (84-90 min):



Due to a better sleep efficiency in episodes well aligned with the **circadian** cycle, people on a regular free running DSPS schedule report a much higher subjective alertness and energy as compared with those on an irregular DSPS schedule. This difference also shows up in data collected with **SuperMemo**.

28 hour day schedule

28 hour day schedule was proposed for those who seek higher productivity and more hours in a day. An example of a 28h sleep pattern design shows a **phase shift** that needs to reach the daily extreme of 4 hours per day for anyone to be able to sustain that schedule for a longer period of time:



28h day schedule design

The advantages of a 28 hour schedule supposedly include longer working days, regular 6 day week, repeatability, long weekends, increased energy, unlimited sleep, etc. (for more see: [28 hour day](#)). This proposition is the other extreme of a spectrum of propositions that begins with [polyphasic sleep](#). However, it seems far easier to sustain as it does not need to involve an alarm clock. Sleep researches believe that this schedule is so extreme that nobody should be able to sustain it in a long run. 4 hour phase shifts are so unlikely that researchers choose it for their experimental forced

desynchrony protocols. These are experimental protocols in which the body is supposed to fail to adapt to the timing of zeitgebers. Such an **entrainment** failure is beneficial in studying free running **circadian** variables. 4 hours shifts have been used in both advancing and delaying protocols (20 hour days (Wyatt et al. 1999^[33]) and 28 hour days (Carskadon et al. 1999^[34])). All research to-date seems to indicate that the circadian cycle keeps running free in the background in forced desynchrony protocols due to the fact that resetting stimuli cancel each other out and sleep episode intersect with the **circadian** variables in unpredictable patterns that result in segmented sleep, premature awakening, shortened sleep, reduced REM, and other symptoms of asynchrony. In short, **28 hour day is considered extreme enough to cause perpetual lack of synchrony between the timing of sleep and the circadian cycle.**

28 hour day in DSPS

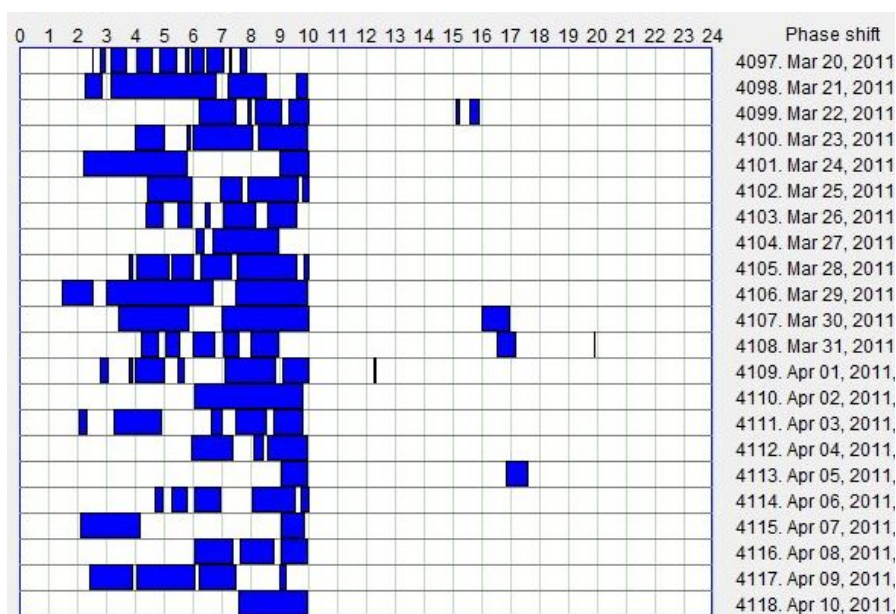
Some sufferers from DSPS report feeling better on the 28 hour schedule than on a conventional 24 hour sleep schedule. I do not think it is likely there are individuals out there with an innate ~28 hour **circadian** cycle, however, it is conceivable that the effort to squeeze a DSPS cycle into 24 hours is more painful than the alternative in the form of stretching the cycle to 28 hours. The main difference is that the shortening of the cycle usually involves the painful use of an alarm clock, while stretching the cycle requires "only" extra 2-3 hours of zombified wakefulness. Even in severe DSPS, it should be pretty hard to adapt one **circadian** cycle to the 28 hour schedule as the [phase response curve](#) indicates that the sleep phase does not respond strongly enough to strongly delayed bedtime, which may, in extreme cases, cause a phase advance. Phase delays beyond 2 hours should be extremely rare.

For most people, it is pretty hard to tolerate even minor deviations from one's optimum cycle period. For this reason, all designer schedules should be avoided unless they come from a strict analysis of one's own sleep preferences. Again, free running sleep is a better option, even though it may be less predictable and less convenient in planning one's social or professional life.

Let us consider an exemplary case of Subject S, and compare her sleep efficiency on conventional, 28 hour, and free running schedules.

Conventional schedule in severe DSPS

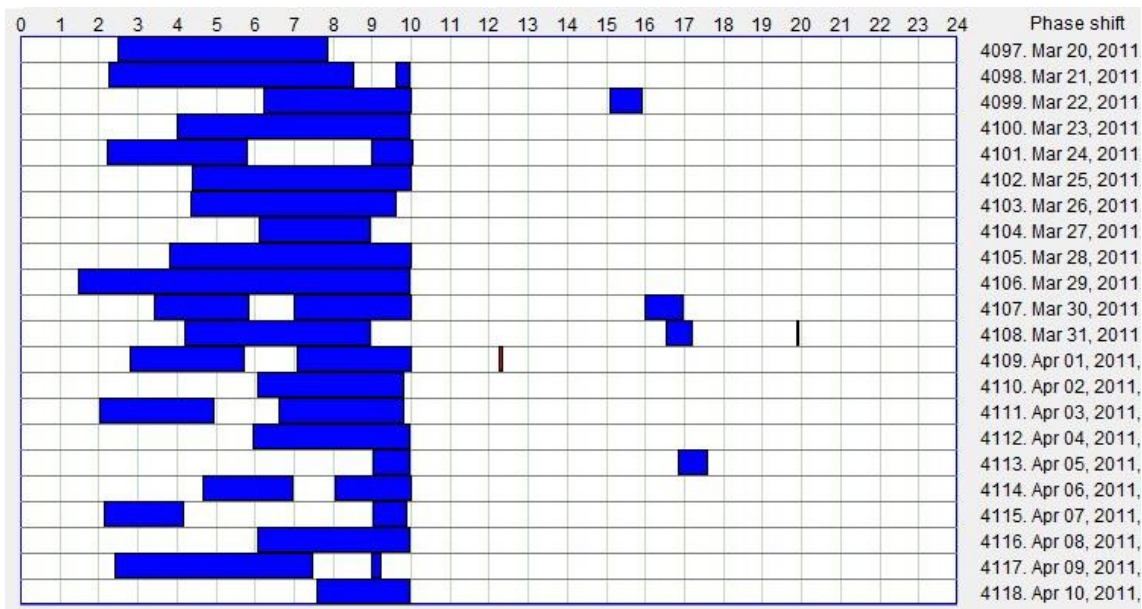
When S attempts to adhere to a conventional sleep schedule, under medical supervision, with the help of sleep medication (incl. [melatonin](#)), the sleep is strongly fragmented, short, unrefreshing, and the schedule is unsustainable:



Subject S on an unsustainable conventional schedule.

This type of sleep is tantamount to mental torture, and all individuals with a similar degree of **entrainment** failure should always be allowed to let their sleep run free on the grounds of severe disability.

In the presented chart, a pattern of possible free running **circadian** cycle can be noticed in the chart with the **subjective night** leaving the conventional night bracket around April 6, 2011. This is more noticeable upon **sleep episode consolidation**:

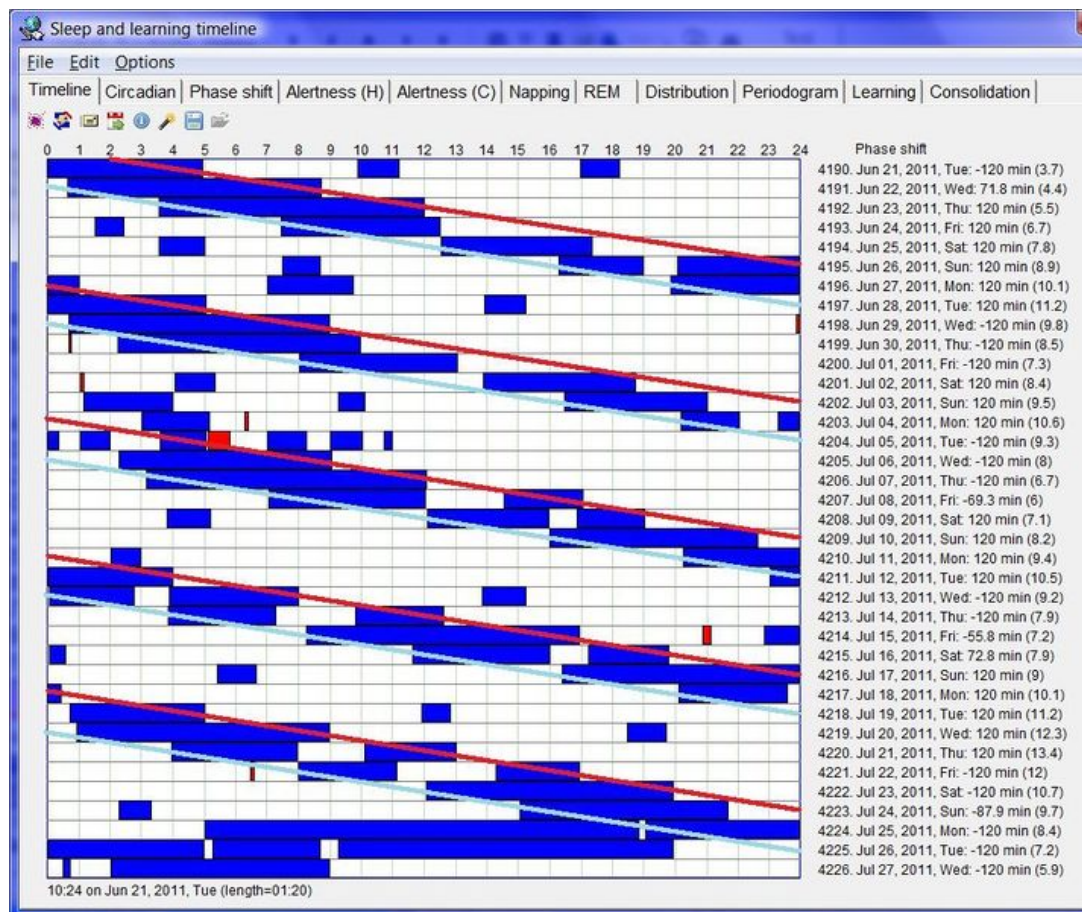


Subject S on an unsustainable conventional schedule (sleep episodes consolidated).

Needless to say, the conventional schedule, if maintained for longer, may lead to serious health problems due to the state of persistent **sleep deprivation** compounded by medication. Even though the presented case is pretty drastic, the number of people suffering from similar sleep problems is constantly increasing and is definitely affecting overall population health and productivity.

28 hour schedule in severe DSPS

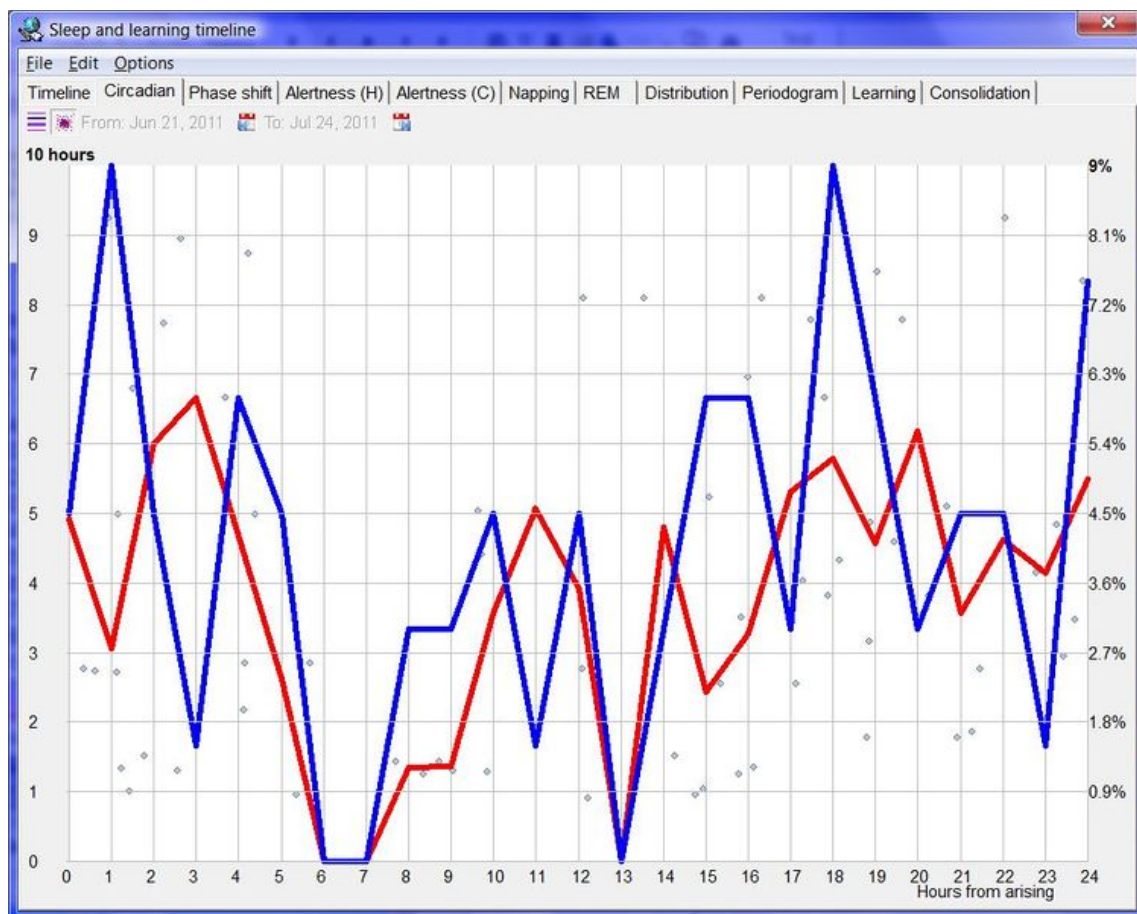
When S attempts to adhere to a 28h day schedule, her subjective sleep quality increases dramatically along with the total sleep achieved. Detailed analysis of the sleep chart, however, shows that sleep fragmentation is still substantial showing strains in the sleep control system:



Subject S on a 28h day schedule.

Segmented sleep starts showing after two cycles which might indicate that the actual **phase shift** lags behind the planned phase delays. Segmented sleep is often a sign of premature bedtime and shows up when the 28h schedule bedtime falls ahead of the presumed free running **subjective night**. When the sleep schedule undergoes an eventual collapse, the positioning of lengthy recovery sleep episodes seems to indicate that the average daily **phase shift** might have actually been much less than 4 hours. In an extreme case, large disparity between the **subjective night** and the planned nighttime might result in self-cancelling phase shifts that might paradoxically stabilize the sleep cycle.

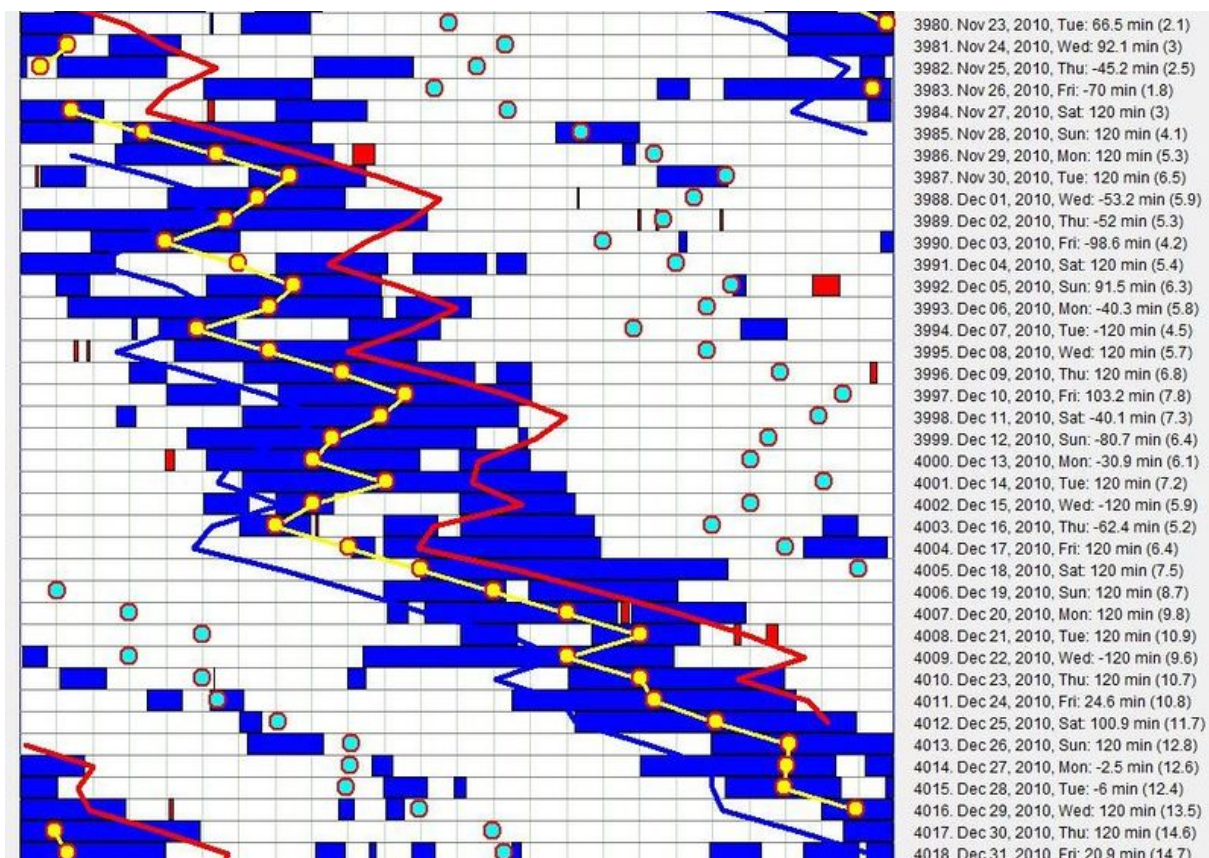
Circadian graph for the same 28h day schedule illustrates the degree of chaos in the sleep control system:



Circadian graph for Subject S on a 28h day schedule.

Free running sleep in severe DSPS

When the sleep chart of Subject S running free just a few months earlier is inspected, the sleep **phase shift** is closer to a mere 41 min per day (as opposed to 240 minutes needed to smoothly sustain the 28h day schedule):



Subject S on a free running schedule.

However, the chart shows that even in that period sleep was strongly fragmented and irregular. Similar analyses are often misleading due to compounding circumstances such as a disease, family problems, medication, and even a wrong choice of bedtime (e.g. in an attempt to stabilize or accelerate the cycle).

In similar cases, it is paramount to chart one's precise **circadian** preferences. For this reason, a few weeks of uninterrupted free running sleep would be precious to determine one's natural innate daily **phase shift**. Once this is done, more can be said about the sustainability of a 28h day schedule for a given individual. However, **continual free running sleep is always the best option for those who are absolutely unable to balance the cycle** and those who can afford the sleep schedule that is hard to reconcile with the rhythm of the outside world. See: [Curing DSPS and insomnia](#).

Curing DSPS and insomnia

If you cannot live without an alarm clock to wake up in time for school or work, you might be suffering from a delayed sleep phase syndrome (DSPS). DSPS is also associated with problems with falling asleep if you try to keep an earlier bedtime. In other words, any cure for DSPS is also likely to solve the problem of [sleep onset insomnia](#). If you go to a sleep expert with your DSPS problem, you will likely be prescribed [melatonin](#) or a bright light therapy only to discover their limited impact on the quality of your sleep. If you are an insomniac, you may additionally be prescribed sleeping pills that might help you sleep without achieving the desired effect: a refreshed mind. This chapter should help you solve the problem. Using the properties of the human sleep control system, it can be proven mathematically that the problem of DSPS, and the associated **insomnia**, is always solvable, however, the solution does not need to imply the crispiest mind or the highest intellectual productivity. Moreover, many people will still fail due to the lack of self-discipline! Where modern world encroaches upon human biology, it is still possible to withstand the tide with the rules of reason. However, these imply a religious adherence to the decalogue of healthy living. Life shows that humans find all decalogues difficult to abide by!

Solution for insomnia, DSPS and N-24

This algorithm should help you in all the following cases:

- if you are an **insomniac**, your body most likely tries to sleep in a different phase, if you fix the phase, you will fix the insomnia
- if you are a **DSPS** case, esp. a long-term sufferer, you will be very skeptical of the algorithm. You need to give it at

least a few weeks of well-disciplined try to see that your sleep cycle can be modified with the right tools

- if you are a **Non-24** and you believe there is no pattern to your sleep, you are most likely wrong. There are rare mutations that can totally mess up your sleep, but a more likely explanation is that you are a DSPS case who just introduces enough chaos into your sleep pattern to make it seem unpredictable. If you are otherwise healthy and if you try [free running sleep](#), you will notice the pattern. For the pattern to emerge your "free" sleep must truly be free. No regulation. No artificial control! After that, you can try the algorithm presented below to see if you can show enough self-discipline to set your cycle stable.

DSPS and lifestyle

Even though there are various genetic influences that play a role in DSPS, the problem is, for most people, largely a matter of lifestyle. I claim that due to the fact that a return to a [farmer's lifestyle](#) provides a guaranteed disappearance of the DSPS problem. Below, I have compiled a simple algorithm that should resolve DSPS in a vast majority of cases given sufficient self-discipline. Until now, I have been far more successful in showing people how to cope with DSPS using free running sleep than with the prescription listed below, which is a derivative of free running sleep with some limitations targetted at preventing a phase delay. The presented algorithm fails primarily because of one issue: violation of the rules! There are true hardcore DSPS cases with some psychiatric overtones or other health issues that might be particularly intractable, however, those should form a rare minority in the ever-increasing mass of people struggling with DSPS. That mass now includes a countless population of insomniacs who have never heard of DSPS and never even arrived to the problem of phase shift due to the employment of the alarm clock. Weitzman hypothesized that a significant number of patients with sleep onset [insomnia](#) might be suffering from undiagnosed DSPS (Weitzman et al. 1981^[35]). Now we know that hypothesis certainly holds true, which can be demonstrated by letting insomniacs free run their sleep. A significant phase delay may be observed within the first few days of such a release from the restrictions on the timing of sleep. At the same time, there is an accompanying and nearly instant disappearance of sleep-onset [insomnia](#).

Implausible solutions

People who suffer from DSPS often resort to their own implausible solutions that include:

- (poorly managed) free running sleep with an inevitable phase delays that ultimately result in sleeping through the day
- skipping a night of sleep at a point when the bedtime reaches an outrageously late hour (i.e. usually after the dawn)
- stabilization of the sleep pattern with medication (incl. [melatonin](#)) and artificial zeitgebers such as an [alarm clock](#) or a mom who pulls a sleepy student out from his or her bed for school
- messy sleep that occurs at unpredictable hours with the loss of sense of the nighttime and long bouts of drowsiness, low energy, or poor health. This sleep pattern is often labelled Non-24 or N-24, however, in most cases it differs from DSPS only in the lack of self-discipline or knowledge needed to adhere to a natural sleep cycle, even if its period is longer than 24 hours

Only a well-managed free running sleep can produce healthy sleep in DSPS with a minimum risk of negative health outcomes. However, very few practitioners do really adhere to the rules of their own body clock as there are always excuses or inescapable reasons to violate the [subjective night](#) when it collides with daytime obligations or diversions. People who try to "free run" their sleep in DSPS for many years are at a risk of messing up their sleep control system. I conclude that from the fact that their sleep patterns often become less and less regular^[32], and the quality of their sleep often decreases. This effect would almost certainly be minimized if the sleep was truly free without medication, light therapy, artificial delays, or the use of the alarm clock. They may even falsely claim that their cycle started getting longer and longer, while it is the lifestyle demands that keep stretching the waking time. The culprit here, naturally, is not free running sleep per se, but various violations thereof that are inevitable due to a conflict of sleep with daytime activities.

Plausible solutions

If we exclude a healthy [farmer's lifestyle](#) and the renunciation of evening electricity, we arrive at only two reasonable lifestyle solutions to the DSPS problem:

- (well managed) free running sleep with phase delays, high creativity, high productivity, good health, and schedules that are nearly impossible to reconcile with the outside world
- stable 24h sleep cycle, with monastic self-discipline, good health, and lower productivity

I write about free-running sleep throughout this article. I worship free sleep so much that I have been accused of labelling DSPS with the stamp of incurability. Here I would like to present a plausible algorithm for sustaining a 24h sleep pattern in DSPS with minimum artificial intervention into the fabric of sleep.

The algorithm

The only reasonable 24h solution to the problem of [insomnia](#) and DSPS is the change to the sleep phase. We can advance the sleep phase using evening measures (pulling the sleep backwards) and morning measures (pushing the sleep backwards). That takes care of the circadian component of sleep. In addition, all measures that boost homeostatic sleepiness in the evening are also welcome. However, without the circadian components those might actually compound insomnia. This is why only a comprehensive approach, as presented below, provides a solid chance you will leave your DSPS and/or insomnia behind:

- **Determine the length of the day:** Use [SleepChart](#) to determine your [optimum length of the waking day](#). You may need a few weeks of free running sleep data to make a good estimate. If you cannot free run, and/or the procedure seems too complex, you could just make an educated guess. For example, if you believe you need 8 hours per night, in free running sleep it might be closer to 7 hours, and your optimum waking time would be $24 - 7 = 17$ hours. However, due to the problem of possible insomnia, it makes sense to start from a slightly longer day and shorter sleep, e.g. from 17.5 hours of waking.
- **Determine the preferred waking time:** This should be the same time every day! If you have to get up early only once per week, your entire cycle should be positioned to accommodate that early hour, or you will risk never-ending ripples in your circadian system and a possible failure. If the waking hour is late enough to ensure bright sunlight in the morning, your chances will increase greatly.
- **Religious bedtime:** By adding your optimum waking time to your chosen waking time, you will get your optimum bedtime that must be respected religiously. This respect is one of the keys to success. You will encounter many obstacles in the process. One of the most confusing ones is the change to your optimum waking time depending on the contents of your day, your activities, your stress, weather, season, social interaction, and so on. For most people those changes are less than one hour. However, you are more likely to be in the wild variations category as this is one of the underlying problems in DSPS. Start adhering to your optimum bedtime as if your life depended on it. If you are very excited or stressed, and you are not sleepy at your bedtime, you can try again 20-30 min. later. You need to be sure you won't toss and turn, and that you do not wake up prematurely. If you see any signs of insomnia, you will know your bedtime comes too early and you allocated too much time for sleep. If you are very sleepy ahead of your bedtime and you have no doubts you will sleep like a log, go to sleep earlier. Your optimum bedtime is the guidance, your actually sleepiness is the ultimate yardstick.
- **Start the algorithm.** Ideally, you should start the algorithm at a time when your waking time precedes your desired waking time. Otherwise, you may need to temporarily resort to using an alarm clock. However, each use of the alarm clock will add to your stress and anxieties related to early bedtime. If you have to use an alarm clock, and if you struggle with getting up in the morning, you should consider taking a full free running cycle with a daily delay of 20-40 min. until you arrive at getting up comfortably 2-3 hours before your chosen waking time. You could then try to re-start the algorithm.
- **Protected zone:** As you suffer from DSPS, your primary objective is to prevent phase delay. This means that, in your last 2-4 waking hours, you need to avoid light, electricity, excitement, stress, intense sports, TV, computers, social interaction, e-mailing, web surfing, etc. If the presented algorithm does not work for you for a longer time, you may have to extend this "protected zone" up to a point where the resulting "inaction" results in more stress or frustration than it actually eliminates. Extending the protected zone beyond 2-3 hours of dark silence will probably be counterproductive. See for yourself. Remember, that the protected zone is not a time for lying in bed! Unproductive time in bed will add to your stress, and if you fall asleep early, you can mess up your sleep on that night and actually delay the phase! Obviously there is a very limited range of activities you can do in the protected zone. I leave it up to your imagination. Perhaps moderate exercise in dim light. Or sex? Or walking and thinking? [Seth Roberts](#) swears by one-legged standing before sleep.
- **Morning light:** One of the most powerful zeitgebers is light. If sunlight can stream into your room at the time when you should wake up, you might eliminate half of the difficulty in achieving a 24h balanced cycle. If this is impossible due to the season, or your early waking hour, or your living arrangements, you might consider using one of the commercial devices used in the "bright light therapy", esp. if you turn on the lights with the timer (if your device has no timer, you can use a timer that cuts off the supply of electricity for the night). Please be sure you read all the relevant safety instructions to prevent any long-term impact on your health.
- **Morning exercise:** Another powerful zeitgeber is outdoor exercise. If possible, you should schedule that exercise early in the morning, or at least in the first 5 hours of the day. Morning exercise will affect your intellectual performance. You will most likely tire faster. However, this is also one of the factors why exercise should help you sleep better. Intense exercise late in the day may have the opposite effect and might delay your phase. However,

some forms of exercise will not have this effect as the phase-shifting stimuli will be counterbalanced by the amplification of the homeostatic sleep drive and the "fasting effect" that will help you sleep early. Those evening exercises should be free of stress, injury, emotion, etc. Gentle calisthenics, yoga, or stretching would be an example of harmless evening exercise. Perhaps even body building, if not too exciting or strenuous. This late exercise would best be performed in dim light and in absence of other rousing stimuli. If you can swear that evening exercise helps you fall asleep faster, even if strenuous, remember that sleep itself has a phase-shifting power and can actually outweigh the opposite effect of adrenaline or locomotor activity. If you are not sure, experiment on your own.

- **Evening fasting:** Unless you are a ravenous type that cannot sleep without a snack, give up meals in the last couple of hours of the day. As explained in the [DMH](#) section, food may have an additional impact on the positioning of your circadian cycle, and you do not want your brain to think that evening is an opportune time to get food. A healthy breakfast in the morning should have the opposite effect on the sleep phase and is always recommended by nutritionists even if sleep phase delays are not in the cards (note that [Seth Roberts](#) recommends skipping breakfast, but this should apply to those who suffer from early waking or ASPS, not for onset insomniacs or DSPS). Don't be discouraged by research that may claim that evening fasting will not affect your circadian cycle. For example, Sensi found that morning meals seem to favor carbohydrate metabolism, and meal timing, within the studied range, did not impact circadian cycles (Sensi and Capani 1987^[36]). Fasting has many other added benefits, incl. slimmer waistline. Try it for yourself and see the impact of evening fasting on your sleep and health within a week! Read more: [Fasting](#).
- **Adding pressure:** If you keep failing by waking up too late, or not being sleepy at the desired bedtime, keep adding up pressure at both ends of your night sleep. More exercise in the morning, brighter lights in the morning, longer protected zone in the evening (free of stress, computers, lights, TV, etc.). The harder your case, the more you need to add. Choose a day free from other obligation for an exhaustive exercise marathon (which, for you, may be just a few hours of brisk walking), and spend the evening on undemanding relaxing activities that will help you advance your bedtime. You will need to figure out for yourself what exercise intensity ensures you do not wake up prematurely and what advance you can actually afford without making the situation worse.
- **Emergency: Melatonin:** If your "protected zone" is stretched to the limit. You may consider an occasional pill of melatonin (e.g. 2 hours before your optimum bedtime). Remember that melatonin will affect your creativity and alertness, and should not be used on a regular basis. You could resort to melatonin on days when you are particularly wound up or when your waking time was particularly late. Remember also that large doses of melatonin may backfire. I guess you should not ever exceed 3 mg, however, you would better consult your sleep expert to make the final decision as to the dosage and timing. If you keep failing with the algorithm, you should rather increase the frequency of taking melatonin. You should not increase the dosage! Do not use marijuana as a "melatonin substitute"! If you think that your sleep and your brain performance do not suffer on MJ, you are wrong!
- **Emergency: Radio timer:** As the algorithm is supposed to let you sleep without an alarm clock, you cannot expect to wake up at the same time every day. Actually, the larger your DSPS problem, the larger the variations you may expect. Achieving a very regular waking time is a matter of practice that some good sleepers develop over many years of repeated habits. However, if you regularly oversleep by more than an hour, or even still experience the dreaded phase shift, you may consider some occasional mild form of artificial sleep regulation such as turning on your alarm radio at the minimum sound level. Such a gentle alarm is only to help you wake early from the shallowest stages of sleep early in the morning. It should not deprive you of valuable REM sleep, and it should absolutely be set below the level that could rouse you from deep sleep. Your goal will always be to get rid of any interruption or intervention in the morning. Consider this only as a temporary measure that may help you in the initial adaptation period that is bound to include minor failures. You have probably heard of alarm clocks that read your sleep phase and help you minimize the pain of waking. I am not a great enthusiast of such solutions. The concept makes sense, however, it only minimizes the pain of possibly cutting a vital portion of your sleep. Set up an On-timer in your TV, on your favorite channel, at a minimum volume. If it fails to wake you up, you will know you need to work on other points of this algorithm. Trying to wake up for a specific hour is stressful enough to act as a substitute alarm clock that works for many people pretty well. Some scientists believe that [ACTH](#) secretion is set to ensure timely waking. I believe that this type of compacted sleep is still better than the one interrupted by alarm clock. At the very least, natural waking after short sleep definitely feels better than sleep interrupted at its deeper stages with an alarm clock. In conclusion, you should remember that your determination to succeed is also an important component of the algorithm. Determination may be unhealthy, it might affect your hormonal profile in sleep, it may weaken your immune system, however, balancing DSPS without giving up modern lifestyle will always have some residual negative health effects. Only a return to an ancient lifestyle would provide a hermetic solution.
- **Napping:** A very controversial issue in DSPS is napping. Many experts will tell you that you should avoid napping altogether. I disagree. Naps may cause a phase shift if they are taken too late. Early naps, e.g. taken in the 6th

hour of your waking day, will not have this effect. Naps will help you get your evening productivity, esp. if early waking in bright sunlight or early exercise aren't too good for your morning alertness. If you keep failing to achieve your 24h balanced cycle, you can gradually shift your naps to earlier hours. This will reduce their length and their efficiency, however, this will also minimize their phase shifting effect. Only if all other suggestions fail, you should drop napping altogether. If you bemoan the loss of mental acuity, remember that we have not evolved to be alert and productive all day. 100% sharp mind is only our desire that has, among others, contributed to the DSPS problem in the first place. See: [Best nap timing](#)

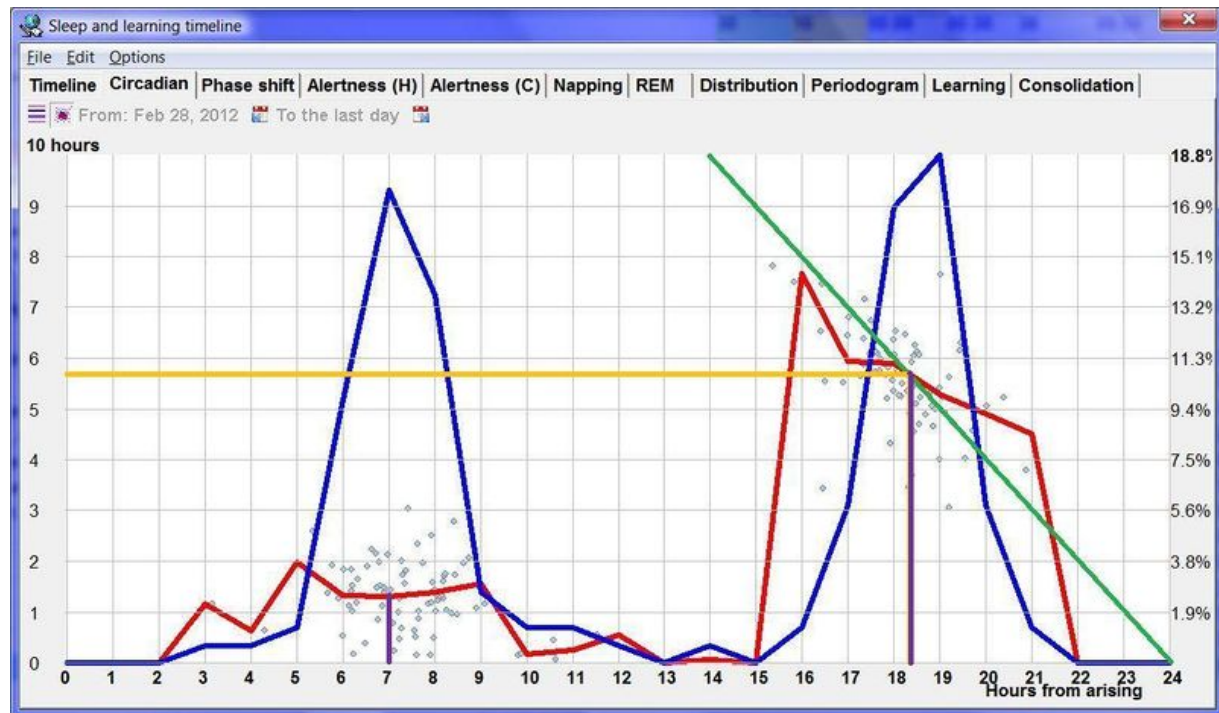
- **Caffeine:** Sleep experts will often tell you to wean yourself off caffeine. However, I beg to disagree. A cup of early morning coffee or tea will likely have a beneficial effect. Its impact on the homeostatic sleep drive will increase your alertness, which on its own has a phase shifting power. Early caffeine will help you advance your phase! You should avoid caffeine in the later parts of the day though. Before sleep you will already be in mild withdrawal, which, theoretically, should boost your homeostatic sleep drive and allow for a slightly earlier bedtime. This way, caffeine may help you achieve phase advances at both ends of your night sleep.
- **Alcohol:** Drinking [alcohol](#) before sleep may have disastrous effects on your effort to balance the cycle. One of your major enemies will be premature waking after premature bedtime. Alcohol will increase that risk manifold. Premature awakening will result in insomnia, in powerful phase shifts, in difficulty in waking, in sleep deprivation, and in an early collapse of all your efforts! Western culture is generally tolerant of moderate drinking in the evening as opposed to the morning when we are supposed to be productive. I think this tolerance should change. As much as early drinking undermines the thinking, evening alcohol might do even more damage by destroying sleep.
- **Stress:** Stress can ruin all efforts presented in this algorithm. Wherever possible, try to pile up stress in the morning, and let the second half of the day be always free from worries and anxieties. Naturally, stress that lasts for days is a general enemy of healthy and productive living. If this is your problem, please have a peek at the [stress](#) section of this article to see if you can find any useful hints there.
- **Myopia:** If you are shortsighted, you should consider getting a correct prescription. Some theories of myopia favor underprescription (Rehm 1981^[37]), however, you will also find evidence to the contrary (Coghlan and Le Page 2002^[38]). If you lean to the underprescription side, consider using the correct prescription only in the morning. Only the first 2-4 hours matter. You may recall from your physics class that the amount of light reaching the retina will actually be reduced with the increase to the focal power. However, well-focused light will be more likely to produce strong maxima with a phase-shifting power. Analogously, you might also consider using dimmed spectacles in the evening. Naturally, these are not recommended for "close world" applications (such as reading the computer screen) as these might accelerate the progression of myopia.
- **Computer screen:** There are computer screen filters and applications that can help you filter phase-shifting light frequencies that can dim your monitor in the late evening. I hear from users of those applications that they are helpful in their DSPS battles. As always there is a risk this might be a [placebo effect](#). However, the cost of trying isn't high.
- **Difficulties:** If you keep experiencing phase shifts, move your siesta to an earlier time, or give it up altogether (at last until you regain the balance). Use emergency measures (melatonin, radio news) only as a last resort. If those last resort solutions keep being necessary, it may appear that a shifting free running sleep cycle does less damage than trying to stick to a "healthy" stable rhythm. Review all the recommendations on this list. Did you employ them all? Did you show self-discipline? If so, it should work in most cases. All the failures I have seen came from rather flimsy excuses and minor violations. All the success I have seen came from treating sleep regimen as a religious routine. If all else fails, [write to me](#) with your story.
- **Target:** In the initial period, lack of experience, misalignment of sleep control variables, sleep debt, lack of conviction, etc. will make it a bit harder to stick to the presented algorithm. This is particularly difficult for those who do not need to get up early for work. Their mind might vacillate. Is early rising worth the effort? It may therefore be psychologically helpful to begin one's sleep reform 3-4 weeks before an important event that requires early rising. The thought of participating in an important event with a fresh mind will increase the motivation to adhere to the rules.
- **Creativity dip:** Once the presented algorithm works for you, you may be disappointed to notice that your creativity isn't as rampant as on those weekends when you get your solid 8 hours of sleep, or when you go to sleep at 5 am (whichever is your cup of tea). That's the unavoidable cost of sleep phase resetting and phase advance measures. We have evolved to live 24h lives with a primary concern for surviving, getting food, etc. Crisp or creative mind isn't that important when you are to run away from a predator. When you meet a lion on a street, you are bound to be in your top shape for flight. The degree of your creative decline may be proportional to the degree of the original problem as well as the length of the period in which you tinkered with your sleep control systems using the alarm clock, sleeping pills and other brain health enemies.
- **It works!** Remember that every healthy individual can stick to a 24 hour cycle on a [farmer's lifestyle](#). Some disabilities, e.g. blindness, may make it impossible, but these should only be an exception to the rule. At worst

you could try out the [farmer's lifestyle](#) to realize that it solves your sleep problem, and then try to reconcile that extreme with the presented algorithm. There is an optimum for you somewhere in-between and it does not need to be unhealthy.

- **Ultimate cure?** The title of this chapter should not make you think that you can cure DSPS for good. It is always there. You can temper your response to the temptations of modern life and return to a balanced sleep pattern as your reward. Your lifestyle is your cure.

Outcome: Balanced 24h sleep cycle!

If you use [SleepChart](#), you can see the impact of the presented algorithm in the [circadian graph](#). Exemplary outcome of the application of the presented algorithm is presented below:



Perfectly balanced 24h cycle in DSPS.

In this example:

- the green line determines the conditions for the balanced 24 hour cycle (waking time + sleep time = 24 hours)
- the nap is taken in the 7th hour from arising (the left blue peak) and lasts 1.2 hours (the left purple vertical line). The nap is used to partly compensate for a short nighttime sleep
- the optimum length of the waking day is 18.3 hours and is determined by the crossing of the green line that determines the 24h sleep-wake cycle and the average sleep time depicted by the red curve. Shorter day is possible but entails a risk of sleep-onset [insomnia](#). Longer day will result in phase delays (the area where the red line is located above the green line)
- the optimum length of the night sleep is 5.7 hour (horizontal orange line).
- the cycle implies 5.7 hours of sleep in the night and nearly 6.9 hours of total sleep, which might be equivalent to 9 hours of nighttime sleep in monophasic sleep (see: [Optimum nap duration](#))

Summary

In the presented algorithm, you try to stick to your optimum bedtime and waking time every day. You establish a protected zone in the evening to favor phase advance (minimum light, computers, stress, excitement, etc.). You wake up to bright sunlight and use morning exercise to advance the phase in the morning. You ingest caffeine only in the morning. You avoid alcohol in the evening. If you nap, you nap early. If your phase keeps shifting, you add more light and exercise in the morning. You also extend your protected zone in the evening. In emergency, when you fear falling out of synch, you could occasionally use melatonin in the evening, or delicate sounds in the morning as the minimum effective departure from the free running sleep principle.

Advanced Sleep Phase Syndrome (ASPS)

Advanced Sleep Phase Syndrome (ASPS) is the opposite of DSPS. People suffering from [ASPS](#) get very sleepy early in the evening and wake up very early in the night. Their [circadian](#) clock runs at less than 24 hour period or get easily reset in the morning (e.g. by stress). [ASPS](#) people constantly struggle to survive awake to a reasonable evening hour, sleep less, wake up early, and experience increased tiredness during the day.

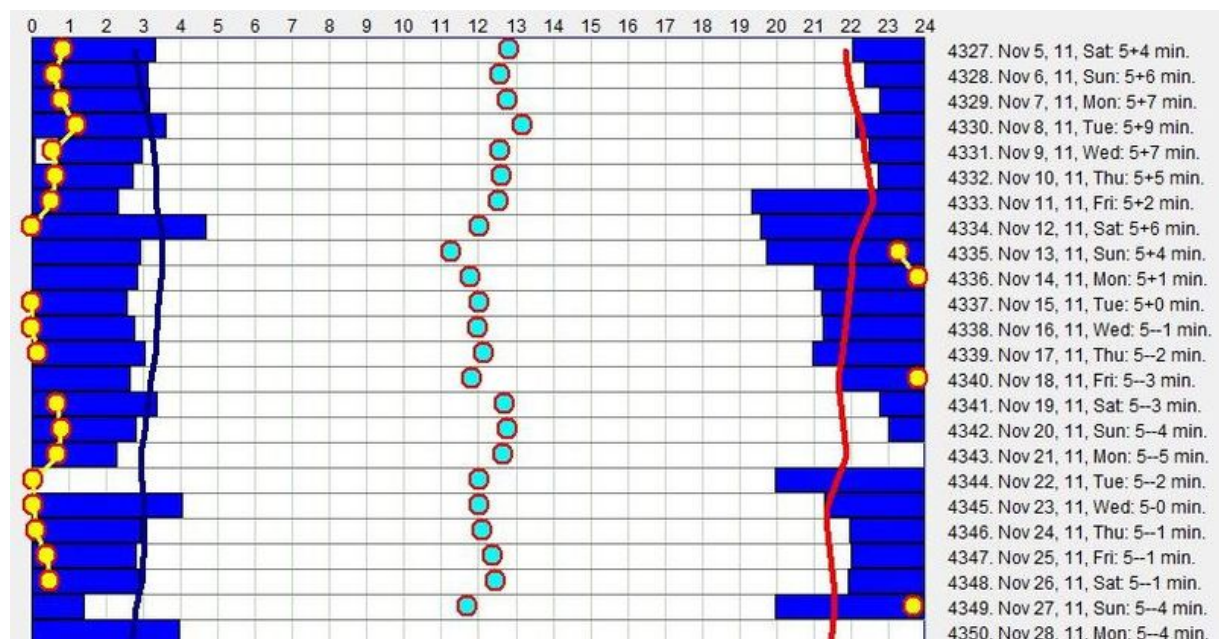
Genes and lifestyle in ASPS

ASPS often runs in families and is then called familial [ASPS](#) or FASPS. Some mutations that may cause ASPS are listed in [this table](#).

While a typical DSPS person is an adolescent student, a typical ASPS person is a retiree or a middle-aged woman with low stress tolerance. The link between the age and sleep phase disorders may be related to aging itself, however, it may also be a result of lifestyle changes that come with age.

Remarkably, while I have received dozens of [SleepChart](#) submissions showing a free running DSPS pattern, I had to actively seek submissions that would illustrate ASPS. This alone can serve as an illustration of personality and lifestyle differences between the two groups. It is the DSPS group that keeps surfing the net till the early morning hours in search for a solution to their sleep problem. In the end, they often arrive at [supermemo.com](#), [download SleepChart](#), and begin logging their sleep in an effort to understand their own sleep patterns. The ASPS group is usually in bed early and often not refreshed enough during the day to seek a solution on the web. I have not received even a single reverse ASPS pattern with sleep starting progressively earlier in the day!

Example 1: ASPS and substance abuse



The presented [SleepChart](#) log illustrates a stabilized [ASPS](#) sleep pattern of a postmenopausal unemployed female with a lifelong history of substance abuse, currently in a period of abstinence and recovery. Without medication, the subject struggles to stay up past 5 pm. She often wakes up at 1-3 am and finds it impossible to fall back asleep. She reports a perpetual tiredness. The only solution to her sleep problems seems to be sleeping pills regularly prescribed by her GP and/or psychiatrist(s). Those pills have also been a part of a vicious cycle of addiction to [benzodiazepines](#) and alcohol.

Superficially, the log seems to look like a picture of a perfectly healthy sleep. However, the entire schedule and the sleep phase are kept in check with a cocktail of [psychoactive drugs](#). The main difference between this ASPS case and a similarly-looking [perfect sleep case](#) is the said persistent tiredness throughout the day. The subject reports that her chief preoccupation is to "*somehow get through the day*" when combating tiredness, and struggling with an ever present threat of a fallback into addiction.

The difference in sleep length on individual days (8-9 hours on good days, 0-3 hours on bad days) comes from the fact that the subject sleeps at different family locations on different days. Some of those are considered better (resulting in better sleep), others are considered more stressful. One of the nights was sleepless due to family stress. This illustrates again how lifestyle determines sleep patterns.

Sleep maintained with drugs always yields fractional cognitive benefits. In this case though, the effect is truly dramatic

with cognitive performance comparable with that encountered in a state of severe intoxication. The drugs schedule, which changes periodically for various reasons, is invariably composed of pick me ups in the morning, and put me downs in the evening, as well as some "extras" for controlling various neural side effects of the "sleep control cocktail". Individual drugs interfere with each other producing a constellation of side effects that result in a horrendous chaos in the system, and long-term consequences that in turn result in an inevitable spiral towards a psychiatric decline and dramatically reduced well-being, ability to function in society, and longevity. The half-life of opposing drugs results in their effects cancelling each other and producing unpredictable resultant consequences. Why is then this pharmacological horror tolerated? For an unemployed individual with a history of substance abuse, for his or her family, and for the doctors involved, anything that resembles normality today takes precedence over the long term consequences. Naturally, for nearly everyone involved, this zombified status quo is preferred to actual intoxication even though that both are bound to destroy the brain in the long run. EEG findings indicate long-term and largely irreversible changes in the function of the central nervous system caused by substance abuse and/or psychoactive medication.

As with all medical intervention in general, psychiatry is particularly troubled with tunnel vision that fails to see the big picture of individual's life and population health in general. New drugs pop up too fast to effectively study their long-term consequences. They are subject to prescription fashions that wax and wane. As [barbiturates](#) gave way to [benzodiazepines](#), and [benzodiazepines](#) to [Prozac](#), a well-meaning psychiatrist is often confused by a welter of contradictory data, never-ending lists of contradictory side-effects and the scourge of scientific observation: guaranteed false data coming from patients who always have multiple reasons for lying to their doctor. Making all patient history records near-to useless. Patients often change doctors to suit their dream prescription, or seek parallel advice and contradictory prescription from different sources. They rarely stick to the drug timing and dosage.

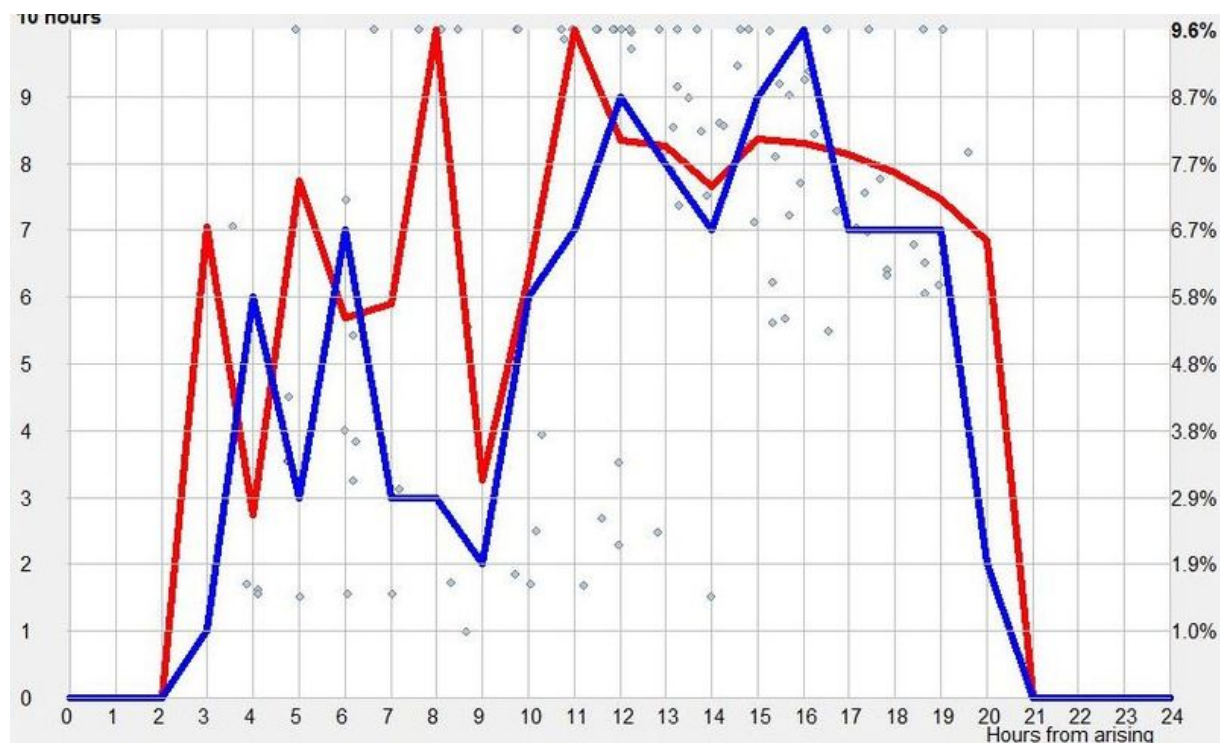
For the record, at the moment of writing, the drug array in use in the presented example was:

- antidepressant [venlafaxine](#) that is able to lengthen the period of the [circadian](#) cycle (8 am, half-life 10 hours)
- antipsychotic [aripiprazole](#) (8 am, half-life 75 hours)
- anxiolytic [benzodiazepine lorazepam](#) (6 pm, 2.5 mg, half-life 15 hours): in use for years instead of the recommended weeks, despite various side effects including severe [sleep apnea](#); possibly the prescribing physician was not aware of the fact
- antipsychotic [olanzapine](#) (8 pm, 20 mg)
- in addition: anticonvulsant [lamotrigine](#) (50 mg)

As of the moment of writing, I was not able to ascertain if these have been prescribed by a single psychiatrist and if the prescribing physician(s) had an insight into the patient's full medical history.

Example 2: Overmedication and daytime drowsiness

The second example shows another severely medicated case. 56-year-old male retiree carries on on an equally potent cocktail of drugs. In this case, poorly-planned irregular [free running sleep](#) helps reveal the degree of daytime sleepiness with sleep episodes initiated regularly starting with the 3rd hour of wakefulness, short and early forbidden zone in the hours 7-9, and preference for short waking day of 12-18 hours:

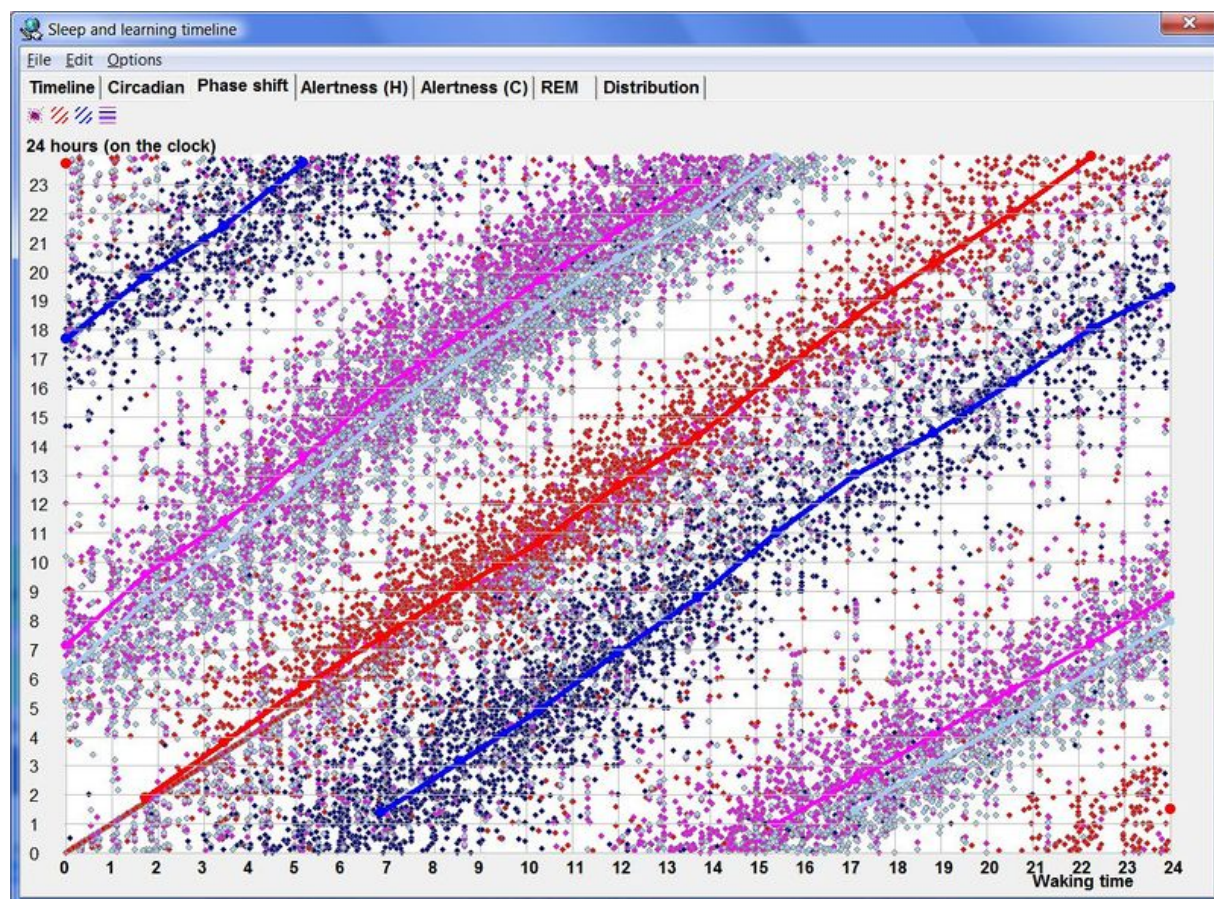


Perhaps due to the impact of the sedatives, the length of sleep episodes may reach an equivalent of a full night's sleep at practically any time of the day. Needless to say, the subject is hardly able to function cognitively and complains of never-ending tiredness. The drugs used in this case:

- between 7-8 am antidepressants: [aripiprazole](#) (5 mg) and [bupropion](#) (150 mg)
- around 11:30 am: an antipsychotic [quetiapine](#) (25 mg)
- around 9 pm: [benzodiazepine clonazepam](#) (1 mg), antidepressant [escitalopram](#) (40 mg), [lamotrigine](#) (200 mg), [quetiapine](#) (50 mg)
- in addition: [tamsulosin](#) to avoid nighttime urinary incontinence

Phase shift graph

The **phase shift** graph may be used by people in free running sleep suffering from **ASPS** or **DSPS**. This graph shows the degree of phase-shift as well as its dependence on the time of day. The graph can be used to see the expected bedtime given a specific natural waking time:



Blue line shows the bedtime (vertical axis) for days with a given waking hour (horizontal axis). Red line shows the next day's waking hours (which are shifted by 1-2 hours in DSPS). Fuchsia and gray lines indicate the **siesta** period. Even though the red waking line begins at the origin of the graph, it shows a substantial **phase shift** at later hours (DSPS). From the presented exemplary graph one can read that for the waking time equal to 7 am (horizontal axis), the expected time to go to bed, as indicated by the blue line, is 1 am (vertical axis), while optimum **siesta** time occurs between 15:00 and 16:00. However, if the wake time is 11 am, the bedtime is likely to come only at 5 am the next day.

Remember! Each individual will have a his or her own unique graph. Moreover, the graph will look differently if it is taken at times of work or at times of summer vacation. It will be affected by stresses at work and at home. It may even change when you move from one house to another, or when you change the climate zone. The graph will accurately reflect your rhythm only if you adhere to [free running sleep](#). If you use an alarm clock, this graph will be meaningless!

Correlates of sleep phase syndromes

It is not known which are the predominant underlying physiological factors that result in sleep phase disorders. Family clusters show that genes may affect the length of the **circadian** period. The lifestyle will affect the levels of [neurotransmitters](#) and via their impact on the sleep phase will affect the period of the **circadian** clock as well. Lifestyle also affects the timing of zeitgebers (e.g. late night web surfing in DSPS). Conversely, the level of neurotransmitters may select for a specific lifestyle choices. Age may have a direct impact on the clock circuits, it may affect neurotransmitters, or it can affect the lifestyle. Last but not least, sleep phase disorders will affect the mood and the levels of neurotransmitters in varying ways depending on whether [free running sleep](#) is used to remedy the disorder, or whether the individual attempts to fit a predetermined desirable sleep schedule.

Subsets of **circadian** rhythm sleep disorders (CRSDs) are strongly correlated with certain personality characteristics, and may have a strong genetic background. DSPS is more prevalent among adolescents, while **ASPS** is more frequently observed in an aging population. Women prevail in ASPS, while a slightly larger proportion of males suffer from DSPS (Sack et al. 2007^[39]). Impaired vision often leads to DSPS due to a lesser impact of light on the **circadian** clock.

DSPS is by far more frequent among students, programmers, avid readers, passionate artists, writers, computer game addicts, etc. It is possible that the same characteristics that help individual's creativity may also lead to problems with falling asleep early. **ASPS** seems more likely in individuals whose life is deprived of intense stimulation (esp. in the evening), who meet fewer new challenges, who are less passionate about their job or hobbies, or who are not facing information overload and the related stress, etc. Perhaps this is why **ASPS** is more prevalent in the elderly. For

hormonal reasons, its prevalence also shows a sharp increase around the time of menopause in women. ASPS tends to run in families. A number of genes have been identified to be involved in FASPS (familial ASPS)(see: [Clock genes and mutations affecting the clock period](#)(Golombek and Rosenstein 2010^[40]).

There is a complex relationship between DSPS/ASPS and psychiatric disorders. 25% of people who could not maintain their 24h sleep-wake cycle were suffering from a psychiatric disorder (Hayakawa et al. 1998^[41]). Some psychiatric disorders or the prescribed medication may induce DSPS, while, at the same time, DSPS conversely may cause various psychiatric symptoms. On one hand, there may be a link between DSPS and manic personalities. Anti-depressants tend to increase the period of the body clock (e.g. [clorgyline](#), [imipramine](#)). On the other, paradoxically, DSPS individuals may be more likely to suffer from depression (e.g. when suffering from persistent insomnia, sleep deprivation, and the resulting social problems, etc.). [Dr Daniel Kripke](#) concluded that DSPS phenotype is familial and is associated with unipolar depression (Kripke et al. 2008^[42]). However, the epidemic of DSPS in creative individuals suggests that those correlates need further investigation. Perhaps some contradictions can be explained by the fact that the state of mind of a DSPS sufferer depends largely on his or her ability to get sufficient and properly timed sleep? Thus more on a naturally manic side when sleep-satisfied, e.g. on a free running sleep schedule, and more on the depressed side when in [circadian](#) trouble (e.g. when forced to an early waking schedule)?

Similarly, low-stress tolerance depressed individuals are more likely to suffer from [ASPS](#). Again, when they are forced to adapt to "normal" life, their symptoms of depression tend to weaken either due to a sense of higher productivity or due to the fact that mild [sleep deprivation](#) counteracts the depression. The cause-effect relationship between sleep phase disorders and mood disorders is complex. Understanding it will contribute substantially to mitigating the escalating epidemic of sleep problems.

Baby sleep

How to make babies sleep well?

People often say "*I slept like a baby?*" A joke says that it means that you wake up every 2 hours and scream. Indeed, babies tend to wake up in the night and seem unhappy (unless immediately soothed with mama's breast). This seems unnatural, unnecessary, and worrying. And yet babies have been designed to wake up many times during the night to feed.

The net is jam-packed with an assortment of advice from and for young parents who seek good sleep for their babies and for themselves. A great deal of that advice is based on myth and/or pseudoscience. If the advice includes the word "*train*" or "*schedule*", you need to triple your skepticism! Even world renowned pediatricians overemphasize the "*routine*" over the actual natural sleep mechanisms. As much as adult's, baby sleep is ruled by [homeostatic](#) and circadian mechanisms, and any attempt to override those is futile and potentially harmful. All routines such as rocking the baby, quiet room, feeding, quiet talking, music, etc. are welcome as long as they are not attempts to enforce a sleeping schedule on a baby. These routines are little more efficient in inducing sleep as all the grandma's advice against [insomnia](#). Neither [homeostatic](#) nor circadian mechanism is trainable (beyond natural phase shifts, etc.). Babies should sleep on demand (*ad libitum*), i.e. only then when they are sleepy and want to sleep. Nevertheless, understanding their [circadian](#) patterns can be very helpful in assisting the routine. As baby sleep is more complex than adult sleep, you can use [SleepChart](#) to see through the chaos. This can help as guidance. Nevertheless, observing the symptoms of sleepiness is the oldest and the best practice.

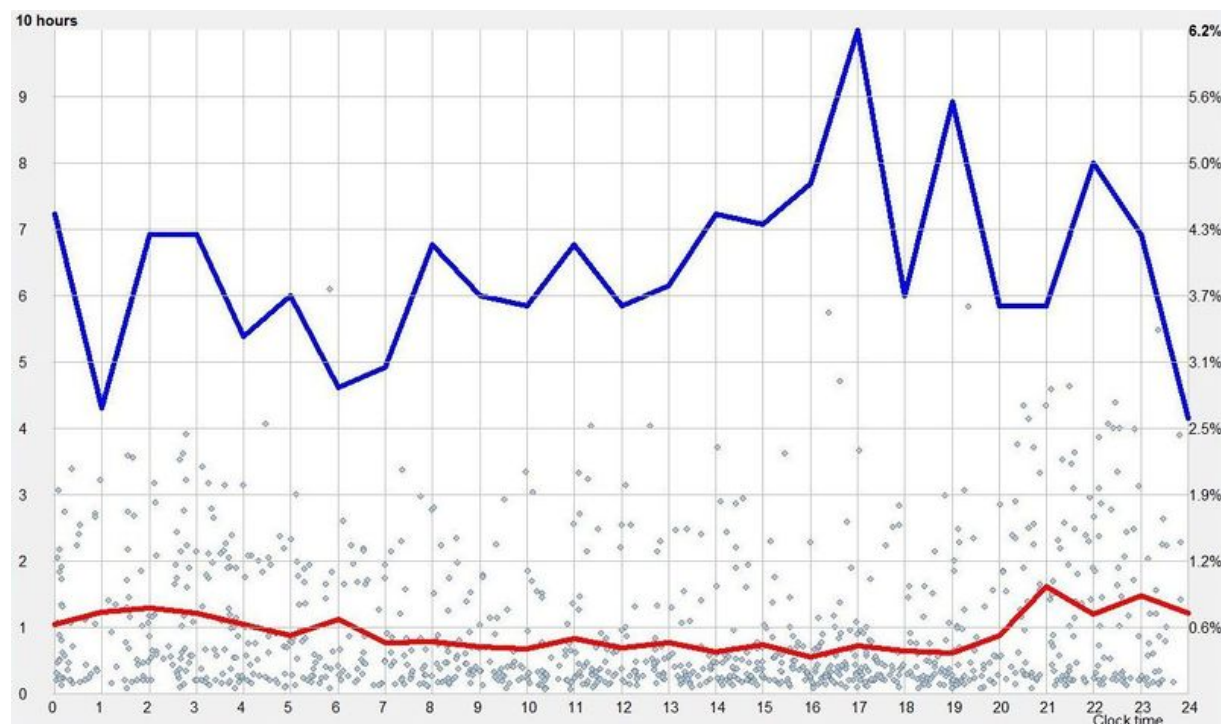
Some moms claim proudly "*my baby sleeps through the night*". However, when actual sleep logs or [hypnograms](#) are analyzed, this appears not to be true. A great proportion of parents will go to any length to make their baby sleep through the night. All too often, parental convenience and comfort take precedence to baby's health. Many pediatricians are pretty ignorant in reference to the rules of chronobiology, which is not prominent enough in school curricula. Some acclaimed methods are plain scary.

The cry-it-out method must have been inspired by Pavlov's methods in conditioning dogs. There is little doubt that prolonged crying and stress will inhibit baby's development. For example, if prolonged crying correlates with later cognitive deficits, it is, at least to a degree, related to the impact of stress on development (Rao et al. 2004^[43]). In the end, Ferber's method seems to serve the parent, not the child. No parent's heart should stand baby's cry, esp. that it is **entirely unnecessary**.

Sleeping throughout the night

It takes roughly 1-2 months for the baby sleep to align into a rudimentary [circadian](#) pattern. This means that initially a

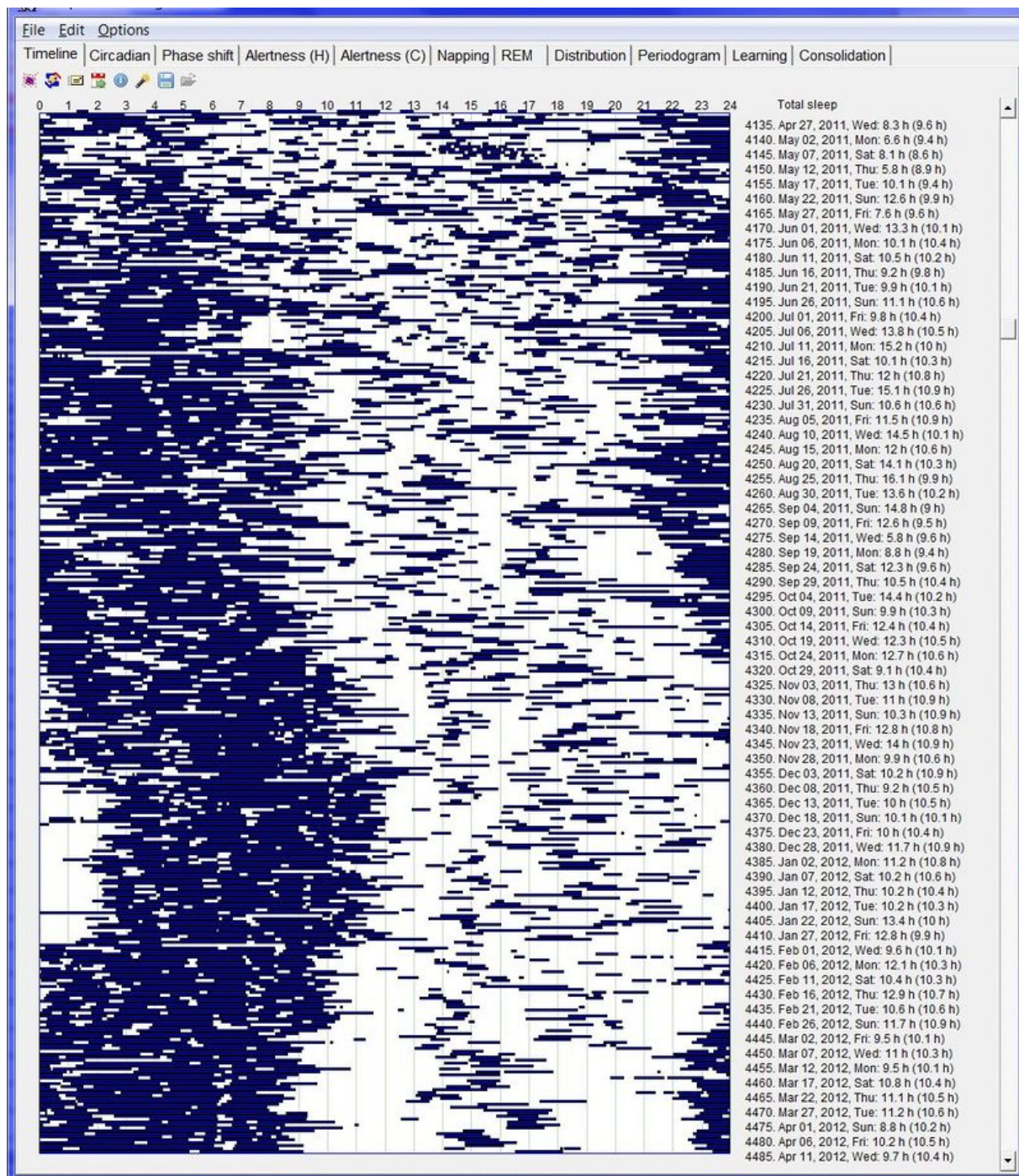
newborn baby does not see much difference between the night and the day! Consolidation of the fasting-associated wakefulness precedes that of the breastfeeding rhythm due to high feeding demands in the first few weeks of life (Odaa et al. 2008^[44]).



An exemplary [circadian graph](#) of [homeostatic](#) and [circadian](#) sleep preferences in the first 2 months of life. The average length of unconsolidated sleep episode (red line, left vertical number line) varies from 0.5 hour at 4 pm to 1.5 hours at 9 pm. There is a slight [circadian](#) preference for initiating sleep in the early evening hours (6.2% at 5 pm) (blue line, right vertical number line) as opposed to the morning (below 3% at 6-7 am). Using various sleep consolidation methods (i.e. methods for adding up episodes that follow in a short succession), the preference for the evening sleep may be shown to be more pronounced.

Your baby may redistribute its sleep episodes equally in the day and in the night. For an ever-sleepy mother, it can lead to the illusion that the baby stubbornly tends to sleep during the day, and just keeps crying throughout the night. No wonder that many moms keep asking: *What am I doing wrong?*, *How can I make my baby sleep in the night?* The short answer is: nothing (unless there is an organic cause disrupting sleep)! Sleep in short 1-4h bursts throughout the 24 hour period is normal in newborns, and nothing can be done about it! **Efforts to make a baby sleep through the night in its first months are a waste of time!** Moreover, whatever parents try to accomplish that goal is likely to be harmful for the baby.

In the exemplary sleep log below, we can see how the chaos of the first months slowly consolidates into a sleep pattern with a major nocturnal sleep episode and several naps during the day. Around five months of age, a pretty consistent pattern emerges with two daytime naps on most of days. Finally, at around one year old, an adult-like biphasic rhythm develops. The breakthrough usually comes when parents, unaware of the consolidation process, realize that the baby does not want to take the early nap and soon put the kid to sleep only once per day. Multiple naps during the day, at this stage, are often a result of health problems, missing some of the night sleep (e.g. due to early waking for infant nursery), bad "baby sleep management" (i.e. mostly not responding to baby sleep signals), or temporary variations resulting from lifestyle changes (e.g. travel, exhausting play, meeting people, etc.). Unless the infant clearly demands multiple naps, a single [siesta](#) nap after passing the age of 12-16 months is probably a pretty safe bet. Some parents try to push the kid to stay awake throughout the day to ensure a more solid nighttime sleep. However, sticking to child's natural preference is always a safer option.



An exemplary free running sleep log in the first year of life

Interestingly, in the presented graph there is a 3 months old long period in which the infant tends to go to sleep very late. Such a sleep pattern may be a worrying prelude to future developmental, psychological or sleep problems. However, in this case it might have as well been explained by lesser resetting impact of morning sunlight in winter months. Spectral analysis of sleep in the first months shows that baby circadian cycle might possibly be quadriphasic with constituent frequencies getting damped over time to develop a typical biphasic rhythm with a major nighttime and a minor daytime crests.

For another example of the crystallization of the [circadian](#) cycle, see this [one father's effort](#) to map the regularities in his baby's sleep. This particular chart begins at a stage when the baby is primarily nocturnal, but still diurnally polyphasic (4th month). Around the 10th month, daytime napping consolidates showing a quadriphasic mode with nocturnal "naps" consolidated into a single long night-time sleep episode. Finally, around the 16th month, the child develops a crisp biphasic pattern. That transition to the biphasic mode might have been delayed somewhat by parental decisions that often determine infant's sleep slots.

Parental decisions as to the timing of sleep will largely determine the baby sleep pattern. This is why the understanding of the natural development of the circadian cycle and responding to natural baby

sleep signals is vital for healthy baby sleep!

Development of a healthy circadian cycle

There are two main factors that will affect the development of a healthy **circadian** pattern in a baby:

1. Exposure to the natural 24-hour cycle of daylight and darkness, and all the associated daily routines.
2. Exposure to mother's **circadian** routines, amplified by co-sleeping

In many animals, the development and the initial **entrainment** of the **circadian** cycle is primarily dependent on the interaction with the feeding mother (Rivkees et al. 1988^[45]). Co-sleeping should assist in the development of a healthy circadian cycle. Mother's presence in bed as well as breastfeeding can both act as powerful cues. They act as both PRC-related and PRC-independent zeitgebers (see: [Phase response curve \(PRC\)](#)). This means that co-sleeping will affect the sleep phase as well as the degree of nocturnal awakening and total sleep. In addition to sensory cues, breastfeeding plays also a hormonal role as the **circadian** cycle of [tryptophan](#) in breast milk correlates with the levels of [melatonin](#) in the child's blood (as evidenced by 6-sulfatoxymelatonin in urine; Cubero et al. 2005^[46]). This naturally calls into question the practise of collecting expressed milk for later use. The development of a healthy sleep-wake cycle will naturally also depend on the fact whether the mom herself applies the adequate principles of sleep hygiene. Millions of children are forced to sleep alone in their cots. This practise is so widespread in the industrialized nations that we may safely conclude that it does not irreversibly ruin the baby's **circadian** cycle, but, theoretically, it might underlie the epidemic of sleep disorders in modern societies.

In addition to the postnatal period, mother's **circadian** cycles exert their impact on the baby's brain already in pregnancy. This adds to the utmost importance of sleep hygiene in gestation.

It remains controversial if nighttime exposure to artificial light can slow down or disrupt the process of the **circadian** cycle development. Research on the impact of light on the development of the [SCN](#) suggests that it is possible to change rhythmicity or sensitivity to light of the body clock. The changes occurring in the course of development might affect the properties of the clock for a lifetime. However, it is also possible that lifestyle can reverse or magnify those changes. The development of the SCN has been studied in many animals and results differ. For example, rat SCN periodicity develops in utero (Altman and Bayer 1978^[47]), while the sleep-wake cycle in the SCN in an opossum develops in the first 3 postnatal weeks (Rivkees et al. 1988^[45]). The shape of the [phase response curve](#), which lays at the root of sleep phase disorders, may actually be influenced by illumination conditions during the development, at least in cockroaches (Page 1991^[48]) [graph: <http://www.cas.vanderbilt.edu/johnsonlab/prcatlas/carltext/figure3.htm>]. Whatever the impact of light and locomotor activity in babies, until we know more, we should always aim at minimizing nighttime exposure to artificial light, and to minimize its [luminance](#).

Despite the usual claims to the contrary, nighttime play might actually accelerate the return to sleep as long as the emphasis is put on physical as opposed to the emotional. However, as motor activity is also able to **phase shift** the circadian cycle, nighttime play on demand should probably be minimized.

For more more see: [Polyphasic sleep in babies](#)

Co-sleeping as a circadian solution

The process of maturing the **circadian** rhythm is neural and largely beyond parental control. However, the **entrainment** of mom's and baby's cycles is essential, and may determine the ultimate outcome of the process. Newborns are driven to sleep homeostatically, and woken up primarily by their feeding needs. Factors such as temperature, hunger, play, lighting, social interaction, etc. only add complexity to the picture. With a number of hard-to-predict factors that affect sleep needs, babies should always sleep on demand. If they want to play, the play should not be denied. All scheduling in their life should be done around their sleep. This basically means there are only two practicable solutions to newborn's good sleep:

- **Recommended** (McKenna et al. 2005^[49]): **Mom and the baby sleep together**. A mom needs to learn to adapt to periodic breastfeeding throughout the night. Mom's sleep will suffer a bit. However, with a bit of practice, breastfeeding can be minimally disruptive, and actually act as a soporific for both the baby and the mom. In other words, after a short breastfeeding session, both the mom and the baby should quickly fall asleep contented with the job well-done. Even though the development of the **circadian** cycle should proceed regardless, co-sleeping should assist that vital biological process. **Baby safety issues related to sleeping together must be addressed beforehand** (you can google for that in minutes; [example 1](#), [example 2](#)). Even a strong one year old can be suffocated easily. If you believe your power baby will scream or wriggle, it is not true! When its chest is

compressed or breathing passages get obstructed, a baby will nearly instantly lose strength and be unable to defend itself! This is why safety is paramount. For a healthy and vigilant mother, statistics are good. A bit of anxiety at the start is unavoidable and perhaps good to develop healthy and safe sleeping habits. Psychologists, behaviorists and all open-minded pediatricians will all admit that the night-time bonding is great for baby's brain development. Perfect formula for both the mom and the child.

- **Emergency: Parental care in shifts with the help of breast milk.** It may happen that for health reasons, the mom and the baby should sleep separately for a while. In such cases both parents can still get excellent sleep if they adapt to a variant of shift-work with the help of chronotherapy. For example, one of the parents chronobiologically adapts to sleeping in the 7 pm - 1 am bracket, while the other takes the 1 am - 7 am shift. In the period when the mom is asleep, breast milk, extracted in advance (or formula) can be used instead of breastfeeding to avoid major disruptions to mom's sleep (remember that milk properties also change along the sleep-wake cycle). If that solution is not feasible for any reason parents will probably need to choose between:

1. their own good sleep, and
2. employing a nighttime nanny.

Needless to say, baby's sleep should never be at stake here. Sleep is vital for adult health. However, for a baby it is literally a matter of life and death as sleep disruption will have an effect on many causes of newborn mortality.

Best timing for feeding

Unless specifically indicated by a qualified pediatrician for specific health reasons, feeding "on the clock" should be banished. **Never wake your baby up for feeding! Feeding on demand is baby's best option!**

One of the cardinal sins of parenthood is overfeeding!

- It is easy to observe that after a hefty dose of formula sucked down in a hurry, babies get drowsy for reasons that have little to do with actual sleepiness. It may then be tempting to feed the baby to sleep. Such a practice is bad for baby's health and will not help him or her sleep overnight. It may only assist a short-lasting sleep that will clear the homeostatic sleepiness and make baby even less sleepy than before feeding.
- Another reason for overfeeding is mom's convenience. In hope of getting some more uninterrupted sleep, mom will feed a baby extra formula before the night or during a nighttime feeding session. Again, parent's convenience may be harmful for the child!

Child's own bed

The American Academy of Pediatrics has amazingly come up against co-sleeping! Many moms will swear their babies can sleep alone in a cot without any distress. And yet most behaviorists and anthropologists will agree: **the mom and the baby should sleep in close contact** as it has been practised by the human race for millennia, and by nesting mammals for millions of years. There could be exceptions on health or safety grounds. However, for an average mom, sleeping with the baby should be a pleasure, a privilege and a duty. The young mom only needs to read about basic safety measures. For a baby, sleeping with the mom should be a basic human right! Many pediatricians, nurses, midwives and "old school" grandmas will still insist that the baby should sleep in its own bed for safety, discipline or convenience reasons. You may hear a medical professional advise: *"Don't reward the baby! You are making a rod for your own back"*. This is very surprising in the light of the fact that baby reward system is pretty well tuned to satisfying its biological needs. An average adult with a number of control mechanisms messed up by the modern lifestyle should often be denied its rewards (a fat doughnut, a morning shot of whiskey, etc.). However, all natural rewards should be considered biologically advantageous for a baby. As for the safety issues, babies do die when sleeping with moms in soft beds, due to alcohol, etc. They do so too when sleeping alone. Simple preventive measures dramatically reduce the risks of the dreaded mishap. The idea that we should train up a child to sleep alone from birth is hard to uproot. One needs to look closely at the biology of breastfeeding and baby sleep to quickly realize that training up at that stage amounts to little less than cruelty (except for cases and moments where the baby does not seem to object sleeping in a cot or in mom's absence from the common bed). A little baby is basically a feeding, growing and learning machine. All its inborn reflexes are targetted at ensuring safety, growth and brain development. The reflexes involved in rooting, sucking and breastfeeding belong to the strongest drives in a little baby. A whole series of brain centers is involved and there is a close relationship between these centers, sleep centers, and the sense of well-being and pleasure. Even though the complexity of the mechanisms involved is far from being revealed to our understanding, denying a baby mom's breast and closeness is bound to have long-term developmental consequences. Metaphorically, you could try to put yourself in baby's boots by trying to sleep naked on cold concrete with horror movies blasting loud throughout the night. I might be overly dramatic here. If a baby goes to sleep on its own without much ado, its proximity craving is definitely not as powerful as described here. However, when a baby's growth is at stake, you should always err on the

safe side. This is why it makes sense to assume the worst case scenario. I would not be surprised, if over time researchers discovered a need to extend the two-process model of sleep propensity in babies by a factor involved in breastfeeding. It has been shown that a tit is a soporific. I would not be surprised if it worked as an integral contributor to baby's [homeostatic](#) sleep propensity, or even a [homeostatic](#) trigger, esp. at time where the [circadian](#) cycle is not yet fully expressed. Needless to say, babies need sleep even more than adults. The degree of neural growth, network remodelling and learning in a young brain is staggering. Both [NREM](#) and [REM](#) sleep components are essential in that process. Changing the sleep structure will affect neurogenesis (Stryker et al. 2001^[10]). In other words, any form of stress before or during sleep will affect baby's brain growth. This is why baby's sleep should be the zone of highest protection. Training up to sleep alone can wait. Piglets weaned early have been shown to suffer damage to their [hippocampus](#) that results in personality changes, fear of exploration, and low stress tolerance.

Many parents oppose [attachment parenting](#) as too expensive timewise. It is hard to argue with someone who needs to choose between feeding the family and behavioristically correct approaches. Here again, modern lifestyle encroaches on human biology in a vicious cycle of long-term consequences in which babies brought up using an assembly line approach are emotionally and intellectually less likely to stand up to challenges of reconciling technological and societal progress with the needs of the human body and brain. For more see: [Is sleeping with my baby safe?](#) (McKenna 1995^[50]) and [The Science of Attachment Parenting](#).

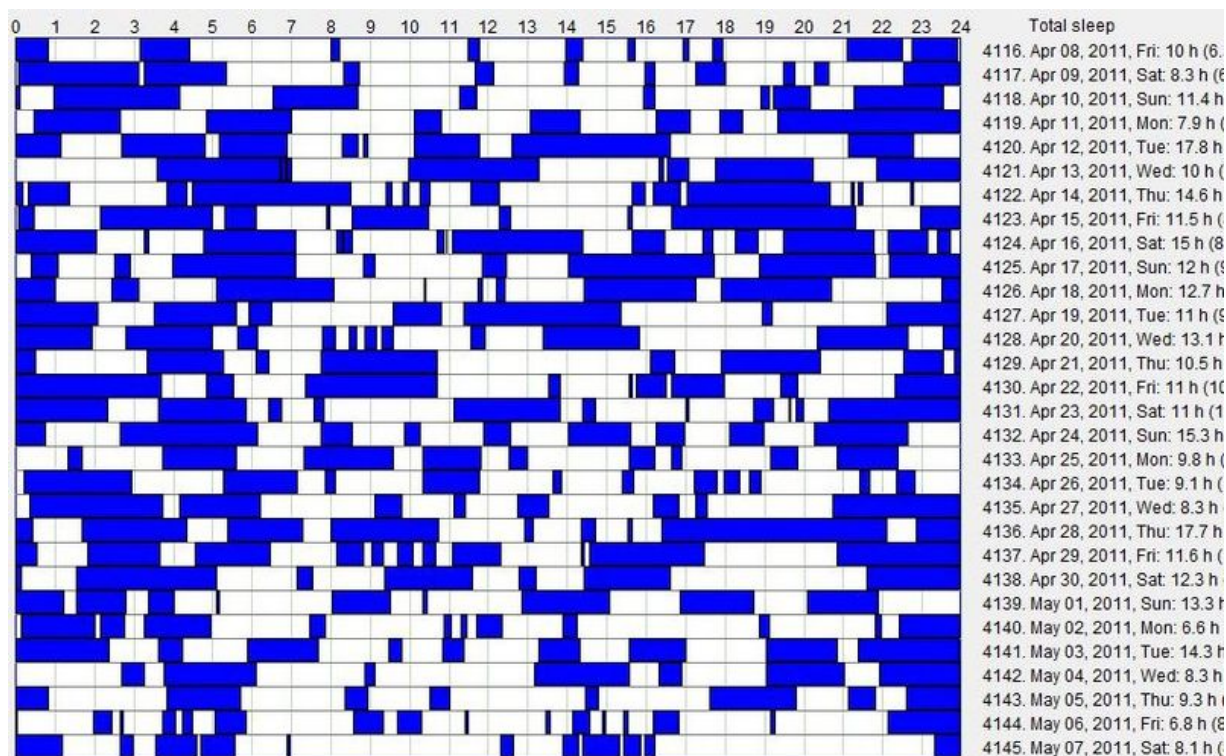
What about the mom?

Is co-sleeping good for the mom? I believe everyone should taste the blessings of [free running sleep](#). However, some of my good sleep advocacy needs to take an exception here as mom's health takes a secondary importance where baby sleep is at stake. Every mother is equipped with hidden or overt instincts that should make the experience of co-sleeping pleasurable. Naturally, in the modern world, stress, mobile phones, TV, Internet, rat race, and other factors can make it very hard. If a mom claims "*I hate breastfeeding*", or "*I cannot sleep with my baby*", she should start from a thorough examination of her own life. Breastfeeding and co-sleeping can be very rewarding if the household is sufficiently sheltered from the storms raging outdoors.

Why babies sleep so much?

Do babies sleep so much because they're learning so much or are they learning so much because they are getting so much sleep? Babies sleep so much because their brains have been designed to do so in the first months of their life. They do learn a lot, and learning does increase the demand for sleep, but this is not the main regulatory factor. Sleep control systems in babies simply work differently, and you probably would not be able to make babies sleep less by making them learn less. On the other hand, long bouts of sleep are used to reorganize neural networks in the brain. In short, sleep helps learning, learning induces sleep, but the whole sleep sequence is a direct outcome of genetically programmed properties of a young sleep control system. Considering the fact that babies spend around 50% of their sleep time in the [REM](#) phase (as compared to around 20% for adults), one of the theories says that even when babies do not learn much during the day while exploring their surroundings, that function is filled up by the exploratory function of the [REM](#) sleep which helps them discover new properties and rules in things they have learned thus far.

You will often hear that newborns sleep most of the time. Actual measurements may show that babies are more likely to sleep through just half of their days, while spending only a small proportion of that in deeper stages of [NREM](#) sleep.



An exemplary *SleepChart* log of sleep in the first month of life. Sum total of all sleep blocks is displayed on the right and averages to slightly above 10 hours per day with substantial day-to-day variations reflecting the impact of rich *homeostatic* input changes such as a walk, family visit, diaper rash episode, formula supplementation, etc.

Conclusion: Perfect formula for baby sleep

Babies sleep best if they sleep on demand and if they are fed on demand! All forms of artificial intervention in those homeostatically-regulated patterns should be considered potentially harmful. It is helpful to spot regularities and pay extra attention to baby signals at his or her preferred feeding and sleep times, however, it is the baby's needs that should determine the actual timing. As sleep is vital for the development of neural structures in the growing brain (Stryker et al. 2001^[10]), any form of intervention and artificial control should be considered potentially harmful in the long-term.

If you want your baby to be smart and healthy, let it play on demand, feed on demand, and sleep on demand.

Insomnia

Insomnia is a difficulty in falling asleep or in staying asleep. Psychophysiological insomnia can often persist for years, and result in untold damage to a person's life. Those who are desperate enough to visit a doctor are often prescribed sleeping pills that are usually not much better than insomnia itself! The good news is that in most cases insomnia can be remedied easily with a sleep phase adjustment as described below. Bad news is that such an adjustment may be incompatible with one's desired work or school schedule.

Half of the population in the industrialized nations has problems with falling asleep! This is called a **sleep onset insomnia**. Except for various underlying organic reasons, the overwhelming majority of cases of sleep onset insomnia result from the inability to entrain one's sleep hours to match the desired waking time.

In other words, most of otherwise healthy people who cannot fall asleep in the evening suffer from the combination of two chief factors:

- going to sleep too early in reference to their natural *circadian* cycle
- suffering from the associated stress: *if I do not fall asleep immediately, I will be totally wasted in the morning*

If the same people were allowed to sleep as much as they wanted and go to sleep only then when they are really tired (perhaps 2-5 hours later), in a vast majority of cases, the problem would not exist! Some scientists speak of insomnia as the *inhibition of de-arousal processes*. In sleep phase problems, the problem of de-arousal does not exist! De-arousal

proceeds correctly. It simply proceeds at a later phase.

For the young studying population, the sleep phase problem is the most frequent cause of insomnia. For students who need to get up for school early, their sleep phase is often positioned too late in reference to the desired waking hour. In other words, the optimum sleep time comes too late. Sleepiness arrives too late, and natural waking comes later by the same degree. Such a student will always battle with [sleep deprivation](#) when going to sleep late, or a degree of insomnia when going to sleep early. In that sense, there is a physical/biological underlying cause. However, as [sleep deprivation](#) is pretty unpleasant, a student may try to go to sleep early (to ensure the night is long enough), but be unable to fall asleep due to the early [circadian](#) hour. If this occurs again and again, a psychological component may compound the original problem of insomnia. The recurring [sleep deprivation](#) will produce a fear of not falling asleep in time and making things even worse. In other words, in a vast majority of cases the problem is both biological and psychological. The only true remedy is to go to sleep later and wake up later thus being late for school (almost certainly a lesser evil given some understanding on the part of the educators). The only natural half-remedy is to measure as precisely as possible the optimum time of going to sleep, and sticking to that time religiously every day. That optimum time is the earliest time that roughly provides 95% or more certainty that [sleep latency](#) will be less than 10-15 min. (i.e. no more than a quarter of an hour of tossing and turning). Very often, this optimum time will provide for a mere 4-6 hours of sleep. However, this sleep is most likely to be the best quality sleep achievable in such conditions. Naturally, affected individuals will suffer a degree of [sleep deprivation](#) on a daily basis. This is still better than futile tossing and turning, waste of time, and fitful sleep associated with insomnia. If you suffer from sleep onset insomnia, and you suspect it could be caused by [DSPS](#), you could research additional remedies such as morning sports, strong morning lights, evening melatonin, and radical solutions such as ... giving up electricity after 19:00.

Another type of insomnia, **nocturnal awakening**, is also often related to going to sleep at a wrong time. People who need to get up earlier than indicated by their body clock, often try to compensate for the short night by going to sleep early. If they succeed in falling asleep, they will often experience premature awakening that is nearly always accompanied by a difficulty of re-initiating sleep. If the same people were allowed to go to sleep only then when they were really tired (perhaps 2-5 hours later), the problem would likely not exist!

If you wake up often during the night, you should identify and eliminate possible reasons, esp. if you appear to wake up tired. The reasons and the way to diagnose them are too many to describe. However, you should always start from the simplest one: problem with the [circadian](#) phase. In simple words, the timing of your sleep may be wrong. Partitioning of sleep is a typical symptom of going to sleep too early. If you are healthy, in [free running sleep](#), you will rarely wake up during the night, and if you do, you will fall back asleep fast, and if you won't be able to, the reasons will be quite obvious such as: stress, noise, thirst, cold, full bladder, etc. However, if you attempt to regulate the timing of your sleep, the partitioning of sleep (i.e. interrupted sleep) will be a frequent result. It is possible to push your sleep slightly ahead or back (e.g. 15-25 minutes per day) without this negative outcome. However, once you try to push too hard (e.g. more than an hour per day), partitioning is almost inevitable. If you push backwards (i.e. going to sleep earlier and earlier), you will likely wake up early in the night, i.e. before your [circadian](#) low ensures deep sleep. On the other hand, if you push forward (i.e. going to sleep later and later), your [circadian](#) low will end before you complete your sleep cycle. As a result, you will often wake up earlier than expected. If this waking up happens very early (when you push ahead very hard), you will be tired enough to fall asleep again. In other words, whichever way you push your sleep, it will not be properly aligned with your [circadian](#) rhythm. You will then wake up early or late in the sleep cycle depending on at which end the misalignment occurs. In a vast majority of cases, waking up problem can be resolved by going to sleep at the time when your body calls for it.

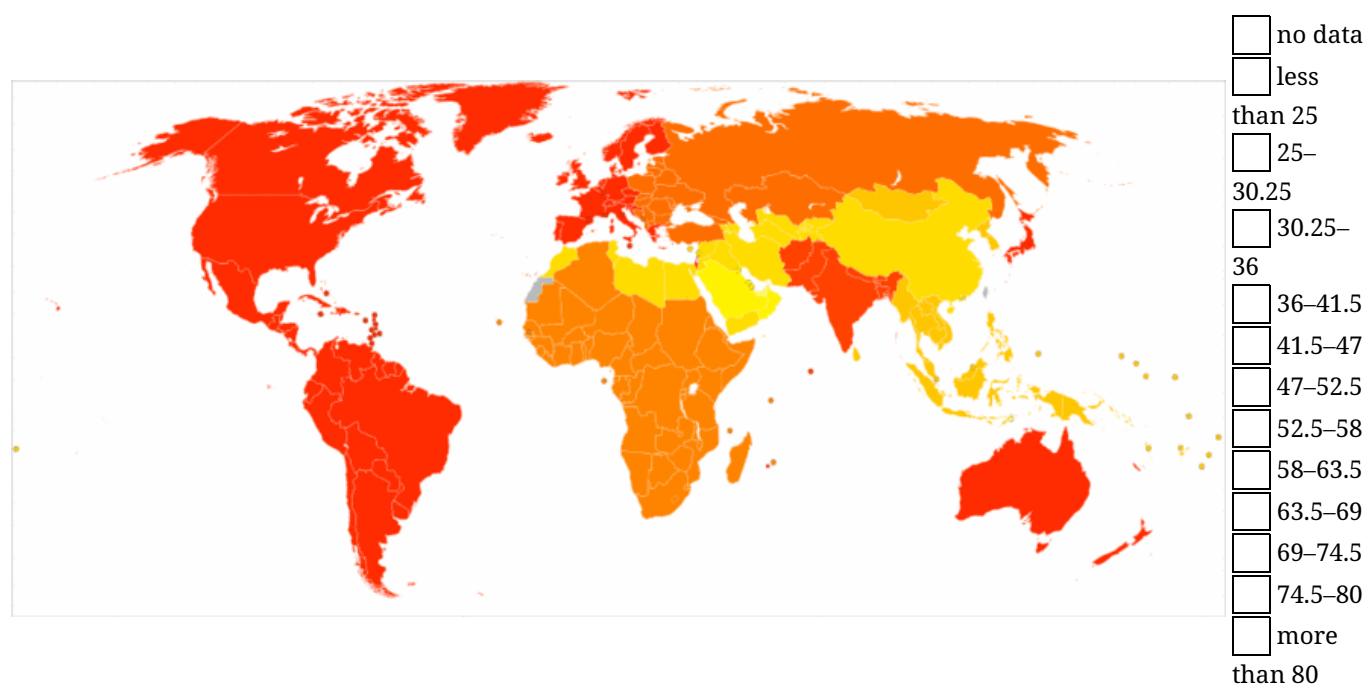
The solution for most of cases of sleep onset insomnia and nocturnal awakening is: **Go to sleep only when you are truly sleepy!** Amazingly, most people do not care to listen to their body. Many struggle with sleepiness to get more life in the evening. Others force themselves to bed long before their optimum bedtime and then toss and turn for hours. This premature landing in bed is at the root of the epidemic of insomnia (even though the official figures put [circadian](#) disorders at only 10% amongst the causes of insomnia). The only sensible and healthy time to go to sleep is when you feel you start getting sleepy. If this natural time is outrageously late, see [Curing DSPS and insomnia](#).

Early waking is also a problem for a large number of people. Those people may suffer from the [ASPS syndrome](#). In their case, going to sleep earlier will often be a sufficient remedy. If you happen to wake up early in the morning, your further sleep decision should probably be made on the basis of how fast you believe you would be able to fall asleep. If you do not think the sleep is coming soon, it is definitely better to get up and do some work. This way you will gain in three ways:

1. get tired and sleepy faster (work is more likely to make you tired again)
2. you will not get anxious about falling back to sleep as soon as possible
3. you will not waste time on futile tossing and turning

Insomnia vs. electricity

Insomnia has reached epidemic proportions since the advent of electric lighting. See how lifetime costs of insomnia match the degree of industrialization.



[Disability-adjusted life year for insomnia per 100,000 inhabitants in 2002](#)

How to fall asleep faster?

There are tons of lengthy books written about sleep onset **insomnia** and there are a zillion tricks that people use to be sure they fall asleep "in time". The sad truth is that all those tricks only fight the inevitable: the natural sleep mechanism. They are based on slowing down the brain at the time when the brain simply does not want to slow down. Yet these tricks rather tend to blow the problem of insomnia out of proportion by adding to the sleeper's stress: *so much effort, so many tricks in use, and it still does not work... I will probably just have to live with this scourge for ever!*

If you follow a conventional insomnia advice (see an [example](#)), you will quickly realize that most measures work great at the beginning, and then, when the placebo effect wears off, you are back to square one. Some hotels offer \$1000 per night services in curing insomnia in jetlaggers. All those services are a big waste of time and money. Without a phase adjustment, insomnia will persist. It can only be masked for a while.

Here is some typical **unworkable** advice that you may get from your sleep "expert" or from your grandma:

- **Ineffective! Count sheep** - this is nothing else than trying to slow neural firing in the brain. This will often work but there is an increased risk of waking up after 20-60 minutes of sleep. As a result, the chances for early slumber may be gone for good. The slowdown in firing can come naturally. However, it can only come at the right **circadian** time which may be 2-5 hours later than you would want
- **Ineffective! Thought dispersion** - by trying to "think about nothing" you can indeed increase the chances of falling asleep; however, this may be of value only in a short period that precedes the ascending **circadian** sleep propensity slope. If you try it early, you will likely hover in a superficial sleep with substantial chances of awakening spontaneously. It is the **circadian** sleepiness that stands for your ability to maintain sleep
- **Ineffective! Cut down on sleep** - this has some power to reset the **circadian** cycle, however, you will feel more tired, your cognitive powers will drop, your insomniac's stress factor will triple, and most of all... your creative brain will not benefit from the last REM-rich hours of sleep! Cutting down on sleep may be an unavoidable solution among those who experience **DSPS** and cannot free run their sleep
- **Harmful! Sleeping pills** (esp. **benzodiazepines**) - pills change the sleep physiology and may affect the quality of sleep. As they often have little impact on modifying the actual **circadian** cycle, they can quickly become a serious addiction. Additionally, they affect short-term memory and the reaction time. Sleeping pills are a major enemy of a creative individual!
- **Ineffective! Warm bath, quiet room, rituals, cup of cocoa**, etc. - all these work to reduce the stress factor and slow down the brain. However, again that won't work well if you try it too early in reference to the **circadian**

cycle

- **Ineffective! Drink milk or eat turkey** ([tryptophan](#) is used in the synthesis of [melatonin](#)) - this is again a method for a mild slow down with negligible effectiveness
- **Ineffective! Take vitamins** - vitamins or minerals are a standard plug for whenever something goes wrong with health. For many people, the first question is "*perhaps I do not get enough vitamins?*" Doubling up on the recommended dose is what often follows. A healthy diet should rarely require supplementation!
- **Ineffective! Do not nap** - well-timed short naps have little influence on the [circadian](#) cycle and not napping may only have a residual [homeostatic](#) influence at the cost of evening alertness. It may help slightly but will not solve the problem. Naps should be avoided only at times of major [circadian](#) misalignment when the body starts losing track of time and [circadian](#) variables start oscillating out of synchrony
- **Ineffective! Avoid caffeine** - when taken in the morning in reasonable quantities, [caffeine](#) should have negligible effect on the quality of sleep. When you are really tired, it is really hard to prevent sleep with coffee. Naturally, giving up the addiction (gradually!) will help a bit and won't do any harm. However, it will never be a solution!
- **Ineffective! Herbs, meditation, yoga, aromatherapy, acupuncture, chamomile, relaxation, massage, magnesium, ...** - ... the list is virtually endless!

Few things can produce as much wasted time in highly effective people as trying to fall asleep at a time when your body does not want to! Do not listen to sleep advice based solely on methods for slowing down in the evening or making you mentally or physically tired! Do not go to bed until your body slows down on its own! Go to bed only then when you are really sleepy!

The question posed in the present headline was intentionally provocative. **You cannot fall asleep faster, but you can fall asleep fast.** All you need to do is to wait for the right time. Instead of trying to fall asleep faster, go to sleep later, and fall asleep fast.

Phase-shift based insomnia

In most cases, the real culprit in insomnia is the relationship of your working hours vs. the [circadian](#) rhythm! This is magnified manifold by the associated stress factor. For many, insomnia produces an unsolvable vicious circle that just has to be lived with. However, everyone with a chance for a flex-time work system or telecommuting should realize that the greatest benefit of these may come from increased productivity as a result of better sleep that complies with natural body rhythms.

A very specific degree of *morning misery* is needed to reset the clock sufficiently in people with [DSPS](#). In the equilibrium state in which misery is sufficient to keep a regular schedule, the whole night sleep is cut substantially. Daily sleep deficit and daily struggle with tiredness result. In such circumstances, it is best to go to sleep only shortly before the expected sleep hour! This way you can reduce stress, on one hand, and help your [homeostatic](#) component on the other (by making yourself tired for sleep).

Dr Kripke (see a [critical chapter on short sleep](#)) says: "*The false belief that people generally need eight hours of sleep is one of the common causes of insomnia. Spending less time in bed is an important solution for many with insomnia*". That statement is only partly true. Indeed, trying to get 8 hours of sleep by going to sleep earlier will backfire. It is better to get less sleep when it is initiated in the right phase than to force extra hours prematurely. However, the key is not in sleeping less, but in sleeping at the right time! If you sleep in the right phase and do not need to get up early in the morning, you might actually get your eight hours with zero risk of insomnia.

If you cannot [free run your sleep](#) make your *morning misery* as regular as possible to reach the equilibrium state. Once you know the equilibrium, stick to your standard bedtime hour. Morning misery solution should only be used as a last resort!

There remains the question of weekends. Many people catch up on lost sleep during weekends. This naturally unbalances the system and results in the Monday Morning Blues. Sleeping it out on weekends, you should weigh up your pros and cons:

- on one hand, you entrain your sleeping cycle to later hours and make it harder to stick to your *misery equilibrium*
- on the other, this is your only chance for quality sleep

There is no simple answer to the weekend dilemma! If you want to maximize the effects of sleep on learning, skills and experience, you would need to quantify how much you lose as a result of never actually getting enough sleep (the losses could be dramatic!) and how much you lose as a result of departing from the misery equilibrium on weekends

thus tripling sleep disturbances early in the week.

For healthy people, the most effective solution for persistent insomnia or work-schedule-related sleep deprivation is [free running sleep](#)!

Free running sleep is simple to define, but a bit harder to execute for beginners. It will often conflict with one's expectations and needs as to the timing of sleep. You will know that free running sleep worked for you if you replace insomnia with no more than 3-5 min. in bed before you fall asleep (without medication).

In healthy people, the time to fall asleep should not be longer than 5 min!

If you succeed with free running sleep and discover that you can fall asleep in 5 min. as long as you go to sleep at your natural hour, you may discover a new problem. You might show a tendency to wake up later each day. If this is the case read: [Curing DSPS and insomnia](#).

Hypersomnia

Hypersomnia is excessive sleepiness in conditions of getting physiologically sufficient sleep. Hypersomnia may be related to serious health problems. However, if you keep battling drowsiness, your problem does not need to have a serious organic cause. There is a simple home-grown diagnostic method that can help you eliminate a frequent and less severe cause: a [phase shift](#) disorder. Try to [free run your sleep](#) for a few weeks. Very often, the phase adjustment will resolve perpetual tiredness! Quite frequently, sleep initiated too early in reference to the [circadian](#) sleepiness will last very long and paradoxically result in the feeling of not being refreshed in the morning. If the subjective [circadian](#) night period overlaps with the actual waking time, you may experience overwhelming drowsiness, yet you will not be able to fall asleep for longer than 20-30 minutes and you will still wake up unrefreshed. Even buckets of coffee may not help in such circumstances. If you do not notice a significant improvement in the quality of sleep after 1-2 weeks of free running sleep, you may suffer from an underlying health problem that will require a professional consultation. See: [Sleep and Hypersomnia](#) at WebMD. A frequent cause of poor quality sleep is Obstructive [Sleep Apnea](#) (OSA). OSA is caused by breathing difficulties during sleep (see the next section).

Sleep apnea

Sleep apnea is a problem with breathing during sleep. In all cases of getting unrefreshing sleep despite adhering to all the rules of sleep hygiene (esp. in [free running sleep](#)), [sleep apnea](#) needs to be ruled out. An initial home-made diagnosis may be made by a bed partner or by video-taping one's own sleep. All pauses in breathing or heavy snoring should be worrisome and consulted with a sleep expert. The most frequent type of [sleep apnea](#) is the [obstructive sleep apnea](#) (OSA), which affects up to 10% of male population (it is about half as frequent in women). OSA involves a loss of muscle tone in the throat and tongue areas. These structures tend to collapse during sleep and block the flow of air. As a result, the patient will wake up temporarily (often a hundred times in a single night) without completing the natural NREM-REM cycle. Patients with OSA wake up feeling unrefreshed. You can also videotape yourself when sleeping. Most often, OSA affects obese and heavily-snoring males. There are multiple support sites for OSA on the web (including recordings of snoring patients and typical signs of interrupted breathing). [Sleep apnea](#) needs to be treated with urgency. It undermines one's cognitive powers in a short-run (due to its effects on the quality of sleep) and in a long-run (due to its negative effects on brain growth and aging). If anyone tells you that you snore heavily, do not treat it as a natural thing: "*my uncle also snores like a tractor and seems to be ok*". All cases of snoring should be investigated. Snoring may be a first sign that your brain is not getting what it needs during the night sleep! [Sleep apnea](#) can also lead to cardiovascular disorders, depression and a whole host of negative health consequences. One of the best natural weapons against [sleep apnea](#) is weight loss by combining a [healthy diet](#) and [exercise](#). Exercise on its own may also be helpful as long as it is chosen carefully to make sure it does not exacerbate snoring (e.g. through nasal congestion).

Napping

Napping is good

The natural sleep-wake cycle makes you feel less alert in mid-day. This period can easily be visualized using EEG measurements. In many tropical, subtropical, and Mediterranean countries this is the time for [siesta](#). The drop in alertness can be magnified by a rich meal and a short nap is likely to quickly restore full alertness. However, the industrial nations do not seem ready to adopt the healthy habit of a postprandial nap. Just the opposite, when the Mexican parliament debated the law on statutory napping, politicians and comedians north of the border had a good

laugh about "lazy Latin Americans". [Siesta](#) Awareness in the UK abruptly cancelled their National [Siesta](#) Day 2009 upon a publication from China that showed that diabetics nap more. Myths galore. Napping is smart, and yet nappers are often considered lazy, or weak. The self-improvement guru, Tony Robbins, provides a typical misguided get-up-and-go advice on napping: *replace a nap urge with press-ups*. Press ups will improve circulation and raise the level of [catecholamines](#). This will make you feel more alert for a moment. However, only a nap can provide a true neural boost to your cognitive powers. Nap is better than [exercise](#). Nap is better than [caffeine](#). Nap is irreplaceable.

Napping and evolution

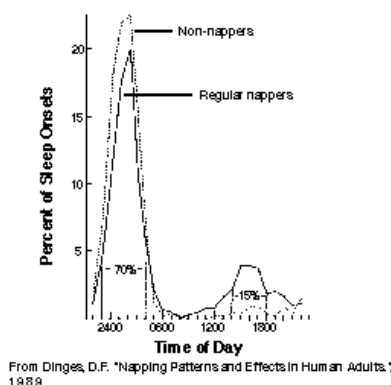
There are few theories on the evolutionary purpose of the mid-day dip in alertness. Most people believe that humans, as all other highly developed tropical animals, have developed a [siesta](#) habit as a way of getting around the midday heat. This explanation has also some cultural background as napping is by far less popular in moderate and cold climates. However, the alertness dip can be resolved by a short nap in minutes. This can make us active again long before the mid-day heat is over.

Another explanation is that the alertness dip is an atavistic remainder of the polyphasic sleeping mode that might have characterized human ancestors. Many animals and newborn babies sleep many times during the day. This might seem advantageous for optimizing memory circuits. However, consolidating sleep into a single night rest period might have offered some evolutionary advantage too. Early humans might have been less efficient in hunting and gathering activities at nighttime. This is why it might be advantageous to spend nights on memory optimization. Possibly, the consolidation of sleep went gradually from polyphasic sleep, through [biphasic sleep](#) to semi-monophasic sleep in modern humans. Actually, similar consolidation can be observed as we get older. By the time of adulthood we are more or less monophasic with a clear dip in alertness that may be resolved with a short nap. As we near retirement, we again seem to tend to become biphasic. This may be a result of the fact that working people are forced to suppress their biphasic tendency. [We remain strongly biphasic throughout the lifetime](#), and the monophasic model has largely been imposed by industrialization.

When I look at learning performance data collected with SuperMemo, I see that the [homeostatic](#) decline in cognitive powers throughout the day is steep enough to provide an alternative explanation: nap is cognitively beneficial, but not essential enough to boost it with a full-swing [circadian](#) support. As a result, we have developed a half-way sleep system that ensures the essential fully blown nighttime sleep, and a window for an optional mid-day alertness booster. As the [circadian](#) component of sleep drive is associated with some physiological functions of sleep, a system with [homeostatic](#) napping might not have been equally beneficial. As for the speed of [homeostatic](#) decline in alertness, it could be inherent to the networks involved and might depend on energy reserves, supply of neurotransmitters, size of the networks involved, etc. It should also depend on the degree of use. The heavier the mental effort, the faster the decline in cognitive performance. In other words, for the brain as it is, and for heavy mental loads, slower [homeostatic](#) decline may simply not be physically possible. The timing of the mid-day nap comes from the fact that splitting the day into two exact halves maximizes overall alertness. Here again, mid-day tropical heat might actually provide an additional evolutionary incentive.

Naps and brain power

The father of the napping science, Dr. D. F. Dinges has spent many years investigating the problem of alertness at workplace and has shown substantial benefits of napping in professions where the alertness may be the difference between life and death. His research showed a substantial alertness boost coming from a nap (Dinges 1989^[23]). He has also noticed relatively little impact of napping on the night-time sleep in regular nappers:



However, when Dr Matthew Walker published his research proving the value of napping for cognition (Walker and Stickgold 2005^[51]; Walker and Nishida 2007^[52]). Professor Derk-Jan Dijk commented surprisingly: "[*there was no clear evidence that daytime napping offered a distinct advantage over sleeping just once over 24 hours \(...\) while the brain effect reported in the study might be spotted in a laboratory setting, the picture became more clouded in the "real world"*](#)". Today, you can measure the benefits on napping on your own using [SuperMemo](#). Comparing [recall](#) graphs of nappers and non-nappers, we can clearly see how non-nappers power at half-steam through the second half of their waking day (see: [Biphasic nature of human sleep](#)). Dr Walker, who confirmed his point with later research, says convincingly: "It's as though the e-mail inbox in your hippocampus is full, and, until you sleep and clear out all those fact e-mails, you're not going to receive any more mail". Take it from a religious napper Mr Winston Churchill: "you get two days in one"! The value of the nap increases in proportion to the degree in which your work depends on your brain and the quality of your thinking.

To nap or not to nap? Nap!

Here is a short summary of pros and cons of afternoon napping:

Pros:

- [Siesta](#) naps, rich in [NREM](#) sleep, result in a significant increase in alertness that will be highly appreciated by people in creative professions. By various measures that boost may be as high as 50%!
- As shown with SleepChart, [napping improves recall and memory consolidation in the second half of the day](#)
- Well-timed napping may help combat [sleep deprivation](#). Some people even prefer to sleep in two 3-4 hour portions throughout their lives!
- Naps reduce blood pressure, improve cardiovascular health, and might, as a result, prolong your life!

Cons:

- Badly timed (late) naps may worsen [insomnia](#). This is why so many sleep experts counter-recommend naps. However, [proper timing mitigates this problem](#)
- Badly timed (late) naps may result in [sleep inertia](#). This can be resolved easily with proper nap timing.
- Napping requires good rest conditions, conducive napping culture, and solid napping skills and habits. All these may be hard to come by in industrialized nations.

If you ever hesitate, to nap or not to nap, take a well-timed nap and see how it impacts your life. If you wake up groggy, remember that napping is also an art. Read about [best timing of naps](#). Chances are, napping might become a beloved habit that will increase your productivity. Many great minds napped habitually. In addition to Churchill, notable nappers included Napoleon, Bill Clinton, and J. F. Kennedy. Interestingly, this group also includes a famous long-sleeper, Albert Einstein and a famous short-sleeper Thomas Edison. Even Bill Gates enjoyed taking naps under his desk in his creative programming years.

Napping in the corporate world

More and more companies in the US have already decided to make a switch from a coffee break to a napping break with special cubicles designed for nappers. In the future, this trend is likely to become [more prominent](#) as [caffeine](#) is not a fraction as effective as a nap in combating fatigue. For neural reasons, coffee, doughnuts, press-ups, and other methods taken together will never prove as efficient in mental restoration as a nap. At the same time, our society drifts strongly towards information processing where alertness is central to productivity. And when the productivity comes into the equation, corporations will definitely avail of the up-to-date research on napping.

Important! Do not confuse the healthy concept of a [siesta](#) nap with a very unhealthy idea of [polyphasic sleep](#).

Napping rulebook

- Do not use the alarm clock! Contrary to popular belief, well-scheduled nap will not result in [sleep inertia](#) (unless you are seriously sleep deprived). Alarm clock can seriously undermine the value of the nap!
- Measure exactly the optimum length of the period between the natural awakening and the nap to maximize the effectiveness of a nap. The nap should come at the nadir of alertness, which usually comes 7-8 hours from natural waking. [Napping beginners often miss the right timing!](#) Choosing 7 hours as your starting point will allow of a 60 min. margin in case you were late for one reason or another.
- Drink coffee or other [caffeine](#) drinks only **after** the nap. Even the tiniest amounts of [caffeine](#) in the system might interfere with the quality of sleep.

- If you drink alcohol before the nap, it should be largely metabolized (i.e. out of your system) by the time you fall asleep
- If you nap for more than 100 minutes, you probably need more sleep in the night (or you nap too late)
- Avoid stress 1-2 hours before the nap. Even things you love can make you excited and make it harder to avail of the benefits of napping
- [Exercise](#) is good. Try to finish your exercise at least 45 minutes before the nap. If you fail to cool down, your nap may end up prematurely
- Meal before the nap is recommended. Unless your doctor says otherwise, your main meal of the day should actually come before the nap (around the 6th hour of your waking day)!
- [Sex](#) before the nap is recommended
- Stick to your ritual (e.g. stick to your best sequence: exercise, beer, bath, meal, quiet place, nap, music, or similar)
- If the above advice does not work, you may need a month or so of trying. Mental slow-down is critical here! Many people do not discover the benefit of napping until some circumstances put them into the routine (e.g. heart condition diagnosis). Even if you cannot fall asleep, you may still need a nap! Sleeplessness may only be a result of a habit or your inability to forget the worries of the day. You may simply not fully understand your actual sleep needs.
- If it all won't make you fall asleep in 10 minutes even after a month of trying, you can probably safely give up napping for good

Napping myths

Myth #1: Only lazy people take naps

In some cultures, this harmful myth makes people feel ashamed that they are weak enough to need a nap. This myth must be abolished promptly. Naps have a great effect on cognitive function and productivity. If you want to take a nap, take it and announce it proudly. You are doing a smart thing. **Naps make you smarter!**

When Newt Gingrich [was caught asleep on camera](#), commentators pointed fingers in all wrong directions: he is getting old, he is tired of the campaign, he might be suffering from Alzheimer's, etc. Gingrich was set to video-stream live via satellite hook-up to the American Israel Public Affairs Committee. During a preceding Panetta speech, he opted for a quick nap in a sitting position. His age or health did not need to have to play any role here. In fact, Newt was doing a smart thing: he was clearing up his brain before appearing before a demanding audience. However, despite a short span of time available, he managed to launch deep sleep and woke up with clear signs of [sleep inertia](#). He did not know where he was and what he was about to do! He recovered pretty fast with stump lines attacking radical Islam. Those sleep inertia symptoms did not need to indicate he was tired of the campaign or that his [sleep deprivation](#) carried over from many days of sleep debt. Even a single night of lost sleep would be enough to put anyone in his position. His being a political old-timer worked against him. No novice would be able to overcome the stress of public sleeping to get a few zzzs. The only obvious mistake Gingrich made was to fail to get his full load of sleep on the preceding night. For more see: [Why naps cause sleep inertia?](#)

Myth #2: A nap is a nap is a nap

This myth says that every nap is a good nap. It does not matter when it is taken and how long it lasts. This myth lives deep in the psyche of inexperienced nappers who often do not realize the myriad of genetic, metabolic, neural, and hormonal processes that cycle through the human body throughout the roughly 24 hour period. In the section titled [Best nap timing](#), I include a general partitioning of the [circadian](#) cycle with a short analysis of what processes occur when a nap is taken at each selected point of the cycle. Naps taken at different points of the [circadian](#) cycles are as different as chalk from cheese. Some are refreshing. Some are a waste of time. [Some may be unhealthy \(or at least inefficient\). Some will last several hours!](#)

Myth #3: Make sure you wake up from Stage 2 NREM

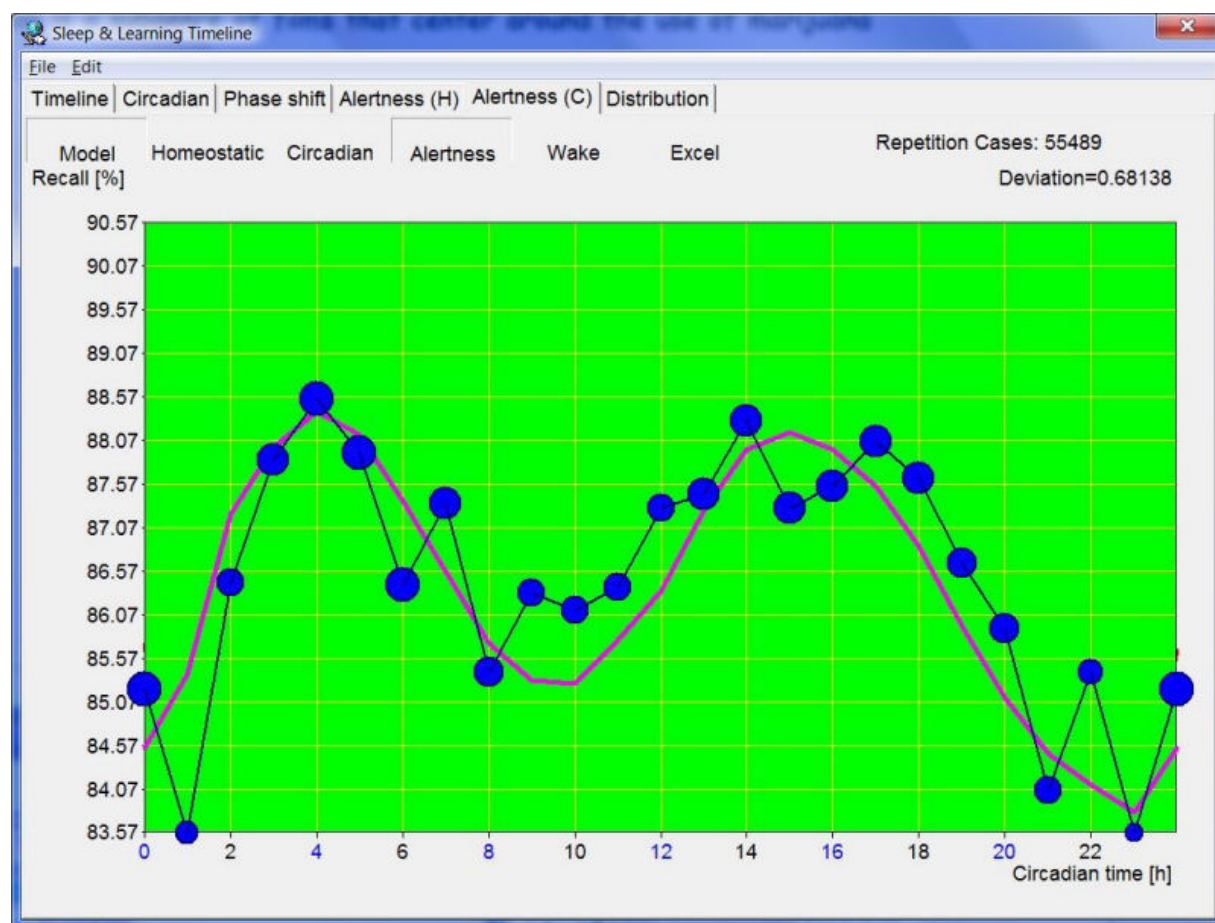
Some napping "experts" will tell you to use an alarm clock to make sure you wake up after 15-20 min from Stage 2 [NREM](#). Supposedly, longer naps send you into deep sleep (Stage 3/4 NREM), and you [wake up groggy](#). In reality, it is the [timing of naps in reference to the circadian cycle](#), as well as the prior [sleep deprivation](#) and [REM-sleep deficit](#) that will determine the nap duration and the effects of the nap. On some occasions, it may happen that a nap cut short with an alarm clock will be somewhat refreshing and will prevent the ripples of a wrongly timed prolonged nap. However, it is always better to choose the appropriate time for a nap. It will usually be around 7-8th hour of the subjective day. This translates to 7-8 hours from waking in [free running sleep](#). However, in conditions of sleep deprivation, or misaligned sleep cycle, it is safer to take an earlier nap or even skip the nap entirely to help cycle re-synchronization.

Did you hear a story in which Einstein supposedly napped with a pencil to wake up as soon as the pencil dropped? I doubt a great genius would make this mistake on a regular basis. I am sure he had a chance to compare the values of a well-timed natural nap and an interrupted nap. Perhaps a pencil dropped indeed. Once? Perhaps the genius brain was thus deprived of some new creative insight? Or conversely he was inspired by an interrupted mentation? Perhaps it was just a nice story to tell over a cup of tea? Whatever the truth, do not follow this example! Let your brain decide how long the nap should last!

Myth #4: The circadian cycle can be ignored or abolished

A harmful myth says that we could ignore the **circadian** cycle, so that the sleep can be reduced to one-dimensional **homeostatic** process. This myth comes from the lack of understanding of the two-process nature of sleep. It made many to believe that **polyphasic sleep** is a good long-term lifestyle choice. The myth comes from the lack of appreciation of the overwhelming power of the primary **circadian** sleep component. Consequently, the myth bears a belief that naps can be induced at will at any time that is sufficiently far away from the prior nap.

Have a peek at the following amazing picture obtained with the help of **SuperMemo**.



The graph shows the powerfully biphasic nature of the human **circadian** cycle. The horizontal axis shows the circadian time, i.e. the time that elapses from phase 0, i.e. the predicted "end of the night" time. The prediction comes from the circadian model employed in SleepChart, and is derived from the sleep log collected in **SuperMemo**. The red line is the predicted alertness derived from the same sleep log data using the two-process model of sleep developed for the purpose of sleep optimization in **SuperMemo** (the model is inspired by similar [work of Alexander A. Borbely and Peter Achermann](#)). The alertness is a resultant of the status of the two sleep-drive processes:

1. the homeostatic process and
2. the circadian process.

The blue dots are **recall** data taken from an actual learning process in **SuperMemo**. In other words: red is the model, blue is the data. Both tell the same story! For skeptics who do not believe in scientific models, blue-dot unprejudiced data should be the ultimate clinching argument. The graph says unequivocally that we got two major peaks of alertness during the day. It also states clearly that there are only two valleys conducive for sleep and napping.

Best nap timing

Naps are a blessing for a tired brain. However, if taken at a wrong time, they can also contribute to messing up your sleep cycle. Many people believe that a nap is a nap is a nap. Whatever its timing, the nap will refresh your mind. This is false. Understanding the optimum **circadian** timing of naps is essential for naps to be your friend, not your enemy! The belief in the universality of naps sparked a dangerous ideavirus: lifestyle based on **polyphasic sleep**.

Napping is a skill. Many people cannot nap even if they are sleepy. Measuring the time between your natural waking and the nap should help you optimize the quality of a nap. Optimally, your tiredness might not even be perceptible enough to easily guess the optimum timing. If you measure the time between night sleep and the nap, you will notice that the length is always the same (minor variations depend on the quality of sleep in the night). In other words, the measurement helps you figure out the timing of your **circadian** dip even on days when you do not feel tired at midday. You may wonder, why nap in the first place then? The boost in cognitive powers is worth the investment (which may be as little as 10-20 min. on a good day).

In a healthy biphasic sleep, a nap taken at **siesta** time is an excellent boost to your mental energy and creative powers. It is important to know that the timing of the nap should not be determined by the clock that hangs on your wall. Your nap should come at around 7-8 hour of your natural waking time. To be precise, only you can determine that value precisely by comparing what happens if you try to take naps a bit earlier or a bit later. The optimum value may not hold if you cut your sleep short with an alarm clock, or fall asleep earlier than usual (e.g. because of an exhausting day), or delay going to sleep beyond your natural sleep hour.

Circadian timing of naps

To optimize your nap taking, you need to understand the impact of the sleep cycle phase. Below, I explain what happens if you take naps at different phases. In the text below, Phase 7 Nap denotes a nap that is taken 7 hours after natural awakening from sleep taken at natural hours. Refer to the following graph which illustrates the biphasic nature of human sleep propensity. This graph shows that there is only one optimum alertness valley (in red) conducive to sleep, usually in hours 7-8:



Phase 0: Waking time

Napping in Phase 0 is napping that takes place immediately after waking, i.e. **Circadian** Time 0 in the graph above. Napping in Phase 0 is possible, and largely depends on the history of prior sleep. Phase 0 naps after a normal night sleep can be considered as a complement to the night sleep if it was not effective enough. Such naps consolidate with

the night sleep in sleep models and are an efficient way of extending the night sleep in cases when it was interrupted (e.g. by noises, bursting bladder, health issues, etc.). Phase 0 naps after a sleepless night can serve as an inefficient substitute for the night sleep. Such sleep will be short, unrefreshing and leave a sleep debt. It will also introduce unwelcome oscillations in the **circadian** system that may take a few days to clear up. Such sleep is often used by night-shift workers to get some mental boost for a day. It is still far better than no sleep at all. The rule is simple: if you are sleepy at Phase 0, nap at will. Your brain clearly needs more sleep.

Phase 3: Creativity time

Napping in Phase 3 should not ever be possible in a healthy well-regulated system (see the red peak in hour 3 on the horizontal axis in the graph above). Successful sleep at this time is an indication of sleep deprivation, poor quality sleep (e.g. due to **sleep apnea**), sleep in a wrong phase (e.g. taken too early), sleep disorder (e.g. narcolepsy), etc. This is probably the hardest time to nap of all. However, I am not aware of any bad effects of such naps for health or for sleep control systems.

Phase 5: Pre-siesta

Napping in pre-siesta slot is possible. However, such naps are likely to be short and not as refreshing as Phase 7 naps. They are also more likely to be REM-rich for **circadian** reasons. Those early naps can probably be recommended to people who suffer from sleep-onset **insomnia**, and who still want to boost the second half of their day in terms of alertness and creativity. Those naps can also be executed "in a hurry" due to their short duration in cases where longer napping is undesirable, or later timing does not fit the day's schedule.

Phase 7: Siesta

Perfect time for napping. As it can be seen in the graph, this is the period when the mental performance is at its mid-day nadir (aim at Phase 7 to make sure being late will still place the nap within the nadir). It is not true that the nadir is caused by a hefty lunch (even though meals have a big impact on sleep control). The nadir is a natural expression of the **circadian** wave. This **circadian** low time comes at the roughly same clock time as the **subjective night** nadir at a roughly 12 hour shift (e.g. if the middle of your night falls at 3 am, naps at 3 pm could be most effective). This is well explained in "[How to nap](#)". The benefits of a **siesta** have been confirmed by numerous studies. It has been practised for ages in many regions of the world. [It will definitely trickle into the corporate world as human productivity becomes increasingly dependent on our creative powers.](#)

Phase 11: Evening

This is not a good time for napping. In a healthy cycle, napping might be hard to achieve or impossible. However, even a minor degree of **sleep deprivation** will produce a nap that might trigger the control mechanisms responsible for the full-night sleep. Late naps are likely to be rich in **NREM** sleep and rob your night sleep of the vital **SWS** component (Werth et al. 1996^[53]). Those naps can last far longer than **siesta** naps. They can make you groggy. Worst of all, they can compound **insomnia**. Unfortunately, this is a type of a nap that a huge proportion of students take! Forced to wake up at indecently early times for school, kids and students struggle semi-conscious through school hours with negligible progress in learning. Learning in such a state only magnifies the pretty universal hatred of school. Phase 11 nap is then the only way to survive the day and get some actual learning done in the evening. The body clock shifts the **subjective night** to the morning hours. The positive side effect is that evenings can be filled with effective studying. The negative side effect is that the student finds it impossible to fall asleep before 3-4 am, and welcomes the new bright school day with an alarm clock that rings in the middle of the **subjective night**. This perpetuates the cycle of suffering and school hate. Nobody has ever estimated the global consequences of this phenomenon that includes an impact on adolescent attitudes that are notoriously fraught with problems. Neither has anyone come up with a practical solution (shifting school hours usually results in kids "adapting" to the new cycle by shifting their bed time as well). I am not able to recommend a solution here either. Skipping evening naps might be better for the quality of night sleep and for the stabilization of the **circadian** cycle in the earlier phase, however, that would effectively rob those students of their only time in which they can learn. Those evening naps are also the only meager substitute for **free running sleep** that those young brains crave. The only time when the brain gets what it wants. If I was to answer: to nap or not to nap, I would probably have to admit that evening napping is the lesser evil in a majority of cases.

Phase 13: Pre-sleep

This is a particularly bad time for napping. Initiating naps at this time should be relatively easy. However, pre-sleep naps are likely to produce one of the following unwelcome outcomes: **long-nap-short-night** or **long-night-early-**

waking (depending on the current status of the sleep control system). A pre-sleep nap is likely to result in triggering the night sleep sequence. However, this sequence is not unbreakable, and can result in early awakening combined with the difficulty in launching back to sleep. This is particularly likely if the **homeostatic** sleep process generates substantial sleepiness while the **circadian** process is not yet mature for the night sleep. As a result, such a pre-sleep nap can yield less total sleep than a normal night sleep. This **long-nap-short-night** will not entirely fulfill the physiological function of sleep. Consequently, your alertness levels for the next day are likely to dip substantially. The less unfortunate outcome of a pre-sleep nap is if you successfully trigger the uninterrupted night sleep sequence. However, you will likely prematurely run out of the **homeostatic** process before the **circadian** function of sleep is completed. You will probably wake up earlier than usual. This is the **long-night-early-waking** outcome that produces nights that are amazingly unrefreshing considering the fact that premature sleep is often much longer than an ordinary night sleep. The reason for this low sleep efficiency is probably the scarcity of **REM** sleep which is strongly **circadian**. Moreover, for **circadian** reasons, your morning is likely to be unusually sleepy!

Phase 15: Segmented sleep

Phase 15 napping should be considered "early night sleep". If you go to sleep at this time you can expect any of the following (depending on the degree of sleep debt):

- if you carry no sleep debt: some **unproductive time** in bed, as you might not be able to fall asleep.
- pre-sleep outcome as in Phase 13 sleep: long nap with a short night, or long night with early waking. This outcome is likely to leave you **less refreshed**.
- **segmented sleep**: you will fall asleep, but will wake up for 1-2 hours in the night only to fall back asleep. This lucky outcome will leave you pretty refreshed.
- **long night**: on rare occasions, esp. if you are sleep deprived, early bedtime will result in a nice long refreshing night sleep.

Due to the precarious nature of Phase 15 sleep, it should rather be employed only in conditions of sleep deprivation, which provides good chances for a positive outcome. Otherwise, early bedtime may be unproductive at best, and bad for the quality of sleep, at worst.

Phase 18-24: Night sleep

If you try to nap in Phase 18-24, you are bound to trigger a normal healthy night sleep. This is ok as long as you do not get down to "napping" with the evil intent of stopping the process in 20-40 min. Here is where the pain of polyphasic sleeping becomes hardest to bear. As Dr Stampi noticed two decades ago, it is not the problem with staying awake or with falling asleep that is most exasperating. The most painful part of a polyphasic life is when your brain wants to trigger the night sleep sequence and a polyphasic adept stubbornly disallows it (Stampi 1992^[54])! This is as bad an interruption as any other abrupt stop to an all-or-nothing physiological process (urination, defecation, orgasm, swallowing, heartbeat, sneezing, coughing, childbirth, and the like). Many polyphasic bloggers note: *"I noticed that when my naps get longer, I get groggy. So I try to keep them under 20 min"*. Duh! If you do not launch the night sleep sequence, you will not suffer the pain of interruption. Why nap in the first place then? It's easier to delay defecation than to stop it in the middle. The most unusual night-time nap control method I have encountered was... *"I keep lots of junk in my bed. That keeps my naps short"*!

Important!

- **The napping phase refers to the optimum natural waking time. Not the actual waking time!** For example, in a premature sleep, or in an interrupted sleep, an efficient nap can take place 10 hours from waking. If your sleep is not entirely natural, you need to take a correction for your inherent **circadian** cycle that might be running in the background independently of your actual sleeping hours. Unfortunately, a vast majority of people with sleep phase problems have no idea how to efficiently measure and plot their natural cycle.
- **The two alertness valleys are biologically dissimilar!** As it will be shown later, only the night-time valley can produce a typical long-drawn periodic NREM-REM interplay with a gradual increase in the proportion of **REM**. The **subjective night** period is marked by a characteristic increase in the release of **melatonin**. The length of **siesta** sleep, as shown below, in the **biphasic sleep** graph, is 4-20 times shorter than the natural night sleep. Phase response is elicited by stimuli that precede or follow the night sleep. However, the same stimuli may affect the timing of the **siesta** nap, which in turn may have an indirect impact on the cycle phase.
- **Timing of naps will determine their structure.** Some researchers believe that this can also affect the efficiency of naps for a particular type of mental task due to the fact that nap timing determines the proportion of **NREM** to **REM**. This might be true if you want to maximize value/time for specific tasks. However, with sleep optimizations, you should always go for the maximum total value. This is why the best nap is a nap well aligned with your

midday [circadian](#) dip in alertness.

Good conditions for a nap are important. A nap in a semi-reclining position, or in a noisy room, or in bright lights, will also bring benefits to your alertness (on condition you actually manage to fall asleep, and perhaps pass Stage 1 NREM). However, a nap in a sleep-conducive environment will often last longer and be far more refreshing.

One nap per day is enough

Many people believe that every extra successful nap can be preciously helpful in restoring their mental energy. In a normal sleeper, who is not sleep deprived, an additional nap is indeed likely to bring increased alertness and improve mental performance. However, on a healthy schedule, all naps outside the [siesta](#) period should be very hard to accomplish. If the goal of sleep is defined as achieving maximum creative productivity, and if the night sleep can run its healthy course (i.e. there is no sleep deprivation), then any nap attempt at times other than the [siesta](#) time will be wasteful. This is because falling asleep should be difficult, and simply resting with the eyes closed does not yield a fraction of the neural benefit of an actual successful nap. Moreover, even if successful, an extra nap forced in in the morning is likely to interfere with the afternoon nap. Similarly, an evening nap may result in shortening of the night sleep. Those extra naps may bring incremental improvement in performance, but will reduce the overall efficiency of sleep and may cause ripples in the [circadian](#) system. Our biphasic nature makes it quite clear, we should strive at a single nap in the afternoon ([in the 7th hour of waking](#)). For some people, even this will be too much, and monophasic pattern is their optimum.

Many young creative individuals come up with their own designer sleep schedules. I often get mail with submissions of new sleep pattern propositions. For example, triphasic sleep: one main sleep episode of 6 hours (00:00-06:00) with two 30 minute naps after meals (12:00-12:30, and 18:00-18:30). Like most of artificial ways of making the sleep system work to design, this schedule is not likely to be efficient. Most people are strongly biphasic, and only biphasic or [monophasic sleep](#) works well for adults. However, if one throws away the second nap, the proposition will be pretty close to a natural biphasic rhythm: 0:00-6:00 and 13:00-14:00. Even though, designer schedules should always be avoided. The only exception is for designs that are an approximation of what [SleepChart](#) shows in free running sleep. As people differ in various parameters of their sleep control system, those who are very regular sleepers might indeed consider wiring a specific timing to their schedule as long as the timing is derived from their actual sleep pattern measurement. If sleep episodes in a designer schedule are not aligned with the [circadian](#) needs then they will often lead to a circadian chaos.

If you want to sleep well and be productive, choose biphasic sleep, monophasic sleep, or free running sleep, whichever works best for you, and whichever you can afford. **Free running sleep synchronized with the daylight cycle is the healthiest and will result in highest productivity.** Once you run free, you will determine quickly if you prefer to sleep biphasically or monophasically.

Polyphasic sleep

The law of accelerating returns

We live in the times of [accelerating acceleration](#). The [Moore's Law](#) makes the world smaller, faster, more connected and more efficient. We are now able to touch and feel [Kurzweil's](#) generalization: [the law of accelerating returns](#). The fast-living young generation is hungry for more. More fun, more information, more accomplishment, more education and... more waking time. It is pretty amazing to see how many people will lean over backwards to shorten their sleep to increase productivity. Young self-experimenters keep cutting sleep short with alarm clock, using controlled substances, pulling regular all-nighters, or trying to use the sleep time for "useful purposes" (e.g. [learning in sleep](#)).

In a [blog](#) of a young entrepreneur attempting to save life by sleeping less, I read (boldface emphasis is mine): "*Sleep is not my friend. As a budding young entrepreneur I have a desire to go about life with less sleep and more waking moments in life. I always feel like those moments in bed are moments that could be used for a **more noble purpose**. [...] As any good Industrial Technologist knows for something to be controllable it must be measurable. So I wrote down the time I went to sleep and time I woke up every morning for a year. Measuring it gave me a good benchmark to improve upon*". A praiseworthy one-year record of measurements followed and produced a [nice graph](#) of healthy and regular sleep averaging an enviable 8 hours per night (slightly less in summertime). A sleep expert might exclaim: "Good for you! Keep it up!" But a budding entrepreneur goes on to "improve upon" millions of years of evolution. "*This is a total of 112 days asleep and 253 days awake. Or, to put it another way, **I slept away 31% of the year**, [...] I tried a few experiments with my day to see if I could reduce the time I spent sleeping. For example, I once tried strictly limiting my sleep to 5 hours each night ... it lasted about 2 weeks and I **gave myself a fever**. Then I tried pulling an all-nighter once a week for as many weeks as I could manage. That did not last long either. Most notably because the 2nd day after the all-nighter was*

always so unproductive that the extra time I was awake did not produce a net increase in my productivity. [...] I have yet to find a good way to sleep less on a consistent basis". I wonder why a good Industrial Technologist did not bother to spend 5 min. to google for the function and the [noble purpose of sleep](#). After all, you do not need an honors degree in biology to know that if the body does something, it is nearly always for an important purpose.

In addition to the said hunger for more productivity and more waking time, the myth-making power of the human mind is now grotesquely amplified by the all-mighty Internet. If there is an idea that could make life better or more bearable, it quickly takes on its own Internet life as soon as it is invented. Along the rules of the [memetic science](#), the idea grows, mutates and evolves. It feeds freely on science as well as on rumor, self-experiment, and unscrupulous sources biased by self-interest ready to trade truth for profits. It snowballs adding new pleasing facts and hypotheses as it rumbles over the unprepared minds. Like a new messiah, it drags behind new followers, advocates, apostles and die-hard guerillas ready to contribute to the ultimate victory of the cause.

Around the year 2000, a new [meme](#) cropped up in several blogs on the net: *The Uberman's Sleep Schedule*. Due to my interest in the role of sleep in memory and learning, it did not take long for the meme to hit my inbox. As the concept kept ballooning on a monthly basis, it left me with little choice but to take a stand.

The Uberman's Sleep Schedule

The idea behind the Uberman's Sleep Schedule is to gain waking hours by sleeping the total of just 3 hours in 6 portions distributed equally throughout the day. There are many variants of the scheme proposed by those who tried to sleep along the schedule. The schedule is supposed to compress physiologically less important stages of sleep and homeostatically upregulate stages vital for mental health. The Uberman's Sleep Schedule was proposed in [this blog at Everything2](#) by a woman hiding behind a nick *PureDoxyk*. The blog reported a sleep experiment with an innocent admission that the Uberman schedule was incompatible with the experimenter's schedule and goals. Yet the meme was picked up in a [Kuro5hin article](#) in 2002. Phrased in a simple and well-structured language, this time it was noticed. Again, the post ended with "*Uberman's sleep schedule is a potentially dangerous way to increase your waking hours*". That did not prevent a frenzy of new followers ready to gain years of waking time. The catchy theme of the concept is that, indeed, if you succeeded in sleeping 3 hours per day instead of the prescribed 8, starting at 20 years of age, you would gain over 11 years in an average Western lifespan. The idea is very attractive. No wonder then that as such it seemed to keep gaining momentum for quite a while.

Polyphasic sleep

More and more frequently, Uberman's Sleep Schedule was being referred to as [polyphasic sleep](#) (the term popularized by research and book by an Italian chronobiologist [Dr. Claudio Stampi](#)). [Polyphasic sleep](#) is known to sleep researchers as a variant of a sleep pattern that is set in opposition to monophasic or [biphasic sleep](#). In monophasic sleep, an individual or an animal sleeps in a single block during a single wake-sleep cycle of 24 hours. In natural biphasic sleep, there are two blocks of sleep in 24 hours: the night sleep and the typical Latin [siesta](#) (the "7th hour nap").

Polyphasic sleep is quite widespread in animal kingdom. In a recapitulation of phylogeny, [human babies also sleep polyphasically](#), and gradually lose their napping propensity until they become roughly biphasic around the age of one. Human adults, as much as all great apes, are [largely biphasic](#). Although a majority of westerners do not nap on a regular basis their alertness shows a slump in the middle of the subjective day. This slump can consolidate in a short sleep episode in free-running conditions.

The theory behind the Uberman's Sleep Schedule is that with some effort, we can entrain our brain to sleep along the ancient polyphasic cycle and gain lots of waking time on the way, mostly by shedding the less important stages of sleep (e.g. shortening Stage 1 of NREM, which seems to be just a transition state to the more "useful" stages of [slow-wave sleep](#)). That theory is flawed as it does not take into the account the magnitude of the circadian [acrophase](#) in the [subjective night](#).

To sleep or not to sleep polyphasically

Having presented [polyphasic sleep](#) as seen by its enthusiastic advocates, let us have a look at its physiological roots and implications. With every passing month, we accumulate a tremendous body of evidence of the [vital role the sleep plays in memory](#) and creativity. In addition, most of us have a good understanding that without sleep there is little chance for an intellectual accomplishment. Even more, we find it hard to stay awake unassisted for longer than 2 days. Although, super-human achievements have been well documented, where people like [Peter Tripp](#) (1959), [Randy Gardner](#) (1965) and [Tony Wright](#) (2007) stayed (semi-)awake for 8, 11, and 11 days respectively, most of the mere mortals cannot even suffer through the first 48 hours of wakefulness and inevitably fall prey to slumber. [EEG](#) and

[actigraphy](#) measurements indicate that humans are basically [biphasic](#). There is a single powerful drive to sleep during a subjective night, and a single dip in alertness in the middle of the subjective day. EEG measurements are confirmed by many other physiological variables such as temperature measurements, [cortisol](#) levels in the blood, [melatonin](#) levels in the saliva, levels of other hormones, blood pressure, gene transcription, immune cell activity, subjective alertness, and countless other parameters. In 2007, I have finally been able to see the same effect in the [circadian changes in memory recall and consolidation in SuperMemo](#). At the root of human 24h periodicity is the activity of the suprachiasmatic nucleus (SCN) in the brain, which is driven by a [24 hour cycle of gene transcription changes running a classic feedback loop](#). Tiny mutations in the genes responsible for the [circadian](#) periodicity may lengthen or shorten the period of the circadian cycle. They can also lead to complete arrhythmicity. Many of such mutations have been studied in fruit flies and in mice. Human mutations leading to sleep phase disorders are also known (e.g. familial [ASPS](#)). However, those mutations are rare, and for a vast majority of healthy humans the length of the period is slightly longer than 24 hours. Dr Charles Czeisler has measured it to be 24.2 hours with amazingly little variation among individuals under the conditions and within the sample studied (Czeisler et al. 1999^[55]). The circadian cycle (incl. the gene transcription and the activity of the SCN) can be prodded and shifted slightly on a daily basis. The degree of the shift is determined by the phase response curve ([PRC](#)) and requires a very precise timing of the phase-shifting stimulus (Khalsa et al. 2003^[56]). In other words, with a stimulus such as light, physical activity, or social interaction, we can move the period of maximum sleepiness slightly. Although the precise measurements of the [PRC](#) speak of the possible shift of up to 3 hours in a single day with a single strong stimulus, it is hard, in practice, to shift one's [circadian](#) rhythm by more than 1 hour per day. We all get a little backward prod daily when we try to fit the 24 hour day. This daily resetting is painless for those who apply the principles of sleep hygiene. It occurs in the morning with light, activity, and/or stress. An increasing portion of the population use the alarm clock to do the job that should naturally be done by sunlight and activity. This is not a healthy solution and is usually forced by our electrically-lit lifestyle with evening TV, evening reading, evening Internet, evening partying, etc. For those out of phase, it is easier to shift the sleep schedule to later hours (e.g. by activity late in the night) than it is to shift it back (e.g. by bright light in the morning). This asymmetry comes from the fact that we can consciously control the waking hours, which can only be used for a forward shift. It is easy to will oneself to stay up late. It is far harder to will oneself to wake up early. Naturally, an alarm clock can be used to accomplish the latter, but use of alarms should be avoided in chronotherapy and in healthy sleep due to disruptive effect of alarms on the progression of sleep cycles. While it is possible to shift the sleep phase, we do not know any biological mechanisms that could be used to significantly reduce the length of a healthy sleep block without inducing a degree of [sleep deprivation](#). Shortest effective sleep can be accomplished on a [free running sleep](#) with strong morning resetting stimuli and strong evening phase delay stimuli. However, even natural stimuli can induce a degree of [sleep deprivation](#). Shifting the sleep phase has a relatively small effect on the length of the main sleep block. The change is proportional to the degree of shift and has the same sign (i.e. shift delays reduce the length of [subjective night](#) sleep). Most importantly, the change reverts to the baseline shortly after the shift. This illustrates the homeostatic nature of sleep control mechanisms that respond to phase-shifting stimuli by stabilizing the new sleep schedule at the new offset within a very short time as long as shifts are small enough and are generated by well-timed phase shifting stimuli. A more decisive intervention in the sleep patterns may result in circadian chaos. In Siberian hamsters, it can even cause arrhythmicity (Ruby et al. 1996^[57]). Those dramatic changes can have a serious health effects and may be difficult and slow to reverse.

The well-defined effects of natural stimuli that affect sleep patterns lead to an instant conclusion: the claim that humans can adapt to any sleeping pattern is false. A sudden shift in the schedule, as in shift work, may lead to a catastrophic disruption in sleep control mechanisms. 25% of North American population may work in variants of shift schedule. Many shift workers never adapt their sleep pattern to the shift pattern. At times, they work partly in conditions of harmful disconnect from their body clock, and return to restful sleep once their shift returns to their preferred timing. At worst, the constant shift of the working hours results in a loss of synchrony between various physiological variables and the [worker never gets any quality sleep](#). This propels an individual on a straight path to a volley of health problems, which include cardiac disorders, suppression of the immune system, diabetes, gastrointestinal disorders, obesity, depression, chronic fatigue, sleep disorders, etc. Shift-workers are also at a higher risk of accidents and family problems (e.g. experiencing higher divorce rate). Shift-work design should [apply the laws of chronobiology to minimize the adverse effects of shiftwork on health](#). It is often better to keep workers working by night on a constant basis than to induce a regular sleep disruption and stress on a weekly basis by a cycle of never-ending schedule shifts. It appears that [polyphasic sleep](#) encounters the precisely same problems as seen in jet lag or shift-work. Adult human body clock is not adapted to sleeping in patterns other than monophasic or [biphasic sleep](#). In other words, the only known healthy alternatives are:

1. a single 6-8 hours sleep block in the night, or
2. a night sleep of 5-7 hours combined with a [15-90 min. siesta nap](#). Those numbers differ substantially across the population and there is no single recommended dose of sleep for everyone.

If a degree of pressure is exerted on the [body clock](#), e.g. by going to sleep later than the body's optimum, the mid-day nap may serve as a compensatory buffer counteracting [sleep deprivation](#). In such conditions, the nap may last longer than the usual 15-30 minutes. [The more pressure is applied on the night sleep, the longer the siesta nap](#). Similar biphasic consolidation can also be produced experimentally in rats. It appears that with sufficient pressure the nap may become longer than the night sleep, effectively reversing the sleep pattern by 12 hours. This effect confirms an important biphasic nature of the human sleep that is not fully accounted for by the present sleep models. In rare cases, individuals may learn to sleep in two blocks of 3-4 hours. However, in a vast majority of cases, the pattern in which sleep occurs in two equal blocks within 24 hours is unstable. In other words, individuals on the proportional biphasic schedule quickly fall back to long-night sleep and short [siesta](#) sleep, or back to [monophasic sleep](#). Often, the portion of sleep that occurs during darkness takes the role of the night sleep. However, it is more likely that this role is taken by that portion of sleep that was longer before the establishment of the proportional biphasic pattern. This again indicates the underlying physiological asymmetry between two sleep blocks in a biphasic pattern. In other words, the body remembers which sleep block is the [subjective night](#) block, even if that block happens to occur during the daylight period. Through sleep deprivation, by employing the [homeostatic](#) component of sleepiness, polyphasic sleepers can [increase the number of naps during the day](#). However, the pattern of one night sleep and multiple daily naps is highly unstable, and can be maintained only with a never-ending degree of [sleep deprivation](#). Naturally, if you happen to use an alarm clock, you can easily run multiple "naps" during your [circadian](#) low-time during the [subjective night](#). This is not possible during the subjective day (except in conditions of extreme sleep deprivation). To a degree, an alarm clock can also be replaced with your internal alarm (e.g. thinking "I must get up in 20 minutes"). None of "naps" executed in similar conditions will do the job of natural sleep. They are not only largely a waste of time, but they also contribute to dismantling your sleep control mechanisms. [Dr Stampi's research on polyphasic sleep](#) has also clearly identified the forbidden zones for sleep where naps are very difficult to initiate without substantial [sleep deprivation](#). [Those zones map well on the biphasic rhythm with the subjective evening naps preceding the core night sleep particularly ineffective for rested individuals](#). All the above findings inevitably lead to a conclusion that it is not possible to maintain a [polyphasic sleep](#) schedule and retain high alertness and/or creativity! As it will be shown later, practice is no less lenient in judging the impracticability of [polyphasic sleep](#) for creative individuals.

Anecdotal evidence seems to indicate that highly creative individuals perform best in a [biphasic sleep](#) pattern. However, the only valid rule of a thumb for maximizing creativity and alertness is to sleep then and only then when you feel sleepy. When this rule is applied, individuals may fall into a number of diverse schedules. They might be quite effective in any of these exemplary mono- and biphasic patterns: typical 7+2 or 6+1, long sleeper's 9+0, short sleeper's 4+1, or even 4+0, etc. Only you can determine which schedule is optimum in your case. However, you can expect that if you are a normal healthy individual, this schedule will not be polyphasic (other than biphasic). If you attempt 3+0.5+0.5+0.5, you will either be seriously sleep deprived (i.e. you will maintain the schedule only with the help of an alarm clock), or you will revert to 3+0.5, or more likely, you will fall back onto a standard 6+1 pattern. The possibility of hooking up your naps to the ultradian rhythm without [sleep deprivation](#) is a myth.

5 years since the Uberman Big Bang

In the years 2002-2005, I noticed an exponential increase in the interest in the Uberman Sleep Schedule. I kept receiving more and more mail with questions about the impact of Uberman on health and learning. As a result, I wrote [Polyphasic Sleep: Facts and Myths](#). In the course of the five years that followed, I received some 500 pieces of mail and got in personal touch with many [polyphasic sleep](#) adepts. Of those attempts that I was given a chance to monitor, all were unsuccessful. Some of the critics of the original article claimed that they do sleep polyphasically, but I received no data that could serve as the basis for verification. The most interesting conclusion coming from the mass of mail received is that people drift towards [polyphasic sleep](#) less as a result of their hunger for achievement, and more for their prior problems with sleep. They often think of [polyphasic sleep](#) as a panacea for all their sleep problems. This perception is magnified by multiple blog claims. I received a couple of [SleepChart](#) data submissions demonstrating how difficult the struggle with the [polyphasic sleep](#) is. Admittedly, I was quite impressed with the degree of determination some of those experimenters showed. As the newest version of [SleepChart](#) makes it possible to model the changes in sleep propensity, it provides some insights into the phase-shifting chaos that occurs in [polyphasic sleep](#). With every passing day, we know more about [polyphasic sleep](#) and its potential impact on health. The news is not good for the proponents of the [polyphasic sleep](#) as a lifestyle.

The mail that I have received in reference to my [polyphasic sleep](#) article was mostly critical, but it should not be used as a measure of success. It is not important what proportion of readers would agree with me. It is important how many gave up the idea of sleeping polyphasically as a result. Within the five hundred pieces of mail, I roughly estimate the distribution of their nature as follows: 50% - criticism, 40% - requests for help in implementing polyphasic sleep, and 10% - word of gratitude for the warning against adopting [polyphasic sleep](#). 10% may seem like a very low conversion rate. However, this translates to hundreds of hours of someone's time. I am sure it also translates to

tangible health benefit. For example, a great deal of polyphasic attempts end up with a cold or influenza, which must reflect the impact of this sleep schedule on the immune system. What Aaron wrote is pretty representative of the 10% group: *"The idea of sleeping in naps spread throughout the day intrigued me as I have always suffered from what I was unable to properly quantify, but now know is [DSPS](#). If I do not use an alarm clock, and go to sleep when I become tired, I see my sleep/wake times shift to significantly later times every day (hours later). This has been a constant source of frustration for me, and I considered a polyphasic schedule in order to help correct the problem. However, after reading ["Polyphasic Sleep: Facts and Myths"](#), I have decided this would be a sincere waste of my time"*. Criticism of my article would usually skirt around the science argument and quote from blogs of people who claim they have succeeded with [polyphasic sleep](#). For example Kop wrote: *"There are MANY people who successfully adapted. [...] You simply neglected to cite them, and you cited only people who failed. I think this is very unfair and misleading to your readers. I may sound like a broken record, but even if you believe that everyone who claims to have been successful is lying you should let your readers make this choice and you should definitely not just completely leave out all the information you personally don't agree with"*.

Compression of sleep stages in sleep deprivation

One of the myths of *"Uberman sleep schedule"* is that it makes it possible to enter [REM](#) sleep and skip non-REM sleep stages entirely. That myth is derived from another false claim that implies a non-essential role of deep sleep. I will ignore these claims as standing in total disagreement with laboratory findings. Instead, let us focus on a more plausible claim of the possibility of compressing sleep stages in [polyphasic sleep](#). It is true that people who are sleep deprived are able to enter deep sleep much faster than normal sleepers. After a period of sleep deprivation, less important stages of sleep are compressed, while the core [SWS](#) predominates. Also [REM](#) deprivation will result in [REM](#) upregulation at recovery time. Initially, the sleep system will work on catching up with the outstanding SWS, and only later with the outstanding [REM](#) sleep (often only on a second recovery night). It appears then that indeed, we are more effective at sleeping after we had been sleep deprived. Moreover, it is possible that the [homeostatic](#) control of sleep is not very efficient at detecting the true neural sleep needs. If you look at our mammal relatives, you may be surprised that a giraffe can do well on 2 hours of sleep, while a bat may need 20. Smart and fast-learning elephants need 4 times less sleep than less brainy felines. Behavioral observations will then quickly lead us to the conclusion that the amount of sleep is not directly correlated with the amount and complexity of memory acquisition and [neural computation](#). We may then hypothesize that the sleep control may employ auxiliary physiological parameters that are only loosely related to the requirements of neural optimization. It is also possible, that evolution took account of the fact that the nighttime is not a very useful time for activity in early hominids. Sleep control mechanisms might then have attracted a number of additional physiological functions that might improve survival even if sleep lasted longer than what is needed for memory consolidation and optimization. [Hence the possibility of all sleep mechanisms proceeding at leisurely rate with lots of added function that would not require loss of conscious awareness in the first place](#). If the above thinking is correct, we might indeed be able to execute the same neural job in a shorter time given the favorable circumstances. However, little is known of the true nature of the link between neural optimization and [homeostatic](#) sleep control. Our present knowledge still seems to firmly indicate that we can maximize our creativity to sleep cost ratio only with [free running sleep](#). In other words, there is no evidence that by playing with sleep deprivation, you can increase your creativity. The only possible exception might be a tiny degree of deprivation resulting from delaying sleep by 30-60 minutes. Longer delays affect alertness beyond what might be considered a "gain". It is simply possible that between the extremes of free running sleep and a slightly delayed sleep phase, the trade-off between (1) time gain due to sleep compression and (2) an accelerated [homeostatic](#) sleepiness might produce an optimum somewhere in between. Naturally, this tiny prod to a sleep cycle has nothing to do with the employment of alarm clocks, shattered schedule and never-ending battle with grogginess typical to those who experiment with Uberman sleep. Moreover, even that little hypothetical intervention in the sleep cycle will inevitably result in phase shifts that may have numerous negative side effects, including, most obviously, the inability to function effectively in a society that is largely synchronized with daylight. [Well-entrained and balanced free running sleep is still your best bet for maximum cognitive performance](#).

In [sleep deprivation](#) induced by polyphasic schedules, [REM](#) sleep will occur faster due to sleep stage compression. Yet it is the slow-wave sleep that is the primary target of [homeostatic](#) upregulation strongly determined by the duration of prior waking. As [REM](#) sleep is far more associated with the circadian phase, its proportion in sleep will actually drop, esp. in naps initiated in the subjective evening period. You may want to study [sleep models by Alexander A. Borbely and Peter Achermann](#) which nicely explain the mechanics of these processes. Laboratory findings seem to indicate that the drop in [REM](#) gradually recovers towards the baseline over successive days of sleep deprivation, but the reversal is never complete. In other words, you will get less [REM](#) sleep on a polyphasic schedule as compared with a free running schedule. This [REM](#) sleep diet is as much absolute (as measured in minutes) as it is relative (when compared with deep sleep NREM). The problem of [REM](#) deprivation becomes more pronounced if you use an alarm clock when waking up from naps. By using the alarm clock, you statistically hit [REM](#) sleep more often as its proportion

nearly always increases over sleep time. This is why polyphasic sleepers often remember their dreams on awakening. **That's not a sign you get more REM. It's a sign you are destroying REM sleep.** By using very short blocks of sleep, you affect REM even further by a strong **homeostatic** upregulation of Stage 4 **NREM** that displaces whatever REM you can get.

Getting more REM in polyphasic sleep is a myth. You will get less REM and your creative powers will dip.

If you (1) do not fight sleepiness and (2) wake up from your naps naturally, the problem of sleep disruption does not occur. However, it is impossible to regularly fit a pre-planned polyphasic schedule without some help from an alarm clock. This comes from the fact that the only stable sleep patterns in healthy individuals are mono- or biphasic. **Polyphasic sleep** patterns may be stable and sustainable in various cases of **hypersomnia**, **narcolepsy**, and other sleep disorders. When the sleep control system is disrupted and the **homeostatic** sleep component works in overdrive, frequent napping may occur and be recommended (e.g. in infection, chemotherapy, etc.). Needless to say, the total sleep increases in such circumstances. This is exactly what polyphasic adepts are trying to avoid. A degree of sleep fragmentation may also occur as a result of stress, social life, excitement, going to sleep too early, etc. Those disturbances may occasionally allow for days with more than one nap occurring naturally. If you give up the alarm clock, you take away the major culprit that makes **polyphasic sleep** unhealthy. However, without an alarm clock, it is your body that will decide the sleep schedule, not your pre-planned "rationalized" schedule graph. That schedule will not resemble anything Uberman.

If your goal is to get many naps with lots of REM, you might want to know that more than two naps with solid REM sleep are diagnostic for **narcolepsy**.

Sleep and creativity: Less is more

Polyphasic sleep is bad for your health and bad for your creative capacity. However, even if you want to maximize time spent in the waking state it might not be your best option assuming you need a reasonable degree of alertness for whatever you do in your waking time! Only when approaching substantial **sleep deprivation** can polyphasic schedule be superior to biphasic schedule in that respect (see: **PureDoxyk Law**).

Some people like firefighters or emergency surgeons may sacrifice their sleep for the sake of others. The number of people that need to make a sacrifice can be reduced by a **well-designed shiftwork**. Most of the remaining population should optimize their sleep for best health and best creative performance during the waking time. **Polyphasic sleep** is definitely not the answer to such optimization goals.

These are not the times of the pyramid of Giza when the genius of a designer had to pair up with 50,000 drudges reduced to mere back-breaking labor. As we move towards the **knowledge economy**, it is the alert and creative minds that provide the basis of success in most projects. **One minute of insight may be worth a century of shoveling!** It might have been a single creative eureka that produced $E=mc^2$. Probably even Einstein himself would not be able to track back the exact moment when his brain produced that formula. Nor would he be able to formulate a sure prescription for others for similar accomplishments. Human creativity is primarily a game of chance. Yet it breeds only on fertile grounds. Top-notch mind in a top-notch shape in conjunction with top-notch sleep is the best formula for more of such insights in the future. **Polyphasic sleep** is the antithesis of that formula! If you scan the blogs of polyphasic experimenters you will see them choose an "engaging activity" again and again just to stay awake. Why would they prefer to meet people or go for a jogging over, for example, getting down to a mentally challenging project?

Tony Wright in his attempt at Guinness Record of **sleep deprivation** (11 days without sleep) realized that he could do anything but writing. After 10 days without sleep, his brain was not up to the challenge of writing even a couple of words. He concluded: *As it turns out writing while sleep deprived is easily the most difficult thing to do, for that reason I have decided I won't write anymore, so this will be my last entry.*

Why would learning a difficult subject be such a mental drag in sleep deprived state? As sports or social interactions stimulate the aminergic arousal centers in the brain, these are effective counterweights to the **homeostatic** drive to sleep. The brain uses its last resources to mobilize the lesser used portions of the cortex to compensate for overloads in the hippocampus and other central memory areas. Creatively, you may be brain dead, but you will still be able to meet people or go for a jogging.

Learning is a powerful contributor to the homeostatic sleepiness. Soporific power of learning is one of the most visible connections between sleep and memory. If you have problems with falling asleep, nothing serves as a better natural hypnotic than learning! Not just passive reading. Active learning! The best **homeostatic** sleeping pill I know is

[incremental reading](#). Naturally, you need a [circadian](#) component of sleepiness for the "pill" to work. Otherwise, learning (or incremental reading) is, paradoxically, your best "creativity pill".

The circadian phase determines the positive neural feedback of learning that generates the creative enthusiasm (after sleep), or the negative neural feedback of drowsiness (before sleep).

There may be more at stake though than just alertness, creativity, and long-term health. It is conceivable that the sleep control centers in the brain become affected by polyphasic experiments. Researchers have noted cases where shift-work or other forced schedule patterns were able to put the body clock out of kilter. Some have speculated that Peter Tripp suffered long-term consequences of his [awakeathon](#). Polyphasic schedule is less drastic in terms of sleep deprivation, but more drastic in [circadian](#) disruption. Dr Stampi has put one Francesco Jost through a diet of 3 hours of sleep for 2 months without measurable adverse effects. Yet, looking at other neuropathophysiological processes, we might worry that it might be possible to actually kill cells in the nuclei responsible for the [SWS switch](#), [REM-on switch](#), [REM-off switch](#), etc. We know that disregarding mental hygiene, depression, excessive cell activity, [glutamate](#), [cortisol](#), [hypoxia](#), and other neural stresses can lead to cell loss. We know that it is possible to uncouple the [circadian](#) cycle in Siberian hamsters with light stimuli (Ruby et al. 1996^[57]). As long as this area remains gray, playing with one's sleep schedule is tantamount to dicing with one's long-term ability to effectively control sleep-wake cycles. This might be not much different from dieting, once you put your appetite control centers out of service, you are sentenced to a lifelong struggle with diets and yo-yoing weight. Recent research shows how junk diet causes [glial damage](#) to brain centers that control the appetite (Szwartz et al. 2012^[58]). I bet that chances are very high that junk sleep will cause loss of effective sleep-wake control. The mechanism is the same: when you put a brain center in overdrive, you risk injury. We can see the same mechanics in a dozen of physiological contexts. Some polyphasic adepts reported sleeping differently after their experiment ended. Some of those reports could hint at the flattening of the [circadian](#) cycle, which is a characteristic of sleep control in the elderly. In conclusion:

By defying the natural progression of sleep-wake cycle, you risk a permanent damage to your ability to produce healthy, regular, entrained, and refreshing sleep.

Why less is more? Because by giving your brain as much sleep as it wants, you can be far more creative and productive in your waking time. Not just far more. In a polyphasic sleeper, the creativity may dip by an order of magnitude. It's like with top performance sports. Wrong timing of meals could deprive Usain Bolt of his Olympic Gold. Do not let yourself be marginalized in the race for intellectual excellence!

Polyphasic sleep in babies

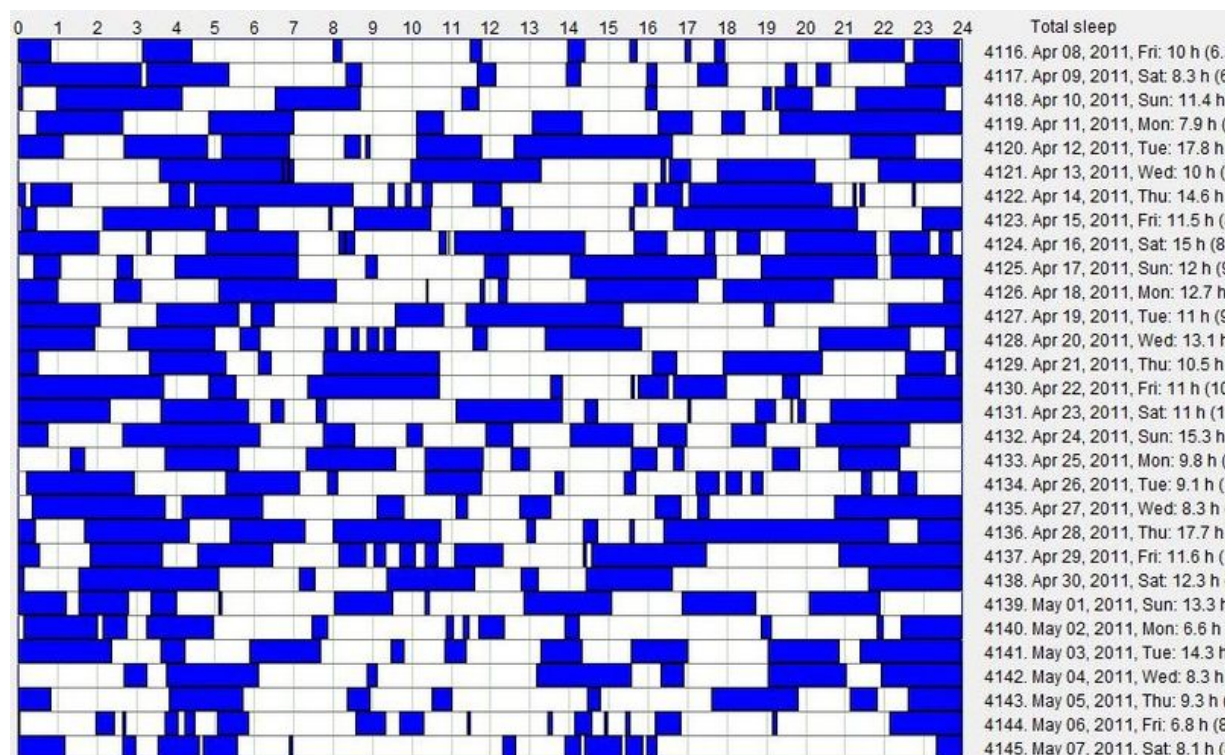
Newborns sleep polyphasically. [Clock genes](#) start cycling already early in development in utero. First [circadian](#) rhythms also start showing in utero and are entrained to mother's circadian cycle (e.g. kicking, breathing, heart rate, etc.). However, the [circadian](#) sleep-wake cycle develops only after birth. The [SCN](#) keeps growing at a very fast rate after birth. For example, it contains only 13% of the adult numbers of [vasopressin](#) expressing neurons (Swaab D.F. et al. 1990^[59]). A hypothesis says that it is the connection between the visual system and the SCN that develops only after birth (Swaab et al. 1994^[60]). Research conducted in premature baby wards shows that moderate dark-light cycle accelerates the development of the [circadian](#) rhythms, while constant light has an opposite effect, incl. slowing the overall child growth and development (Mirmiran et al. 2000^[61]). There was even a report of a full term baby that did not develop a [circadian](#) cycle in the period of study, possibly due to the fact that it was the only infant fed in full light during the night (McMillen et al. 1991). Immaturity of the SCN and its afferents in newborns results in their inability to entrain their cycles to daylight in the first month of postnatal life. In the meantime, some preference to sleeping in the night might be related to cycles entrained in utero and/or postnatal [entrainment](#) to breastfeeding and mother's cycles, incl. co-sleeping.

Some proponents of [polyphasic sleep](#) claim that baby sleep is the most natural way of sleeping and that babies lose it early in life due to their *social training*. The opposite is true. Newborns show no discernible [circadian](#) preference in their sleep patterns. Those patterns develop quickly over the first 1-3 months of life, and have little to do with training. The development of the typical biphasic [circadian](#) rhythm is a biological process that is programmed in the genes and is largely inevitable in normal lighting and normal social setting.

Babies sleep polyphasically. Their [circadian](#) sleep cycle develops naturally in the first 1-3 months of life, and has nothing to do with "social training". Natural light, breastfeeding, and [co-sleeping](#) assist the development of a healthy [circadian](#) cycle.

In addition to propagating the "social training" myth, proponents of the [polyphasic sleep](#) overlook the fact that babies

sleep for far many more hours than the alleged polyphasic sleepers (say, 10-16 hours instead of the desired 3). A healthy individual cannot possibly keep sleeping polyphasically, nor sleep for 16 hours, unless in a state of serious **sleep deprivation**. Babies do not use alarm clocks to control their sleep timing (except their hunger alarm). See an exemplary graph of a newborn **polyphasic sleep** in the first month of life to notice that sleep episodes come irregularly as a result of a confluence of various **homeostatic** factors:

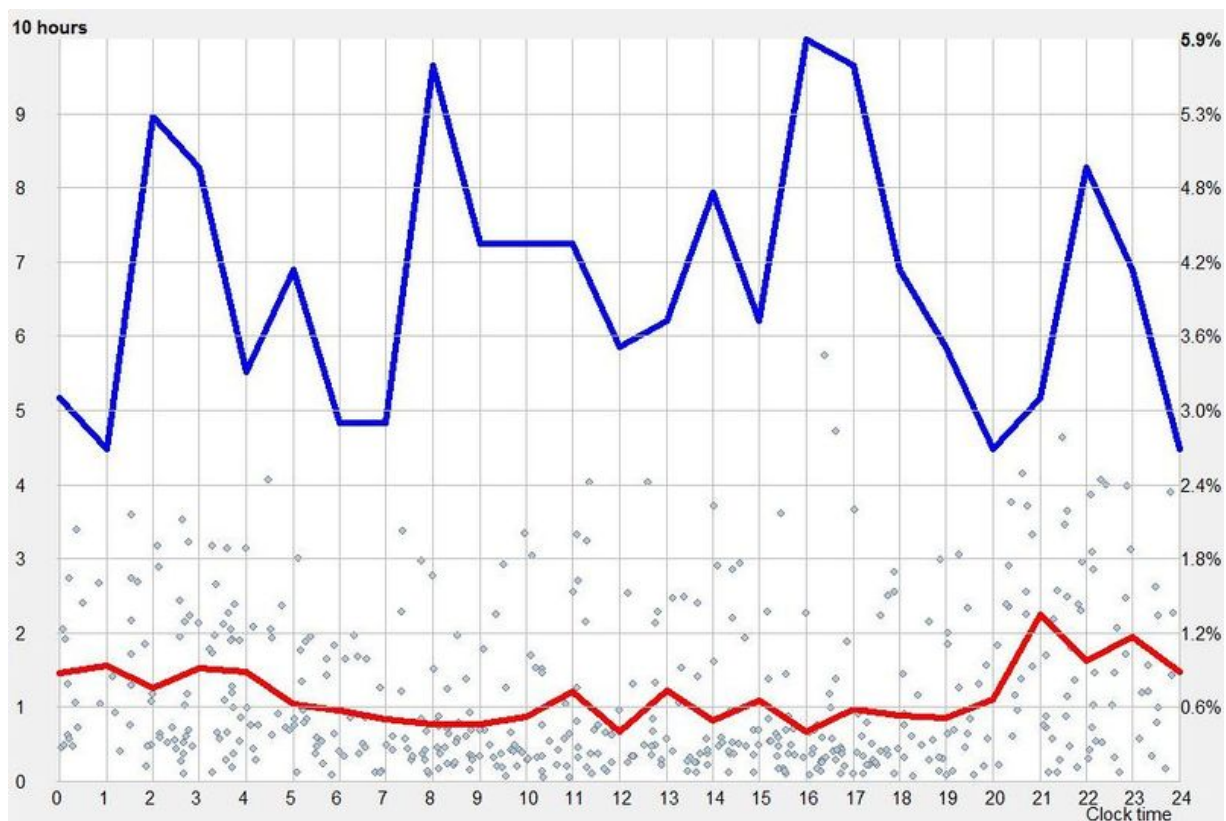
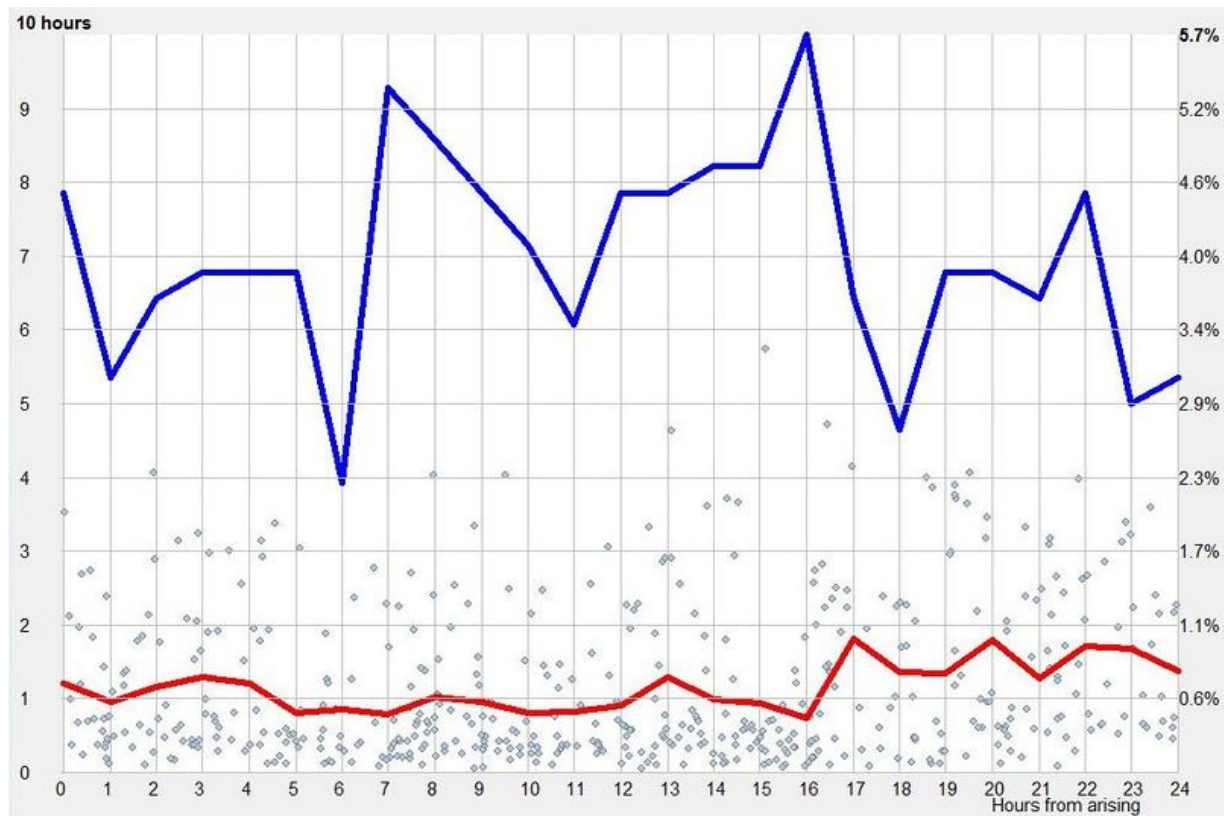


In healthy babies, the two primary homeostats that control sleep onset are sleep and feeding. Needless to say, there is no sign of the regular Uberman pattern. If there are ultradian cycles, they are poorly expressed and difficult to filter out. On the other hand, it is possible to see a set of slowly emerging **circadian** preferences, esp. with sleep episode consolidation. In the presented example, the density of sleep episodes is higher in the 22 pm - 5 am bracket (see more in the next section).

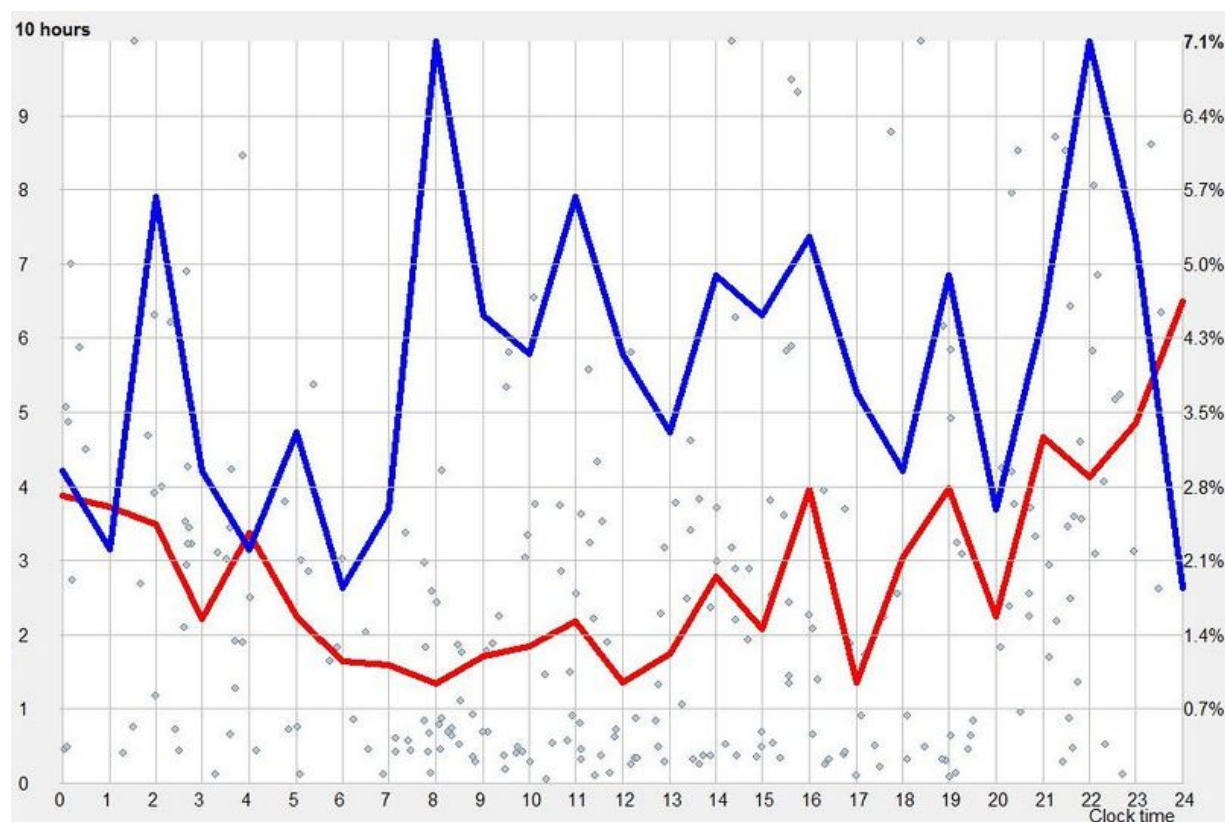
Last but not least, **polyphasic sleep** advocates, despite a widely circulated polyphasic myth, lose **REM** sleep in the first order. Babies, on the other hand, may spend as much as 65% of their sleep in REM, without which their cerebral cortex would not even develop correctly (as evidenced in sleep deprived kittens (Stryker et al. 2001^[10])).

Ultradian oscillations in babies

Circadian graphs in **SleepChart** can be used to seek ultradian rhythmicity in the polyphasic phase of sleep in infants. The presented graphs, corresponding with the first 7 weeks of life, show no clear ultradian oscillation, even though peaks in intervals that are multiples of 3 hours constitute 75% of all peak intervals:



The red circadian line is rather flat, but, as it can be seen in the third graph, some preference for evening and night sleep can be demonstrated with consecutive adjacent sleep episode consolidation:



Do Piraha people sleep polyphasically?

While scientists do not know any natural biological mechanisms that could be practically used to reduce the length of sleep episodes without a detriment to health, Daniel Everett's field report on Piraha people claims that members of the tribe rarely sleep more than 2 hours per day. We know of unhealthy ways of reducing the length of sleep. We can hormonally reduce the length of sleep (e.g. by stress). We can use an alarm clock. That includes the natural brain clock based on the release of [ACTH](#). We can sleep in a wrong phase. We can reduce the [homeostatic](#) sleep drive (e.g. with coffee, drugs, exercise, etc.). All unnatural ways of shortening sleep time will induce sleep deprivation, which is a function of the degree of the interference with sleep. The net is buzzing with anecdotes about the merits of the polyphasic sleep, but no established scientific fact can be used to assert that sleep length can be reduced. The example of Piraha people should certainly be of interest for sleep science. However, the inaccessibility of the tribe leaves little room for research beyond a speculation on a report by a missionary. A report could be a simple exaggeration. Piraha people could also be an example of the dominance of culture over physiology (as it is the case with the "polyphasic sleep" crowd). We know of many mutations that affect [circadian](#) cycles, and it is conceivable to see a strong prevalence of a specific gene in an isolated population. However, this would make Piraha sleep depart far away from the standards well established in our primate group. In short, if the report was correct, the sleep habits of a westerner would have to be more distant from a Piraha tribe member than from an orangutan.

Polyphasic sleep: scientific challenge

I keep garnering criticism for my pop science writing on [polyphasic sleep](#). However, little of that criticism addresses the basic premise that makes it easy to predict that [polyphasic sleep](#) cannot be used as a plausible lifestyle choice. I am therefore at a point where I need to ignore the criticism unless it addresses that basic scientific premise:

Human sleep patterns reflect the underlying [circadian](#) oscillation whose period is roughly equal to 24 hours. Human circadian cycle calls for a major sleep episode every 24 hours. The body clock can be entrained with phase shifts of up to 3 hours. However, the [circadian](#) period of maximum sleep propensity cannot be partitioned. The timing of the sleep propensity [acrophase](#) cannot be positioned in any other way than by a [phase shift](#). Periodicity cannot be eliminated without a detriment to health. Circadian cycle underlies the structure of sleep that is essential for its neural function. Therefore, in individuals with a healthy sleep control system, no sleep schedule can go around the main period of the prolonged night sleep.

In practise, the above premise means that only mono- and bi-phasic sleep patterns are healthy and recommended. I consider segmented sleep a variant of ancient [monophasic sleep](#) induced by periods of prolonged darkness. All forms

of nocturnal waking are a norm and should be considered part of the nighttime sleep episode. The choice between mono- or bi-phasic sleep will depend on the **circadian** wave function, which has two minima in a 24 hour period, only one of which has been proven essential for health and well-being (until now).

Are early risers better at polyphasic adaptation?

Early risers will suffer in **polyphasic sleep** as much as owls. The **chronotype** does not matter. People suffering from irregular sleep-wake rhythm characterized by a loss of the **circadian** cycle do nap at irregular intervals but they neither feel energized nor sleep less than healthy individuals. Neither early risers nor owls nor short sleepers can adapt to a regular polyphasic schedule. **Polyphasic sleep** can save lives in conditions where vigilance is in demand, but it will also shorten lives of those who are forced to practise it.

Why so little research into polyphasic sleep?

From anecdotal evidence I can conclude that **polyphasic sleep** is not sustainable enough to do much damage. However, it also helps perpetuate lots of catchy myths that may affect how young people approach sleep and health in general. **Polyphasic sleep** is not a neat study subject. Scientists like simplicity. They construct simple research models to make it easier to arrive at valid conclusions. I, for one, love **free running sleep** concept as a research model. It speaks of unadulterated natural healthy sleep. I wish more researchers paid more attention to the free running condition as all forms of laboratory designer schedules introduce a degree of chaos into data that very often makes it hard to interpret it or leads to a false interpretation! **Polyphasic sleep** was suggested for unnatural survival situations, and its Uberman variant is a widely mutated invention of teenagers who hope to save time on sleep or solve their sleep problems. Choosing a **polyphasic sleep** as a model would be like choosing a multiplanet system to test Newton/Keppler's laws, while a two-planet system would do as well and produce results eons earlier. Instead of a complex Fourier analysis, we have simple and clear formulas that tell the entire story.

Medical supervision of polyphasic sleep

Some polyphasic adepts keep wondering if it wouldn't make sense to make regular checkups at their doctors to avoid potential health hazards of a **polyphasic sleep** schedule. The problem is that a family doctor's ability to detect trouble on polyphasic regimen is not much different from his ability to see trouble in a novice smoker. The damage is not done instantly and it is not obvious, even though I am pretty sure that **polyphasic sleep** will do its ravages faster than smoking. Cognitive tests would be first to show the change. Probably followed closely by the immune function and the glucose metabolism. However, a big part of the damage is the opportunity cost of **polyphasic sleep**. It is not only what it does to health, but also what one could have accomplished as a result of the intact mental capacity.

A GP cannot easily detect long-term effects of possible damage at the neural level, e.g. within the scope of the sleep control system. Nor can he or she see the impact of changes in the neural function on his or her patients' long-term growth and intellectual accomplishment. Things you do not learn today may change the entire course of your life. No one can estimate that cost. Even a substantial neural damage in Alzheimer's disease is not easily diagnosed at first, and it does not become obvious until the affected person enters the advanced stages of the disease when significant portions of the brain are gone! Human brain is great at compensating, and spotting damage is not easy.

Visiting your GP for a checkup is always a good idea. However, it is pretty useless as a way of preventing damage done by sleeping polyphasically. Polyphasic sleepers often report symptoms typical of sleep deprivation: thermoregulation problems, changes in appetite, immune deficiency, etc. It is hard to drive those to become serious threats in a short run. After all, even a few hours of "core sleep" quickly remedy most of these.

Someone suggested to me that "*sleep deprivation is bad because it is a source of stress. But how bad it can be depends on how well one can handle stress*". It is true that the susceptibility to stress in **sleep deprivation** is increased, but it is not true that stress management can be a solution to **sleep deprivation**. It is true that a good diet might improve the health of a smoker, but diet alone does not solve the problem of smoking. The only ultimate solution to smoking is no smoking. Similarly, **the ultimate solution to sleep deprivation is sleep**.

My own polyphasic sleep trial

Very often I am being asked how I can claim any authority on **polyphasic sleep** without ever trying it for myself. For starters, I do not claim to be a **polyphasic sleep** expert. As a humble biologist, I simply need to **recall** the ABC of chronobiology to figure out that **polyphasic sleep** is not feasible. You do not need to be a junkie to study drug addiction, even though a glass of vodka might be a recommended one-time treatment to an abstinent investigator of alcoholism. I understand the pain of the alarm clock because I used it sparingly during my university years. I understand the pain

of jet lag and [sleep deprivation](#) from my early turbulent years of involvement in the [SuperMemo](#) business. However, I need a fresh brain for my work. Even one day of a hazy mind is a loss. I cannot possibly hope to struggle through a polyphasic routine in hope of proving that the elusive and ever remote "adaptation" is just an urban myth. If I was to take on my own sleep experiment, it would rather be a segmented sleep attempt (Wehr 1992^[26]). I can imagine it could do wonders to learning and creativity. However, few people in this world can afford a 10 hour waking day. It seems that only paid volunteers are ready to taste the blessings of [excessive sleeping](#). Before a superficial reader concludes from Wehr's work that *polyphasic sleep is possible*, let me stress that his segmented sleep experiment spoke of chunks of very long sleep, not Uberman-like mini-naps.

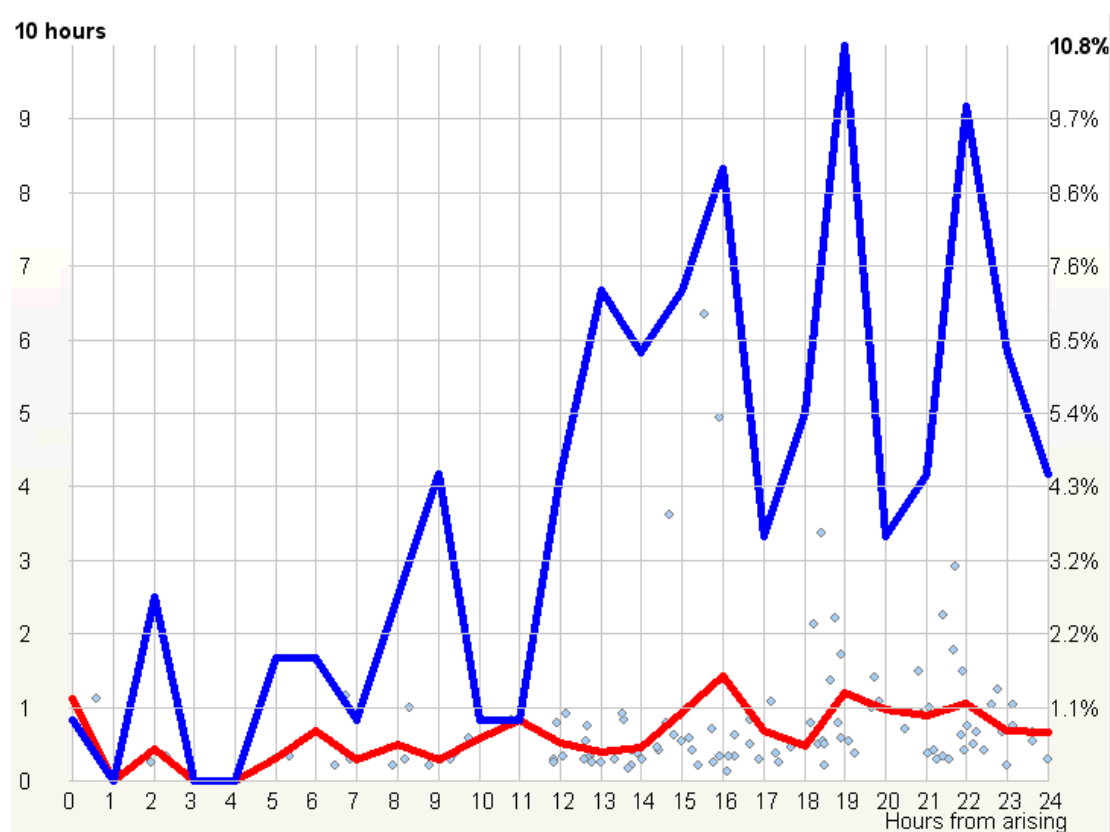
Charting polyphasic sleep

Source of data

After publishing "Polyphasic sleep: Facts and Myths" (Wozniak 2005^[62]), a few dozen of young men wrote to me requesting assistance in entraining to [polyphasic sleep](#) schedule. Ethically, I could only proceed from an attempt to dissuade the young enthusiasts from proceeding with their experiment. Needless to say, these are not the types that are easily persuaded to veer off their course. As I wrote in [Facts and Myths](#), these are "rebellious men ready to seek new ways for maximum productivity". No scientific argument can be persuasive enough in such circumstances. After all, all reasoning can easily be quashed with "science does not yet have all the answers". None of the young rebels succeeded in entraining polyphasic sleep, yet some were persistent enough to provide valuable [SleepChart](#) data that helped shed some light on the implausibility of the long-term use of the [polyphasic sleep](#) schedule.

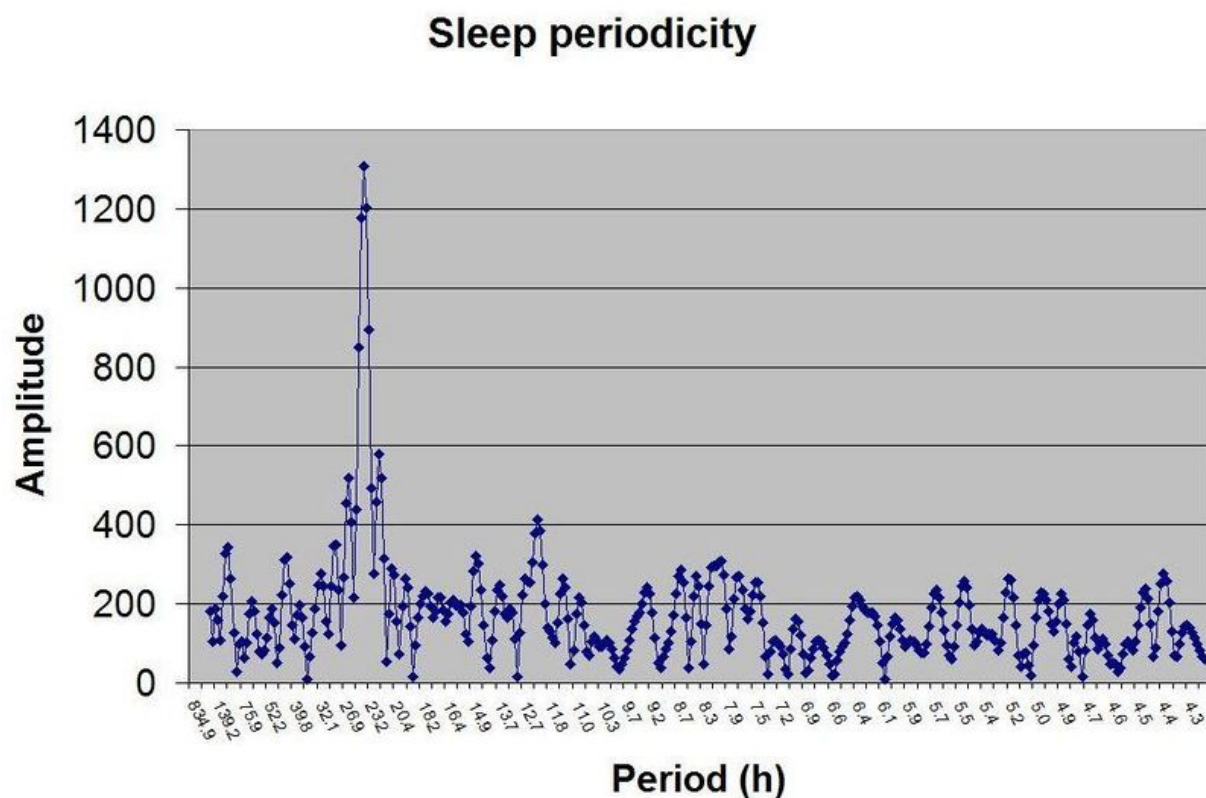
Stampi yachting research

In [data obtained by Stampi](#), we see the timing of semi-polyphasic sleep of a solo sailor in an actual yachting race. In this case, the [Circadian graph](#) reveals the forbidden sleep zone in the first part of the day, and a clear [circadian](#) preference for initiating sleep in the hours 15-24 of the waking day (blue line):



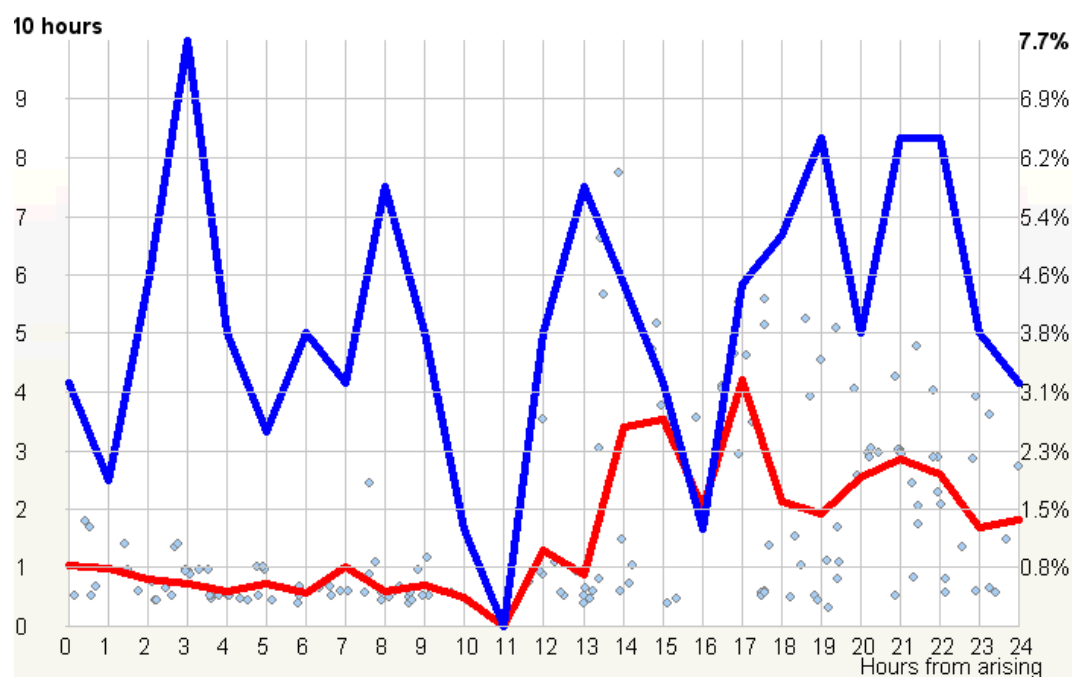
The red circadian curve is meaningless here due to the fact that sleep is artificially interrupted. In addition, artificial control of sleep is the reason why there is a role reversal between the sleep maintenance curve and the sleep initiation curve. In this case, it is the sleep initiation curve that best expresses the [circadian](#) sleep propensity.

A periodogram generated for this seemingly noisy sleep shows a typical biphasic pattern with peaks at 23.9 hours and 12.1 hours. 23.9 hour day and the associated phase advance are most likely caused by the impact of change in time zones when sailing eastward:



Polyphasic sleep attempt

In an attempt to entrain to a **polyphasic sleep** schedule, a male adept started his experiment with a schedule of 4 naps of 30 min., and a "core sleep" of 3 hours at 20:00 with an intent to reduce it to 30 min. in "due course". The **entrainment** ("adaptation") appeared elusive as the adept kept failing to fall asleep during some naps, while continuing to struggle with alertness in some of the allocated waking periods. The [circadian graph](#) shows the ultradian sleep initiation with a circadian preference for sleep in the period of the **subjective night** in hours 14-22 from the estimated beginning of the subjective day:

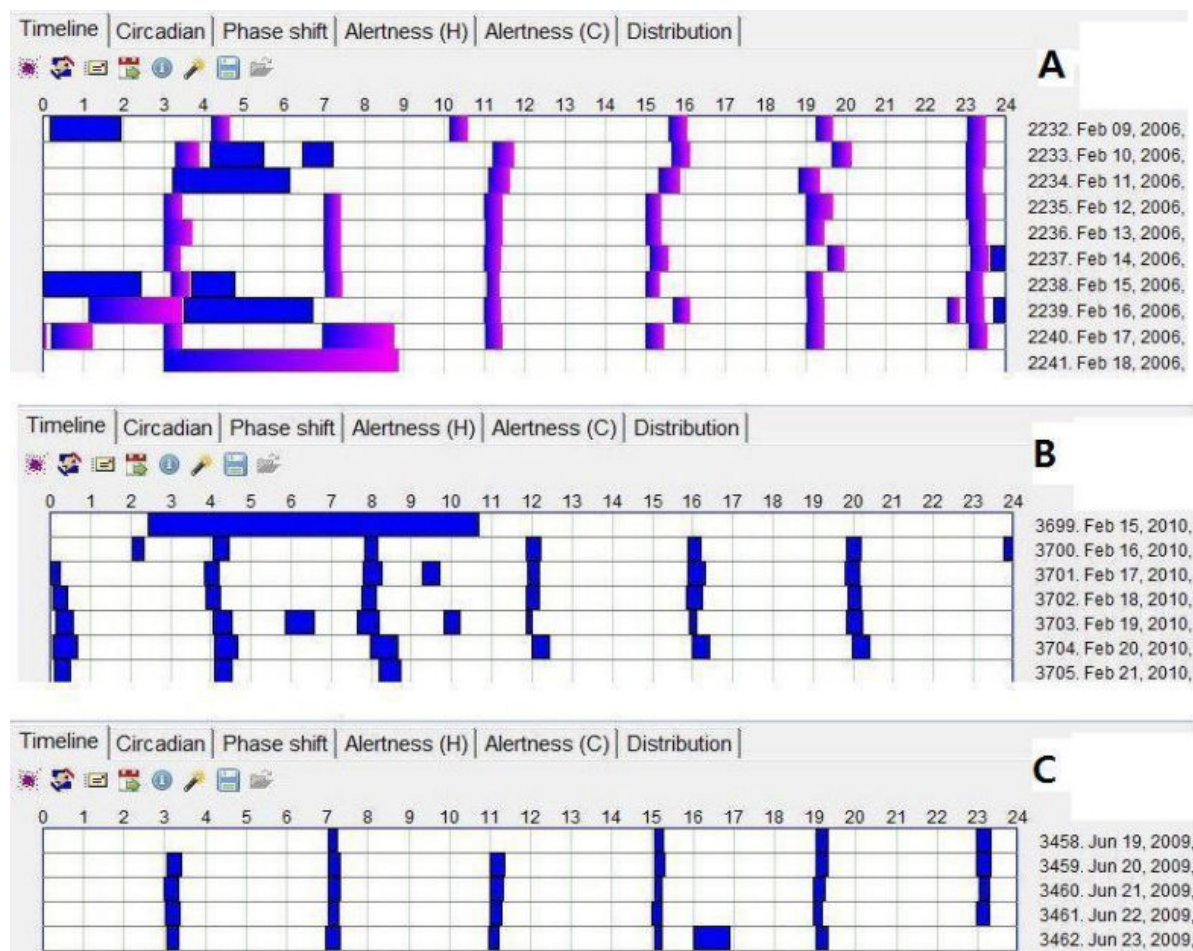


The core sleep could not be shortened as planned without a progression into more and more severe **sleep deprivation**. Instead, the core sleep increased in length slightly and moved to a later hour. Gradually, daytime naps started disappearing until the adept moved to a typical **biphasic sleep** of 5-6 h in the evening, with a 30-60 min. nap in the morning (and an occasional extra nap during the day if the core sleep resulted in heavy sleep deprivation). One year later the adept was nearly monophasic with only one rule leftover: "*try to go to sleep before midnight*". The effort is

documented in this [blog](#).

Uberman sleep logs

The picture shows [SleepChart](#) logs of the three most disciplined Uberman sleep adaptation attempts that I managed to collect from prospective polyphasic sleepers. The graph illustrates the efforts of Greg (A), Bryan (B) and Claudiu (C):



At 9 days, Greg's attempt was quashed by the clustering of "core" sleep in the early morning hours towards the end of the experiment (**log A**). This clustering was certainly caused by the mounting [sleep deprivation](#) adding to the peak of circadian sleep propensity in the periods of the [subjective night](#).

At 22 days total, and 13 days without "core sleep", Bryan's attempt was the longest (**log B**) (full log is included in the [next section](#)). This attempt started showing signs of "strain" already on the first day with four extra naps in the first four days. Some oversleeping started showing consolidation in the period of the [subjective night](#) on Day 7. Finally, at midday, on Day 14, the subject fell into a long restorative 11-hour sleep bout. The attempt continued for some 8 more days with numerous extra naps, oversleeping, periods of grogginess alternating with elation. In the end, Bryan's detailed notes allowed of an interesting conclusion: **the circadian cycle of sleep propensity was most likely running free in the background during the entire experiment showing a nearly perfect 25 hour cycle period**. For a detailed analysis and explanation see: [Free running circadian cycle in polyphasic sleep](#).

At nearly 5 full days, Claudiu's attempt was the longest "pure Uberman" before experiencing his first lapse into an extra nap (**log C**). It is equally notable for its never having missed a single nap beyond Day 1. It is important to note, however, that many nappers find it difficult to determine if they actually fell asleep during naps that come in forbidden zones. What they mark as a nap might have actually been a few short moments of microsleep.

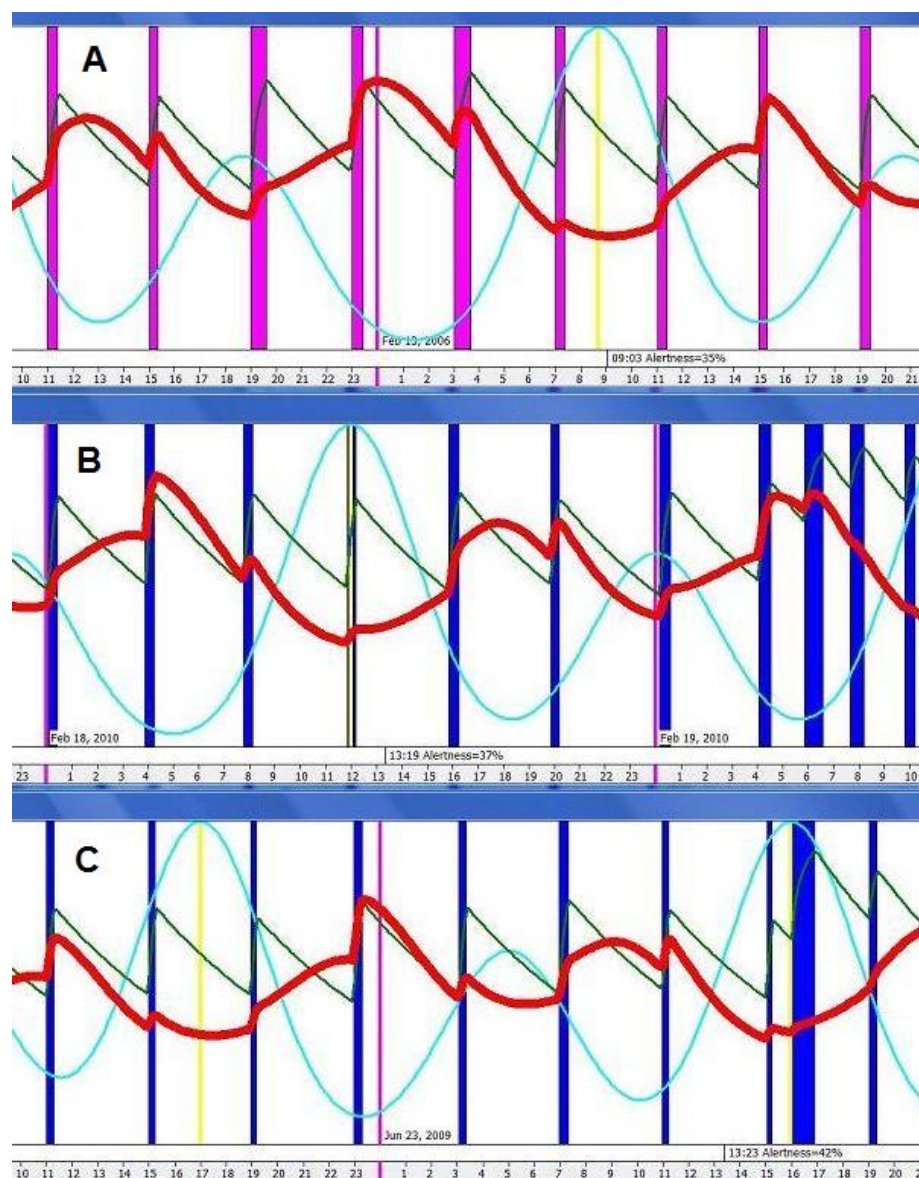
Most bloggers who claim success with [polyphasic sleep](#) seem to have trimmed their standards of satisfactory alertness and creativity. When statements such as "my successful experiment" and "groggy" come together, you can be certain that "the experiment" does not effectively maximize their alertness and productivity. [Sleep inertia](#) should be foreign to a healthy sleeper.

There could be many interpretations of "successful" Uberman sleep claims that are pretty numerous in the blogosphere. None of these "successes", however, is likely to be explained by the disappearance of the natural

circadian rhythmicity that makes **polyphasic sleep** so hard to bear. If the adept was indeed to become arrhythmic, this would spell a serious health and longevity risk. At best, this could imply a dysregulation and decoupling of sleep control centers (see: [Sleep-wake flip-flop](#)). At worst, this might involve a **glial injury** to the brain centers responsible for sleep control. Needless to say, such dysregulation or injury changes would be difficult to reverse and would result in serious problems with achieving refreshing sleep. That would be the antithesis of the goals of Uberman hopefuls.

Two-process sleep model vs. polyphasic sleep

Polyphasic sleep data collected from Greg (A), Bryan (B) and Claudiu (C) (see [earlier](#)) was processed with **SuperMemo** in an attempt to see how the timing of naps in an unpredictable circadian phase affects the sleep propensity:



SuperMemo implements a variant of the two-process model [Borbely model](#) that makes it possible to predict alertness and/or sleep propensity on the basis of the history of sleep and wakefulness. Users of **SuperMemo 15** (or later) can inspect their own sleep propensity prediction data using *Shift+click* in the sleep log at any selected point in the timeline.

In the presented picture, the thick red line represents estimated alertness, and an inverse of sleep propensity. The **circadian** sleep propensity is marked in aqua blue. It is easy to see that the shape of the alertness curve depends on the circadian phase at which a nap occurs. The graphs were juxtaposed so that to align nap timing while having them occur at different **circadian** phases that produce different alertness estimates. The graphs show that **the same nap timing may produce entirely different alertness profiles**. This explains why the "energizing power" of **polyphasic sleep** is an easily propagated myth.

In polyphasic sleep, depending on the **circadian phase, naps may produce a high degree of alertness or a severe [sleep inertia](#).**

Even though the sleep model used in [SleepChart](#) applies to [free running sleep](#), the symmetry of [Uberman napping](#) nullifies the need to correctly predict the circadian peaks and valleys. Wherever the [acrophase](#) peaks occur, they will largely intersect with the nap grid at random. In addition, if regular sleep data had been collected before the [polyphasic sleep](#) experiment, correct subjective nighttime [acrophase](#) estimations from that period would carry over across the first few days of the polyphasic experiment. After all, only consistent phase shifts can reposition the [circadian](#) sine wave phase. The same mechanism that makes polyphasic sleeping so hard to sustain can also be used to explain it with the model designed to serve a [free running sleep](#) condition.

Polyphasic rollercoaster

What primarily emerges from the application of the [two-component model](#) to "Uberman sleep" data presented above is a typical "rollercoaster effect" of alternating alertness and grogginess. Unlike a typical sleeper who wakes up refreshed and goes to sleep tired, a polyphasic sleeper will experience moments of extreme euphoria (e.g. at 4 am in the [graph B](#)) and discouraging downers (e.g. at 3 pm in the [graph C](#)). The presented alertness estimates correlate well with the subjective "focus and motivation" assessments made by the sleepers themselves. In the [graph C](#), where a nap at 11 pm produced a major surge in alertness, the nap at 3 am, just 4 hours later, delivered nearly nothing. This produces a typical rollercoaster of enthusiasm and self-doubt in a polyphasic sleeper. After short naps that occur at the minima of [circadian](#) sleep propensity, a polyphasic sleeper may reach heights that are not known to ordinary sleepers. Those surges of enthusiasm verging on euphoria are pretty unique due to the fact that an ordinary sleeper nearly never naps at [circadian](#) sleep propensity minima. Those moments can make a polyphasic experimenter update the blog with "never felt better - creativity at its maximum". At the same time, some naps can only make things worse. For example, the nap at 3 pm in the [graph C](#) taken on June 23, 2009 does not seem to produce any boost in alertness. It was then followed by an hour long "correction" that would not boost the alertness either. Moreover, the cresting [circadian](#) wave always produces the unpleasant feeling of grogginess due to a [circadian sleep inertia](#). This is the type of inertia that is pretty familiar to shift-workers. That combination of sleep process variables is also responsible for the [foggy head of the jet lag](#). This illustrates what [Dr Stampi](#) noticed in his experiments that it is not hard to stay awake on a [polyphasic sleep](#) schedule. The hardest part of a polyphasic regimen is the process of waking up from naps that occur at the [circadian acrophase](#) (Stampi 1992^[54])

Free running circadian cycle in polyphasic sleep

Bryan's polyphasic attempt (mentioned [earlier](#)) brought the most interesting observation: the [circadian](#) cycle was most likely running in the background as if in zeitgeber-free conditions. In line with the chaotic impact of [polyphasic sleep](#) episodes on the sleep control system (see: [Phase response curve in polyphasic sleep](#)), the episodes largely cancel each other out and allow of a free-running [circadian](#) cycle run in the background. Moreover, return to the monophasic lifestyle can be nearly painless if the right phase for sleep time is chosen.

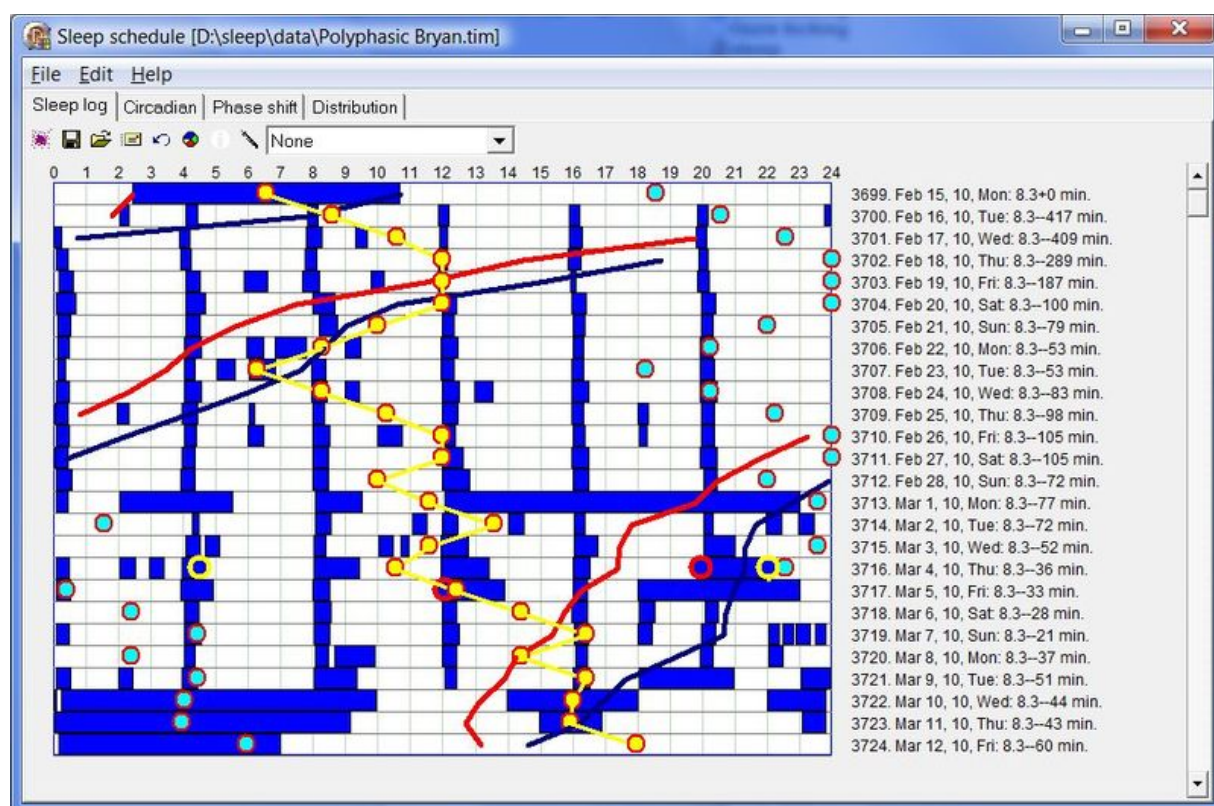
Bryan would keep his log in Excel with detailed annotations. Interestingly, he used coloring to denote periods of alertness or even euphoria, as well as periods of grogginess or sleepiness (yellow):



enthusiasm

The columns correspond with successive days of the experiments and include preceding and succeeding **monophasic sleep** blocks. The rows correspond with half-hour periods. Sleep blocks are marked with their duration in minutes. In the graph, Bryan's Excel notes have been modified slightly to visualize the extent of the **subjective night**. Most importantly, his oversleep blocks were marked yellow instead of blue to differentiate them from an artificiality enforced polyphasic sleep, which tells us nothing about his actual sleep propensity. This way a visually distinct diagonal yellow band emerges where the presumable maximum circadian sleep propensity is marked without a distinction between the oversleep episodes and periods of grogginess. I demarcated that yellow band with blue and red bedtime and waking lines of putative boundaries of the **subjective night** in the same way as it is done in **SleepChart**. The blue line is the actual optimum time where Bryan should best go to sleep (instead of sleeping polyphasically). The angle of those lines, and the related phase-shift of the **circadian** cycle point to a nearly perfect 23-day turnaround, which roughly corresponds with a 25-hour body clock period. In other words, we can guess that the **circadian** cycle was running free in the background despite multiple chaotic and unpredictable inputs to the phase-shifting system. It is also remarkable to see how easily Bryan returned to his monophasic lifestyle by hitting the exact brackets of the **subjective night** in his free running **circadian** cycle.

Bryan's **SleepChart** log shows that statistical approach used in demarcating the **subjective night** brackets (**SleepChart** 1.0) failed to track his hypothetical free running circadian cycle:



Red and blue lines in the graph show a phase advance, while the rhythm almost certainly showed a phase delay. The reason for that failure is that the statistical method of **SleepChart** 1.0 uses sleep blocks as markers of sleep propensity. Naturally, in polyphasic sleep, those markers are falsified, and throw the algorithm into confusion. On the other hand, the newer approach used in **SleepChart** 2.0, based on the phase response curve (**PRC**), was able to roughly follow the **circadian** trough noticed in Bryan's Excel file. Here, the yellow circadian crest line is thrown into some confusion in the period from Feb 20 to 23. This is why the approximation does not recover in time to match the return to **monophasic sleep**.

Even though, at best, Bryan was able to sustain the pure Uberman schedule for only 3 days in a stretch, his one-month-long effort is still a remarkable demonstration of self-discipline. If you read Bryan's own notes on his cognitive function, you will probably agree that multiple periods of sleepiness, fatigue or grogginess disqualify **polyphasic sleep** as a lifestyle choice for people who use their brain for a living. Still Bryan's own words summarizing his experiment are pretty surprising. He does not seem to be bothered by "periods of sleepiness" or "difficulty waking up", which should never be part of a well-managed and hygienic sleep pattern:

My experiment demonstrated to me, unequivocally, that it is possible to maintain normal (subjective) function (mentally

and physically) on a **polyphasic sleep** schedule, **if** you are willing to adapt to the rigid schedule of naps, and endure a period of sleepiness (circadian low) that lasts between 2-4 hours each day. In parallel to [Stampi's](#) findings, the only significant difficulty I experienced was waking up from naps as the experiment progressed. It became increasingly difficult to wake up; sometimes I would wake up and reset my alarm without any memory of doing so; or my girlfriend would have to shake me for a full minute until I awoke. Once awake, however, I usually felt great, as if I had slept a whole night—but without the sleep hangover (lethargy) from being in bed for 8-10 hours. It is tempting to focus on the difficulty of waking up, to make claims about what that does or does not indicate, but the normal, even euphoric, functioning during waking hours should not be ignored. Given this, I was happy to see that you address these matters in your paragraph titled, [Polyphasic rollercoaster](#).

It is likely that in **polyphasic sleep attempts, the **circadian** cycle is running in the background as if in zeitgeber-free conditions with the chaotic phase-shifting inputs cancelling each other out.**

Claudio Stampi

Probably nobody knows more about **polyphasic sleep** than Dr Claudio Stampi. He dedicated his life to understanding ultradian rhythms and the art of napping. His passion for the idea was born three decades ago when, as a medical student, he was also a passionate solo sailor. He studied sleep in dozens of individuals taking part in competitive sailing. He studied sleep patterns for NASA. He studied **polyphasic sleep** in laboratory conditions. He strapped his subjects with wrist-worn activity monitors and EEG electrodes. He is a worshipper of [napping](#) as nothing counteracts **sleep deprivation** and fatigue better than a nap. In his work, he looks for ways towards improving alertness and survival in life-threatening situations, esp. long-distance boat racing. Yet he is not recommending the polyphasic schedule for normally functioning creative individual who can afford a full night of healthy sleep. His alleged "recommendation" is just one of those myths circulating along with the **polyphasic sleep** meme. Using polysomnographic tools, Stampi looks for troughs and peaks in human alertness. His research tries to capitalize on understanding those ultradian rhythms and maximizing the effectiveness of napping, primarily by optimizing the [timing of naps](#).

Stampi's methods are primarily targeted at minimizing **sleep deprivation**. He is a [biphasic sleeper](#) himself and through his chronobiology expertise can claim proudly "*I am never tired*"^[63]. When speaking about Ellen MacArthur^[64] he puts his research in a nutshell: "*What Ellen is doing is finding the best compromise between her need to sleep and her need to be awake all the time*".

Polyphasic vs. creative lifestyle

Unlike a solo sailor, a creative individual needs no compromise. It is the uncompromising maximum of alertness, attention, and creative powers that is sought. Stampi has shown that **polyphasic sleep** can improve cognitive performance in conditions of **sleep deprivation** as compared with monophasic sleep: *Individuals sleeping for 30 minutes every four hours, for a daily total of only 3 hours of sleep, performed better and were more alert, compared to when they had 3 hours of uninterrupted sleep. In other words, under conditions of dramatic sleep reduction, it is more efficient to recharge the sleep "battery" more often.* Many use this as the argument for the superiority of polyphasic sleep, while silently skirting around the fact that Stampi also notes that the performance on polyphasic schedule is still far less than that in **free running sleep** conditions.

Polyphasic Bible

Many proponents of **polyphasic sleep** will quote from their Bible: Claudio Stampi's book [Why We Nap: Evolution, Chronobiology, and Functions of Polyphasic and Ultrashort Sleep](#) written over 20 years ago. *Why We Nap* is an excellent book, filled with peachy nuggets of information about sleep, napping, evolution, and more. I can wholeheartedly recommend the book as a great compilation of interesting texts from the most reputable experts in the field. The book also includes an anecdotal note on putative sleep habits of Leonardo da Vinci. It is possible that this anecdotal inclusion had an unintended side effect resulting in the [Uberman Big Bang](#). With the advantage of two extra decades of sleep research (e.g. the genetic aspects of the **circadian** cycle), I disagree with some of Stampi's original hypotheses. Largely so does Stampi. This does not change the fact that his research can definitely be considered as pioneering work in the study of the extremes of **chronobiology**. For those who still believe that Stampi advocates **polyphasic sleep** as a lifestyle, an ancient quote from his book should clear things up: "*the author would like to caution against misleading interpretations of these conclusions. What is being proposed here is not that **polyphasic sleep** is preferable to monophasic sleep, nor that everyone should now switch to a multiple napping behavior "panacea."* It appears obvious that quasi-monophasic sleep — monophasic sleep plus occasional naps — is what comes most naturally to the majority of adult humans and a few other species. If somewhere in evolution such species have developed the ability to sustain

wakefulness for relatively prolonged periods, most likely this ability occurred in response to some sort of important and advantageous adaptive pressure".

Dr Stampi writes: "*many experiments have provided direct evidence that adult humans have a surprising ability to adapt to different types — and different levels — of polyphasic sleep-wake behavior.*" This statement is general enough to be correct. For example, [compression of sleep stages](#) is a form of adaptation. This does not imply that an individual will be able to take multiple natural naps during a day. A consensus emerges in sleep research that, in healthy adult individuals, [multiple Edisonian naps require a degree of sleep deprivation](#). Without deprivation, initiating sleep becomes pretty hard. "Multiple naps" should be understood as "more than one after consolidation", where "consolidation" is a process in which multiple naps spaced closely together are counted as one.

Cognitive tests in polyphasic sleep

It is important to note that Dr Stampi could identify only a modest decline in cognitive function during his [polyphasic sleep](#) experiments. This may stand in seeming contradiction with other research or with simple [circadian](#) measurements of memory performance, including [those that are possible with SuperMemo](#). Including a [circadian](#) component in measurements yields significant cognitive differences in the course of a normal undeprived waking day. Simple memory tests, if averaged, might yield a seemingly reasonable cognitive performance assessment due to the [roller-coaster effect](#). The tests Stampi chose to measure cognitive performance skirt around the essential question as to the primary long-term neurophysiological function of optimally timed REM-NREM interplay in sleep. In Stampi experiment with Francesco Jost, [REM](#) and [NREM](#) rarely occurred together. If the hypothesized [memory storage optimization function](#) is considered, it is impossible to verify the status of memory with short-term tests. This is due to the fact that, in theory, the network function of the brain taken as a black box should remain unchanged. The neglect of sleep structure would show only as a cumulative long-term inability of the brain to build up new skills and reasoning powers. Secondly, the creative potential of an optimized storage is also difficult to measure, and will definitely show a cumulative effect requiring a long-term study. Last but not least, lack of the [circadian](#) effect can only testify to an insufficient sensitivity and/or timing of the tests chosen. Even if the [homeostatic](#) component of alertness ensures that we can seemingly focus on simple mental tasks and perform them pretty well (e.g. memory tasks, driving, simple calculations, etc.), the [circadian](#) low will affect the ability to sustain a mental effort or undermine its creative aspect. Tests that could be sufficient for Dr Stampi's goals (e.g. maximizing alertness in a solo yachting race) cannot be used to make claims about the long-term impact of ultrashort sleep on cognitive performance.

In sleep science literature, there is a degree of confusion between the [homeostatic](#) and [circadian](#) components of sleep and their impact on cognition. Very often, researchers fail to differentiate between the two when investigating impact of environmental factors on sleep. We all know that [coffee](#) can help one survive a sleepy moment. It is important to ask though if its effects are [homeostatic](#) or [circadian](#). Can coffee dispel [sleep inertia](#)? Can it help overcome [circadian](#) lows? It is not enough to say that coffee helps overcome sleepiness if its impact on the [circadian](#) sleepiness is negligible. Everyone who is familiar with the jet lag can testify that the foggy brain state does not evidently deprive one of one's basic mental skills, and yet it can entirely ruin one's productivity by affecting self control, creativity, motivation, and more. This is why globe-trotting politicians are a poor material for groundbreaking peace or trade deals, even if they believe they can function well on 3 hours of sleep or in a jetlagged condition. Dr Stampi's findings, highly applicable to emergency situations, should not be used to diminish the importance of well-timed natural sleep for the function of the brain, and the fact that [artificial designer sleep schedules are very harmful](#).

Sleep deprivation is like alcohol intoxication

Sleep researchers love to compare [sleep deprivation](#) to intoxication: both disrupt one's self-assessment abilities. Like an alcoholic who always claims "I am not drunk. I am just inebriated", a sleep deprived person will often say "I am fine. I am crisp and alert", while his or her ability to perform mental tasks may be seriously impaired. The sleepier people are, the more overconfident they are about their ability to perform cognitive tasks. Driving when sleep deprived may be as dangerous as driving while intoxicated. This loss of self-assessment capacity may in part explain why so many [polyphasic sleep](#) bloggers tend to claim they have adapted to the grueling regimen. They tend to write about their success at the moment of lucidity and/or euphoria (see [polyphasic rollercoaster](#)). At the same time, they keep ignoring those brain dead moments as "temporary setbacks", transitory adaptation state, etc. In those hazy moments, a blogger may be unwilling to update the blog, magnifying the bias in the perception of his or her reporting. Natural adaptation to a polyphasic schedule is not possible, but those who boastfully claim it need not be branded as liars. Self-assessment handicap and a lowered bar of expectations should both be used as exculpatory circumstances. As mentioned earlier, it is even possible to flatten or desynchronize the [circadian](#) function bad enough to lessen the pain of waking in the period of [subjective night](#). As this relief comes from malfunction, or perhaps even neural injury, it should serve no comfort to those who hope to adapt. With all the genetic cascades resting on the [circadian](#) cycle,

such an outcome can only lead to a health disaster.

Sleep debt and napping

PureDoxyk is the nick of the "inventor" of the "*Uberman sleep schedule*". Even though she claims to have slept polyphasically for a longer while, a more detailed look at her reports indicates that she slept in a sort of "messy multinap compensatory sleep system" that gradually gravitated in the direction of a pretty natural **biphasic sleep** that she later termed "*Everyman sleep schedule*". Were it not for that gravitation and a tendency to take a "core sleep", I might even suspect that the inventor of the Uberman sleep cycle suffered from a rare mutation that causes **circadian arrhythmicity**. People with that disorder cannot sleep well in a long block over the night and take multiple naps during the day. Those naps add up to a pretty normal total sleep duration and produce a pretty unrefreshed mind that makes the disorder pretty hard to live with. It would be an ironically sad turn of events, if a sick person suffering from bad sleep could have proposed a sleeping "system" that caused an epidemic of lifestyle experimentations by teenagers looking for better sleep only to find more sleeptime misery.

PureDoxyk Law

What strikes me in PureDoxyk writings is that she instantly rings credible and seems to have a very good sense of the link between **sleep deprivation** and napping. Let's have a peek at her claim that I will call *PureDoxyk Law*. Note the "six hour sleep" fragment that indicates that PureDoxyk is not suffering from a serious **circadian arrhythmicity** disorder as speculated above:

Six naps no sleep; 4 naps one-point-five hours sleep; 3 naps three hours sleep; 2 naps four-point-five hours sleep; one nap six hours sleep*.

* I removed two tiny mathematical kinks from the law which was originally formulated as: *Six naps no sleep; 4-5 naps one-point-five hours sleep; 3 naps three hours sleep; 1-2 naps four-point-five hours sleep; one nap six hours sleep* ([source](#))

Obviously, this law would need to be parametrized to fit a general healthy population. In particular, most monophasic sleepers will find it hard to [nap more than once per day](#) unless all sleep episodes in question are terminated with an alarm clock perpetuating the cycle of **sleep deprivation**.

We can instantly see a nearly perfect linear nature of the relationship between the duration of the night sleep and the number of naps taken.

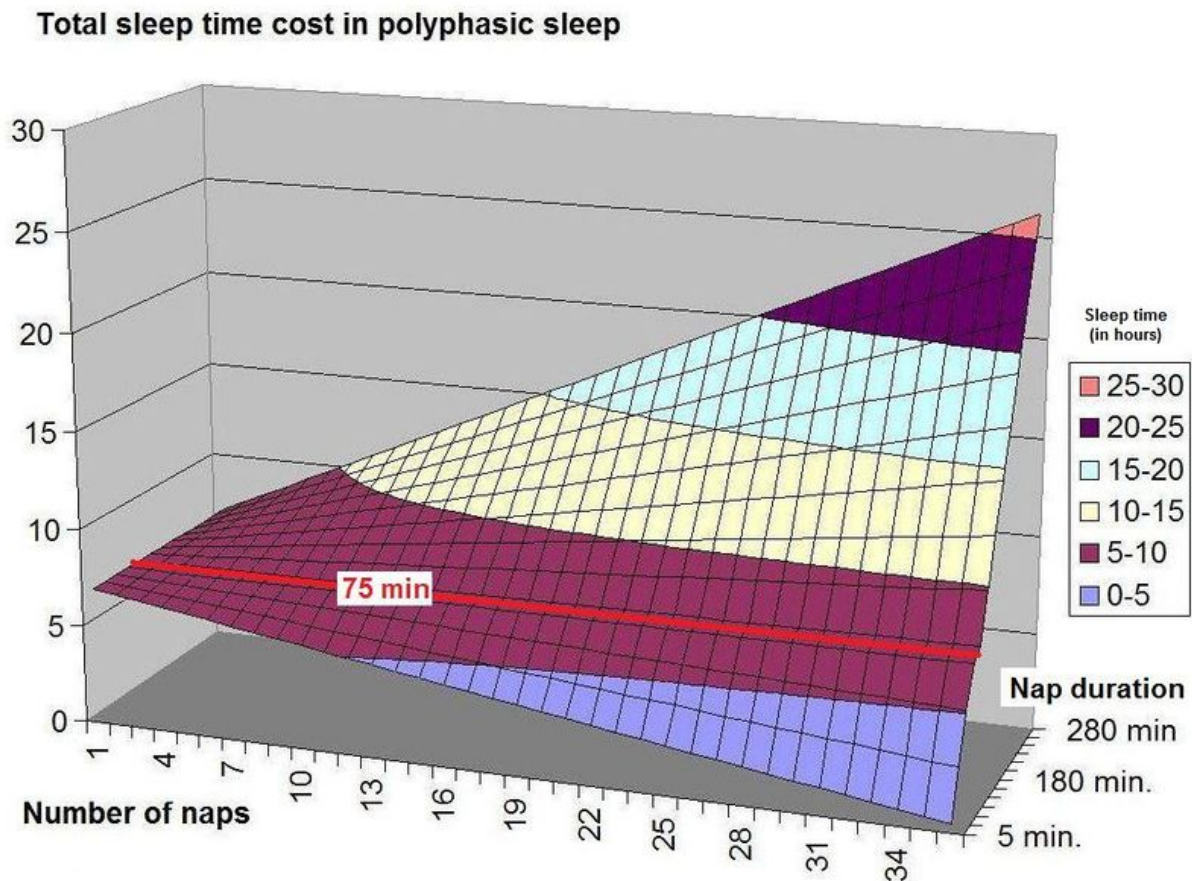
$$\text{NapNumber} = 5.6 - 0.8 * \text{CoreSleep}$$

Minimizing total sleep time

If Puredoxyk Law is true, the duration of naps will determine the breakeven point for the overall time gain in **polyphasic sleep**. Beyond the breakeven point in nap duration, adding extra naps will add to the total cost of sleep. Obviously, that breakeven point will coincide with the situation in which the total amount of sleep is constant (i.e. independent of the number of naps). If we take total sleep as:

$$\text{TotalSleep} = \text{CoreSleep} + \text{NapNumber} * \text{NapDuration}$$

substitute NapNumber from PureDoxyk Law, differentiate for nap duration, and compare the result with zero, we will arrive at the breakeven point at NapDuration = 75 (min), which corresponds with the constant total sleep time of 7 hours. In other words, adding naps shorter than 75 min. would result in an overall time gain in **polyphasic sleep**.



A theoretical graph showing the minimization of the total sleep time along PureDoxyk Law. The proximal horizontal X axis shows the number of naps, the receding horizontal Y axis shows the nap duration, while the vertical Z axis shows the total sleep time in hours. The breakeven nap duration line is labeled "75 min". The graph shows that adding naps that are shorter than 75 min. allows of achieving a total gain in time, while adding naps longer than 75 min. will result in an increase in the total sleep time.

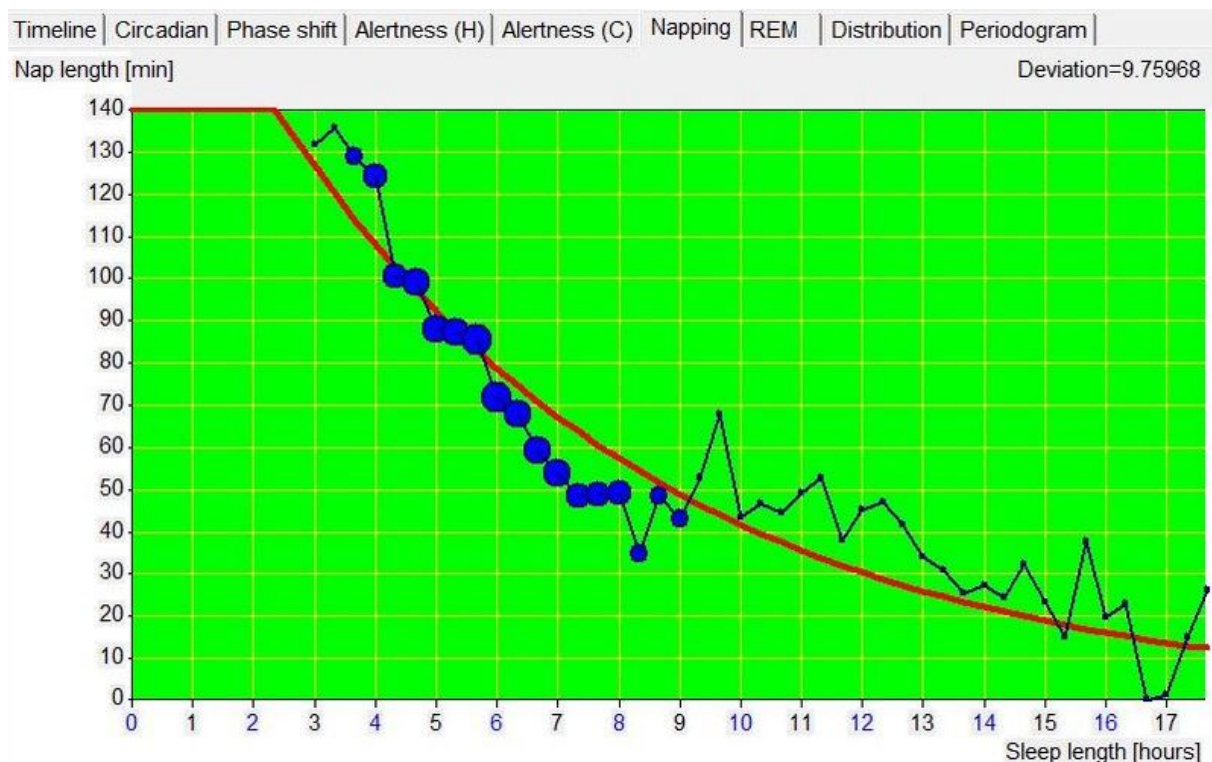
It would be interesting to analyze irregular sleep logs that comply with the above law as they could answer some questions on the winner in the tug of war for sleep efficiency between the regulatory powers of the [free running sleep](#) and the adaptive powers of the [sleep compression](#) induced by the use of an alarm clock in [polyphasic sleep](#).

The net time gain in a short-nap regime obviously does not translate to a brain gain, and this should not be understood as a recommendation to seek minimum total sleep time. I posed the above problem only as an interesting mathematical relationship, which provides a neat formula for the total sleep debt that might be of use in modeling sleep in conditions where sleep is terminated prematurely (e.g. with an alarm clock). Neither [SleepChart](#) nor [SuperMemo](#) account for sleep debt as both have been designed for the ideal [free running sleep](#) condition. Obviously, any form of sleep debt is unwelcome as it implies unfulfilled neural function of sleep.

Instead of aiming at minimizing the sleep time, we should aim at maximizing the brain effect of sleep.

Optimum nap duration

When the actual correlation between the duration of nighttime core sleep and the total duration of naps is investigated, a rather non-linear relationship emerges:



In the presented example, a negatively exponential function provides far better fit to data than a linear function. However, in the most studied range corresponding with the nighttime sleep ranging from 4 to 8 hours, a nearly linear relationship can be observed where each hour of lost night sleep requires 20 min. of replacement nap time. This shows that napping has a powerful compensatory power.

We could then reformulate PureDoxyk Law to make it applicable to a wider population. Most of all, one mid-day nap should do all the job in compensating for lost night sleep (see: [Best nap timing](#) and [One nap per day is enough](#)). As a result, it makes more sense to replace a number of naps with a single nap whose duration will depend on the amount of lost sleep:

$$\text{NapDuration} = (\text{SleepRequired} - \text{SleepObtained}) / 3$$

This formula will hold only for properly timed naps. Early naps will not provide full compensation. Late naps will last longer and will shorten sleep in the following night.

In conditions of sleep deprivation, night time sleep debt requires extra napping time in roughly 3:1 ratio. For each hour of lost night sleep, extra 20 minutes of napping is needed.

Again, this formula should only have a theoretical value. You should never try to terminate a replacement nap. If it is properly timed, it should be allowed to run its natural course and it will then provide the best compensation for sleep lost in the night.

Even though naps provide an excellent compensation for lost sleep in the night, they cannot provide a full functional replacement. To achieve your maximum cognitive capacity, you need to run your night sleep uninterrupted until completion!

Personality characteristics of irregular sleepers

That PureDoxyk got sufficient experience in sleeping polyphasically to formulate the above law without any specific logging tools indicates that she needed a pretty vast array of napping permutations to see the bigger picture, which in this case seems highly plausible. PureDoxyk Law can be interpreted as a demonstration of how a healthy mono- or **biphasic sleep** can be stretched into a **polyphasic sleep** phase space with an increasing degree of sleep debt. PureDoxyk herself calls her new sleeping regime that includes a "core nap" the 3-hour Everyman schedule. This schedule sounds pretty sustainable if it is not too heavy on the use of the alarm clock. After all, a third of Americans can function reasonably ok despite committing the daily neural crime of using the snooze button for the average of 3 times. Needless to say, this Everyman schedule is a pretty wide departure from the original Uberman formulation that I found particularly troubling.

In the past, I have received a number of sleep logs with pretty irregular sleep patterns (including multiple naps). Those logs were accompanied by some anecdotal evidence that seems to indicate that those irregular patterns are strongly correlated with some personality characteristics. I can be widely speculative here and say that those are pretty neurotic and yet quite creative types (excluding cases that could be attributed to the use of prescription drugs). If that was to be the case, those sleep patterns might not be too good for longevity, but even [free running sleep](#) will fail to straighten them out. This indicates that there could be genetic factors involved here, and the "mutation hypothesis" is far more likely to explain a perpetual irregular pattern than a regular fresh&alert Uberman pattern. I would even avoid the use of the word "mutation" here as those "personality genes" must be pretty widespread in the population. How can PureDoxyk's case be interpreted, I have no idea, but it does not seem to be too extreme in its uniqueness, and, as such it can be, probabilistically speaking, deemed credible.

Polyphasic geniuses

An Internet rumor has it that there were many geniuses who slept polyphasically. The implication is that if [polyphasic sleep](#) worked for the greatest minds in history, it should also work for a young ambitious student with a voracious appetite to conquer the world. Yet on a closer inspection, those polyphasic stories are very hard to confirm. Somehow, the group does not include contemporary Nobel winners, presidents, or great athletes. In other words, you cannot just e-mail a celebrity and ask. All great polyphasic sleepers are dead. There are still a couple of individuals who boast in their blogs that they are polyphasic sleepers. Very often their sleep is just a stretch of the [biphasic sleep](#) definition or a combination of various sleep modes with a heavy dose of [sleep deprivation](#). Some of those cases I cannot explain in any other way than by a vested interest or a bloated ego. As their "success" postdates the "invention" of the [Uberman sleep schedule](#), this might simply be a never-credible wish to be added to the list of the great [Übermenschen](#). Even narcolepsy would not explain napping habits of some polyphasic adepts. At any rate, successful [polyphasic sleep](#) cases are not in any way verifiable. Naturally, absence of proof is no proof of absence, and this section is not intended to prove that [polyphasic sleep](#) is not possible. It is the biological argument above that settles the [issue](#). Here, I am only trying to illustrate the myth-making powers of the Internet and human nature.

The list of polyphasic geniuses seems to be getting longer along with the snowballing myth of the benefits of a 22 hour waking day. The list includes da Vinci, Edison, Tesla, Churchill, Benjamin Franklin, Thomas Jefferson, and even Bruce Lee. I would not be surprised if Newton and Aristotle joined soon. Perhaps even Jesus might follow up later. I tried to find out if there is any record of the sleeping habits of the greatest geniuses in history. All I could find was rather a standard adherence to a normal monophasic or biphasic sleep, with an exception for numerous all-nighters at the time of creative high.

Buckminster Fuller

With [Buckminster Fuller](#), I came closest to finding a sort of quasi-polyphasic schedule. Buck's biographers who I managed to get in touch with confirmed that his sleeping habits were quite unusual and that he experimented a lot with various sleeping patterns. In particular, while traveling and lecturing extensively, he would enter what he called a "dog sleep". That sleep, however, had nothing to do with [polyphasic sleep](#). It was a sort of improvised mix of [free running sleep](#) confounded by jet lag, meetings and deadlines. In other words, Bucky would catnap whenever he was tired and had an opportunity. However, if he could squeeze a sound 6 hours here and there, he would not miss the chance. This "dog sleep" did not fit any fixed alarm-clocked schedule. It was just a compromise between [circadian](#) rhythms and Bucky's hectic lifestyle.

Leonardo da Vinci

Although even [Stampi](#) anecdotally refers to [Leonardo da Vinci](#), Leonardo's [polyphasic sleep](#) is probably an urban myth. I could not locate any credible sources with any notes on his sleep habits, and yet da Vinci is nearly always mentioned whenever the art of napping comes into question. It seems quite strange that someone would come up with a crazy polyphasic schedule idea at the time of leisurely Renaissance life that was well-timed by the superiority of sunlight over candlelight. Allegedly, hinting at a monophasic mindset, he spoke of death: "*As a well-spent day brings happy sleep, so a life well used brings happy death*". Even more telling is Bandello's report on da Vinci's work over "*The Last Supper*". Leonardo would work continuously from dawn to dusk forgetting about food and drink. Stunned Bandello would have definitely reported the round-the-clock work of a polyphasic sleeper as even more amazing. It seems to me that using a poorly researched historic case from 500 years ago as a prop in favor of [polyphasic sleep](#) is rather a dated [argumentum ad verecundiam](#).

I suspect the entire Leonardo myth might have originated from a 50-year-old story told by a [psychic](#)! Giancarlo Sbragia reports in his text on ultrashort sleep (1992): *I cannot [recall](#) exactly where or from whom I gathered information about*

Leonardo's sleep habits. [...] I had a friend who was a medium and capable of [extrasensory perception](#). [...] It was probably from her that I learned about the peculiar Leonardo sleep-wake pattern, even though today, 30 years later, I am not completely sure. (Sbragia 1992^[65]).

Incidentally, da Vinci is also a name that crops up on many other suspect lists: the lists of great people suffering from attention deficit disorder, or the lists of great vegetarians. He is also a suspect fabricator of the [Turin Shroud](#). The same memetic mechanism must be placing da Vinci, Jesus, Einstein, Edison, Jefferson, Franklin, and Hitler alongside each other in a number of myths over and over again. They keep popping up on trumped up lists of famous people affected by X, practicing Y or believing in Z.

Nepoleon Bonaparte

[Napoleon](#) is not less frequently referred to in the context of napping or [polyphasic sleep](#) than da Vinci. And his case is rather easy to falsify through historical records. When compared with an artistic genius of Leonardo, it seems even more preposterous that a brilliant military commander could possibly retire for a nap during a prolonged battle or during his intense life peppered with plethora of engagements. He is indeed said to have slept little and frequently. He suffered from insomnia at times of great stress. He was also often interrupted by messengers that might perhaps increase his propensity to napping at daylight. Yet he was to be woken up only with bad news. The hard rule was that the good news could wait. His memoirs indicate that he did not mind dying young. Consequently, he would disregard his doctors on the matter of sleeping little and drinking buckets of strong coffee. As Napoleon's life was jam-packed with stress, his short sleep might have been a consequence of his lifestyle. Low sleep diet did not translate well to Napoleon's military skills. Some contemporaries attribute his errors at Waterloo to [sleep deprivation](#). Yet, during slower days he would sleep for sound seven hours, waking up at 7 and often lazing until 8. Then he would yet add a nap in the afternoon. Records also indicate that at Saint Helena he was a normal sleeper, and while stress was replaced with boredom, he often slept late.

Thomas Jefferson

Jefferson seems easy to falsify as a polyphasic sleeper as well. In letters to Doctor Vine Utley (1819), [Thomas Jefferson](#) writes about his sleep habits. We can conclude that his sleep was not very regular, he would go to sleep at different times (often late into the night), he would always devote at least 30 min. to creative reading before sleep, he would fall asleep later if the reading was of particular interest, and he would regularly wake up at sunrise. In other words, expectedly, there are no traces of polyphasic sleeping in Jefferson's life.

Benjamin Franklin

As for [Benjamin Franklin](#), we might conclude that he did not hold sleep in high esteem. This we can decide from the famous quotations such as "*There will be sleeping enough in the grave*" or "*The sleeping fox catches no poultry*". This attitude resembles the one of those who are ready to practise polyphasic sleeping today. It is also a frequent characteristic of high achievers from the times when we knew little of the [biological function of sleep](#). Yet Franklin is even better known for saying: "*Early to bed and early to rise makes a man healthy, wealthy, and wise*". From this we might conclude that if he wanted to sleep less, his formula would be to get up early. Not to shred sleep into pieces. Moreover, for a high achiever with little regard for sleep, retiring for a nap might feel like a major sign of [laziness or weakness](#). That stigma lasts until today in western culture, where napping is often considered a habit of lazybones. Last but not least, Franklin as an advocate of [DST](#) would say: "*It is silly and wasteful that people should live much by candle-light and sleep by sunshine*". Polyphasic sleeper definitely he was not.

Winston Churchill

We know quite a lot about [Winston Churchill](#)'s sleeping habits. As a wartime PM, his daily routine was watched closely by his assistants. Churchill could work his ministers to exhaustion by staying up late, but he would also routinely take a solid 1-2 hour nap in the afternoon. As such, he was a [classical biphasic sleeper](#). At his house at Chartwell, his routine was quite regular. He would wake at 8, spend the morning in bed reading papers, dictating letters, etc., take a long nap at tea time, and work till as late as 3 am. He averaged 5-6 hours of sleep per day. Those words are attributed to Churchill himself: "*You must sleep sometime between lunch and dinner, and no halfway measures. Take off your clothes and get into bed. That's what I always do. Don't think you will be doing less work because you sleep during the day. That's a foolish notion held by people who have no imaginations. You will be able to accomplish more. You get two days in one -- well, at least one and a half*". Churchill's well-drilled biphasic habits made him one of the most energetic wartime leaders. On a humorous note, F. D. Roosevelt's aides noted that after a Churchill's visit, the US president was so exhausted that he needed 10 hours of sleep for 3 days straight to recover.

Thomas Alva Edison

[Thomas Alva Edison](#) had a love-hate relationship with sleep. Sleep researchers blame him for robbing the modern population of 1-2 hours of sleep. Workaholics like to quote him on his contempt for sleep. Advocates of [polyphasic sleep](#) claim he was a polyphasic sleeper. Indeed, Edison's contempt for sleep is well documented. Yet it can only be attributed to his ignorance. Little was known about the biological role of sleep at his time. He believed wrongly that, as with food, [humans will always sleep more than necessary given an opportunity](#). As a natural short sleeper, he believed that long sleep is a sign of laziness: *"Most people overeat 100 percent, and oversleep 100 percent, because they like it. That extra 100 percent makes them unhealthy and inefficient. The person who sleeps eight or ten hours a night is never fully asleep and never fully awake - they have only different degrees of doze through the twenty-four hours"*. In a parallel flash of ignorance, Edison could not see much value in physical exercise. His winter home featured one of the first modern swimming pools, yet Edison never used it. He just did not share the modern view in which exercise and sleep are considered a good investment in mental and physical health. His co-workers noted that Edison actually slept far more than he would like to admit. Clearly, he would carry sleeping little as a badge of honor. He catnapped a lot, and his nap cots have been preserved to this day in Edison museums. By no means could I though find any credible evidence that Edison's napping complied to any regiment other than "nap when sleepy", which usually turns out to match a biphasic pattern, or at least comply with [PureDoxyk Law](#). The most reliable information I could find about Edison's sleep was his own diary kept only for a short time while approaching the age of forty. From this diary we can learn a lot about his sleeping habits. He seemed rather obsessed with getting a good night sleep as his day would often start with notes on the quality of sleep. Like most of us, the better he slept, the happier he seemed. That's quite the opposite of what polyphasic proponents claim. Instead of maximizing waking hours, Edison would rather maximize the hours in which he could use his well refreshed mind. And that's exactly what seems most rational from the point of view of physiology of sleep, mental hygiene, and productivity.

Nikola Tesla

After a short stint under Edison's umbrella, [Nikola Tesla](#) became a bitter rival of his former mentor. We have all heard of the "war of the currents", but Edison and Tesla clashed in another battlefield. They tried to outbid each other in sleeping little. Tesla noted that Edison slept much more than he would want others to believe. That injects a dose of boastful personality into Tesla and Edison's own reports on how much they actually slept. I bet the same mechanism makes today's bloggers often boast of polyphasic adaptation. Tesla, who could indeed work throughout the night, would often crash for the entire day of sleep after his exploits. He exhibited classic signs of manic creativity, which might have been interrupted by short recuperative naps or long recovery sleep. Otherwise, Tesla was nothing more than a short sleeper. He was too busy with his pursuits to ever think of anything resembling a strict polyphasic schedule. That would be a strait jacket on his flamboyant personality.

All in all, the whole list of polyphasic geniuses seems to be lacking any credible evidence. As such, it is probably a child of collective wishful thinking committed by those who would love to add waking hours to their day.

Sustainability of polyphasic sleep

The main problems with the [polyphasic sleep](#) result from the fact that it is:

1. hard to fall asleep during the sleep's forbidden zones,
2. hard to wake up from deep [subjective night](#) sleep, and
3. the body clock trainability has its limits that make it impossible to circumvent problems (1) and (2).

Clock and Hourglass model of polyphasic sleep

If we use the [Clock and Hourglass metaphor](#), we can explain in simple terms why adaptation to [polyphasic sleep](#) will never happen:

- in the morning, if you are fresh and rested, your sleepy potion (i.e. circadian sleepiness) is cleared and your hourglass is full of mental energy (i.e. your [homeostatic](#) sleepiness is cleared). You are not likely to fall asleep in the morning. Trying to take a nap at that time is a waste of time. You will waste time for nap preparations. You will waste time trying to fall asleep
- in the afternoon, at [siesta](#) time, there is a dip in alertness governed by the body clock. When your hourglass of mental energy is getting empty, you may be able to take a nap. That's ok. Your nap will be short because the nighttime sleepy potion is not there
- in the evening, your sleepy potion is still not there. If you took an afternoon nap, your hourglass is almost full of energy. If you try to take another nap, you will be staring at the ceiling. You will waste your time again

- in the night, your sleepy potion is released. Napping should be easy, but if you fall asleep, you will not wake up. Not naturally. You will need an alarm clock. You may manage to recharge your hourglass fast, but the sleepy potion will make you groggy and tired. You may need a double alarm or a loud alarm, or some help from your Mom (if she ever agreed to this polyphasic experiment). You will fight and struggle. You will never wake up naturally. Not while the sleepy potion is in action. Not when your **circadian** system says it is the middle of the night

If you decide to sleep polyphasically you will have to use an alarm clock. Otherwise you will not wake up in the night. Once you use the alarm clock, you will be sleep deprived. That will make your hourglass conveniently drained of energy. Empty hourglass will make napping easier indeed. But it is the hourglass that determines your mental powers. With the hourglass empty, you will be nothing more than an empty-headed zombie. To generate naps at equal intervals, you would have to kill the 24-h **circadian** component of sleepiness. You would have to kill your body clock, and prevent the release of the sleepy potion. That is not possible. The sleepy potion will be released every 24 hours and make you sleepy; however hard you fight it. The shortest natural night sleep rarely goes beneath 3 hours. Many biphasic sleepers can do well on 4 hours. Yet most adolescents may need 7 or 8 hours of night sleep to function optimally. In healthy sleep, daytime naps are either impossible or very short. If you track your sleep with [SleepChart Freeware](#), you can see it all on your own. You will see how naps tend to cluster at night time (which may be midday for you). That's exactly what polyphasic guru [Dr Stampi observed with solo sailors](#). Remember, for the picture to be true, you should avoid alarm clock, which naturally is not possible in **polyphasic sleep**. Yet even on a forced schedule you will see regular patterns of naps being longer and more frequent at nighttime (each time you relax your discipline, oversleep, etc.). The daytime naps will be shorter, esp. at subjective evening hours (which may be midnight for you).

The limits of the body clock training

I hear it again and again that all biological reasoning is of no consequence because the body can always adapt to training and pressure, and that science has not yet studied successful polyphasic sleepers. Here is a reply based on the clock hourglass model:

- body clock is controlled by genes, and we do not know pharmacological factors that could significantly affect body clock period. **Polyphasic sleep** would require shortening the body clock period six-fold! Another possibility is the complete removal of the body clock so that the hourglass of mental energy could govern sleep cycles
- body clock phase can be shifted with light, activity, [melatonin](#) and other factors, but the length of the period in which sleepy potion is released is hard to control. Drugs can reduce the impact of sleepy potion, but this should be avoided, as this affects the sleep stage cycles. In terms of the [Disk and RAM metaphor](#), not all your PC data may get written to the hard disk and get defragmented
- the speed at which the hourglass of energy is emptied can be affected by drugs (e.g. [caffeine](#)); however, faster hourglass would produce more sleep (instead of less), while slower hourglass would make multiple naps even less possible
- **polyphasic sleep** in laboratory conditions is possible if the alarm clock is used to interrupt natural sleep. Entrained free-running **polyphasic sleep** is not possible in healthy individuals
- science has not studied successful adapted polyphasic sleepers with natural polyphasic rhythms because they do not exist (although there are many claimants to the title). Dr Stampi's experiments do not qualify as they always involve an alarm clock

Conclusion

Healthy body clock runs a 24 hour cycle. This cycle will make you sleepy during the **subjective night** (which can be midday too). This is why you won't be able to wake up from your nap in your **subjective night** without an alarm clock. Alarm clocks are unhealthy. They prevent sleep from fulfilling its function. The choice is yours: either (1) sleep polyphasically or (2) sleep naturally and let your brain develop its full intellectual potential. If you are still not convinced, please [read this message](#) from the inventor of Uberman sleep

Caffeine in polyphasic sleep

Polyphasic sleepers believe that avoiding [caffeine](#) may ease the adaptation. Because of a relatively slow elimination of **caffeine** and its impact on [adenosine](#) receptors cancelling [homeostatic sleepiness](#), ingesting **caffeine** later than 5-7 hours before a nap is supposed to make taking a nap more difficult (except for cases when the ingestion takes place directly before a nap).

It is true then that avoiding **caffeine** shall make taking multiple naps somewhat easier. Yet it won't remedy the problem of [grogginess](#) when waking up in the period of **subjective night**. The problem in sleeping polyphasically is the

asymmetry of the **circadian** cycle (which is only marginally affected by caffeine), and a slow build up of **homeostatic** sleepiness. Even complete abstention from **caffeine** will not generate sufficient **homeostatic** sleepiness to ensure napping at all desired times. Reversely, taking powerful **adenosine** agonists would more likely result in sleep patterns that would rather resemble narcolepsy, not a desired Uberman sleep. That would go precisely against the goal of polyphasic adepts, which is to sleep less. **Polyphasic sleep pattern is inherently unstable, and changing levels of caffeine will have no bearing on this fact whatsoever.**

As for the normal healthy sleep (which polyphasic sleep is not), abstention from **caffeine** is not necessary, but all **caffeine** drinks should be optimally taken only within the first two hours after waking.

Polyphasic sleep mutants

Some **polyphasic sleep** adepts wondered if singular blog reports of polyphasic success could be due to some mutation that made those individual more likely to succeed. This is theoretically possible, but highly unlikely. To make the "mutant theory" workable, we would need a mutation that would produce sleep without a **circadian** component. Such a mutation is actually known and results in a serious disability coming from a perpetual **sleep deprivation**. People affected by this mutation will never be normal sleepers (like **polyphasic sleep** adepts). Another mutation might allow of **homeostatic** generation of states that resemble **circadian** lows that periodically occur in the brains of all vertebrates. It is as hard as to imagine a mutation that would allow one of defecating in 25g portions. Or a mutation allowing of an asynchronous voluntary peristalsis. Or a mutation that would replace a blinking reflex with two separate independent regulatory blinking mechanisms for both eyes. Or a perpetual syncopated heart rhythm with alternating 3:6:3:9:3:6 interval ratios. Or a separate contraction of atria, or separate repolarization of ventricles, etc. Or a menstrual cycle that can be entrained to shift-work with bleeding every 9 days. The closest disorder that can match the hypothesis that **polyphasic sleep** might be enabled by a mutation is narcolepsy, in which individuals node off many times during the day indeed. However, this is a **homeostatic** disorder that does not flatten the **circadian** function. As such, narcoleptics sleep more than healthy people, not less. In 1996, researchers were able to make Siberian hamsters arrhythmic by playing with their exposure to light (Ruby et al. 1996^[57]). However, their body clock was still running its cycle and responding to light-induced phase shifts, while only the locomotor activity rhythm became decoupled. We know that arrhythmicity in humans will cause a serious disability due to sleep's inability to fulfill its function without its **circadian** component. Moreover, it is hard to compare the genetics of humans with an animal that lives in cold climates and spends periods of prolonged darkness deep underground in its burrows. The chances of similar genetic "adaptation" to **polyphasic sleep** are probably comparable to the odds of humans getting their hair white for winter.

Last but not least, how would I tell a polyphasic mutant? He or she would have most likely been polyphasic from birth. Even though **PureDoxyk** has never been truly Uberman-like polyphasic, her sleep patterns have always been somewhat irregularly polyphasic. This is what makes her case credible. In genetic terms, **biphasic sleep** is pretty distant from the well-entrained ultradian **polyphasic sleep**. Even babies are hardly ultradian (see: **baby sleep**). In other words, when an otherwise healthy human being suddenly claims a polyphasic adaptation, I can only be seriously skeptical.

Polyphasic sleep blogs

As I could not run my own polyphasic experiments or encourage others to sleep polyphasically, I gathered a lot of insight into the Uberman concept by reading polyphasic blogs on the web. There are dozens of these and they provide a pretty entertaining reading. In addition to a perpetual struggle with sleepiness or grogginess, those blogs also ooze lack of understanding of the principles of healthy sleep and gross disregard for the importance of sleep in general. Here is a representative quote: *"If someone lives for 75 years, they will be unconscious for 25 of them. That's my entire life until now completely wiped away, unused. Family, school, work, writing, all of you, none of it happened. That is the cost of sleeping eight hours per day. So I cut my sleep to two hours, trying to milk my short life for all it's worth".* For someone who cannot appreciate the role of sleep, this sentence might not sound as outrageous as it should. However, as most of us appreciate the value of work, this sounds to me more or less as follows: *"If someone lives for 75 years, they will be at work for 25 of them. That's most of my life until now completely wiped away, unused. Family, school, sleep, writing, all of you, none of it I had time for. That is the cost of working eight hours per day"*

One of the theories of the biological basis of humor says that it is generated by the sense of superiority over other individuals. Allegedly, those who are able to detect the ignorance of fellow human beings, reinforce their findings through the sense of joy and well-being. Thus seeing others doing stupid things is fun (as long as, hopefully, nobody gets hurt on the way). Supposedly, the evolutionary mechanism of poking fun at the silly ones helped humans preserve wisdom through generations long before written records were available. In that context, if you understand the sleep control mechanisms that imply the impossibility of **entrainment** to polyphasic schedule, you may find studying the

blogs of polyphasic sleepers extremely funny. Actually, hilarious. With clues and red flags all over the place, the bloggers keep hitting the brick wall. Luckily, those individuals usually see the light after a few weeks of pain. We should hope that nobody gets hurt in the process, e.g. as a result of driving in a sleep deprived state. All blogs seem to roughly evolve through similar stages. They begin with a youthful euphoria about the potential of Uberman sleep to change one's life for better. There is a cultish aura around the whole concept. It parallels the work ethic and self-imposed or super-imposed [sleep deprivation](#) of [Aum](#), [Branch Davidians](#), [OTS](#), or [Peoples Temple](#). This monastic appeal is accentuated by the fact that the ambitious adopters often run various forms of diets as part of their "reform". There are lots of hopes associated with the "polyphasic experiment". Those usually revolve around being able to do more, and experiencing "increased energy". The hopes are magnified by the fact that many volunteers find it difficult to get refreshing sleep in the first place. Then the struggle begins, peppered with hopeful references to "temporary adaptation phase". It all begins with grogginess, problems with waking up, and oversleeping. Tiredness mounts and the word count analysis shows that "tired" is one of the most often used words in those blogs (along "I" and "nap"). Yet the happy "polynapper" is usually able to survive the initial phase through sheer enthusiasm magnified by the availability of extra time and tripled energy to execute a major change in his life. Then the negative aspects of the experiment start showing up. Those include insurmountable sleepiness, sleeping through an elaborate system of alarms, problems with thermoregulation, negative somatic symptoms, self-blame due to repeated oversleeping, etc. Repeatedly, oversleeping occurs in the subjective night, while problems with napping occur in the subjective day. Yet "polynappers" are slow at noticing that regularity. They are happy they get the extra waking time, and yet, instead of spending it productively, they desperately look for anything to kill time to "just survive the fog". They waste precious time on futile attempts to fall asleep at a wrong time. When things do not work their way, they start experimenting with various variants of the sleep schedule. Those include: more naps, fewer naps, longer naps, shorter naps, "pseudo-naps", rigid schedule or "flexi-naps", etc. As these are usually fruitless, the concept of "core sleep" or "recovery sleep" comes into consideration. Some experimenters decide to "listen to the body". With "core sleep" and some attentiveness to one's own body rhythms, experimenters drift towards variants of biphasic sleep, and may gradually approach a reasonable sleeping schedule. Yet without understanding the basics of [the two component model of sleep regulation](#), it is very difficult to figure out one's optimum sleep timing. The difficulty is compounded by two factors:

1. conviction that polyphasic sleep model will work, and
2. loss of synchrony in [circadian](#) rhythms.

As for the latter, well-entrained [free running sleep](#) is relatively easy to understand. However, once strong phase-shifting stimuli are introduced into the system, esp. if applied asynchronously or, worse, with irregular patterns, the whole sleep control system becomes chaotic and is essentially unpredictable. In other words, even a seasoned chronobiologist might find it difficult to interpret the correlation between the timing of sleep blocks and alertness. If the unlucky experimenter does not see the biphasic light, he begins theorizing on the causes of his inability to stick to the schedule. These might be bad foods, bad hormones, lack of self-discipline, skipped naps, extra naps, troubles at work, friends, excess sleep, too much REM, too little REM, too little "Stage 4 REM" (sic!), etc. The theorists speak as if one could easily guess the "level of histamine", or the duration of "Stage 3 sleep" in a nap (no blood test nor EEG needed). Falling asleep within 3-5 min. should be a breeze in a healthy free-running individual, yet polyphasic sleepers constantly battle with not being able to fall asleep fast enough while in [circadian](#) high. Equally hard, they battle with waking up from the nap while in [circadian](#) low. No wonder then that oversleeping continues, and the battle with drowsiness takes its toll. In the end, the blogger usually postpones the experiment to "better times" (after Christmas, after vacation, after the crazy period, etc.). Sometimes the blog just ends abruptly without a conclusion. Rarely does the "polynapper" admit defeat, or concludes on the infeasibility of [polyphasic sleep](#). Few, disingenuously, claim the successful adaptation to the sleeping schedule and go on to blogging on other subjects.

Those young men tend to be hungry for life, hungry for experience, hungry for accomplishment, unable to adapt to 10 pm - 5 am sleeping schedule, rebellious and ready to seek new ways towards maximum productivity. These are mostly noble characteristics. But in a mix with ignorance, they can lead to bad health, poor decision making, poor mental performance, and social frictions. These personality types are also at a higher risk of dying young. [Polyphasic sleep](#) may also have its contribution: "*I have just driven polyphasically all the way from Canada*". There is only one major benefit of polyphasic sleep: polyphasic bloggers contribute to our understanding of sleep. No researcher could ethically subject that many individuals to the mental torture of polyphasic schedule. In this article: [Polyphasic sleep: Myths and Facts : Comic Relief](#), I compiled a list of funniest quotes from polyphasic blogs. Those illustrate the phases of the experiment with the special focus on oversleeping and alertness. Naturally, the list is very selective and out of context. Bloggers often claim they feel great, the method works, and they plan to continue indefinitely. Yet interwoven with the enthusiasm are red flags that amazingly keep passing unnoticed. A couple of blogs even scream great success. I won't quote or link to these as I found them quite disingenuous, or carrying a hidden agenda. These would dilute the truth and hype up a potentially hazardous lifestyle.

Polyphasic myths

When reading **polyphasic sleep** blogs, one can identify a number of myths that keep getting transmitted from blog to blog like a bad VD infection:

- **False!** most animals are polyphasic and so must be humans
- **False!** adaptation period is hard but it ends at some point
- **False!** polyphasic sleep saves you time
- **False!** polyphasic naps are REM-only
- **False!** you are more alert if you sleep polyphasically
- **False!** you are more productive if you sleep polyphasically
- **False!** you lose weight on the polyphasic sleep schedule. The opposite will likely happen due to the impact of sleep deprivation on appetite hormones.
- **False!** polyphasic sleep is healthy
- **False!** long naps are bad for you
- **False!** many naps are better than one nap even if you are not sleep deprived
- **False!** Claudio Stampi recommends polyphasic sleep to everyone
- **False!** polyphasic sleep maximizes the amount of **REM** an individual gets
- **False!** many geniuses of history slept polyphasically

To read some funny extract from polyphasic blogs, see: [Polyphasic sleep: Myths and Facts : Excerpts from polyphasic sleep blogs](#)

Factors that affect sleep

Stress

Stress is a sleep killer. Hormones associated with stress, such as [adrenaline](#), [ACTH](#), [cortisol](#), etc. increase alertness and reduce the sleep propensity. It is more difficult to initiate sleep in conditions of stress. Nighttime awakenings are more likely. The sleep structure may also change. The sleep may become shorter and less refreshing. Moreover, **sleep deprivation** will magnify the effects of stressful situations. Stress and bad sleep conspire hand in hand to make life miserable for quite a number of people in industrialized nations. Those who are sleepy and in stress are less likely to achieve their goals. That only adds to the misery.

In addition to its effects on sleep, stress may have a negative influence on creative work, learning, problem solving, etc. At its worse, stress can virtually shrivel your brain! Persistent stress and raised [corticosterone](#) levels have been shown to decrease [BDNF](#) in rat brains. This leads to the atrophy of the [hippocampus](#) - the chief memory switchboard! Stress can cut down your IQ. Not only for a day, but also, to a lesser degree, for a lifetime!

Stress is rooted in our emotional brain. Emotions are very difficult to control and will often determine a person's chances for success or failure. Negative emotions, such as anger, are counterproductive and contribute little to a person's growth. Positive emotions, such as well-dosed passion, help one overcome obstacles that are bound to be found on any race-course. Emotions are also transitive and tend to amplify in social groups. Anger begets anger. Cordiality begets cordiality. Your effort to beget positive emotions, in suitable circumstances, will send positive ripples through the social circles you interact with. Learn to capitalize on positive emotions and circumvent negative emotions. Invite all positive emotions that help you execute your grand plans. Condition yourself to love your work, people, and the world. Run away from sources of negative emotion.

The power of emotion comes from the fact that they are wired into the low-level brain structures that cannot easily be controlled by rational thinking governed by the [prefrontal cortex](#). An angry individual can command its brain to cool down, however, he cannot instantly reduce the level of adrenaline that has already been released into the bloodstream. A drug addict can rationally decide to give up drugs, but when the physical effects of the craving hit his system his rational brain is often powerless.

As it is hard to combat one's reactions to stress, one of the best ways to deal with stress is to run away from it. Stress is so important to your well-being that, if possible, a change of a job, a change of friends, a change of residence, or a change of lifestyle must be considered! Without these, even the best counter-stress advice may not work. Some people are inherently prone to stress and may find it impossible to live a life without it. Others may thrive on stress (to a degree). This article cannot possibly even touch the tip of this troublesome iceberg. If you suffer from bad sleep and stress, tackling stress may be your top priority thing to do. There are tons of books and blogs that deal with the issues of stress. It may seem redundant to produce yet another list. However, I thought I would make a selection sorted by

how much I believe it could be helpful, esp. with the view to sleep and creative work. I believe that prioritization by informative power as opposed to the curative power is important. For example, good health might be the most important factor in combating stress, however, you are probably already working hard on it. On the other hand, fewer people realize the effectiveness of pain in curing one's troubles! I am no expert in stress management, and I have been blessed with pretty strong stress tolerance that can make it hard for me to come up with a comprehensive list. If you think I could add something worth recommending to others, please let me know. Here is my list:

- **exercise:** if you impose a pain of exercise, your other pains may be seen from a new perspective. Try marathon or winter swimming. Few things can bring as much relief and pleasure as pain! Exercise helps you grow the brain - your best anti-stress ally. On the other hand, [sleep deprivation](#) and stress shrivel the brain making it harder to struggle through life.
- **eliminate interruption:** wherever possible, create protected zones in your day when you can focus on creative work. If possible, your entire morning should be protected to keep your mind clear. In that period, e-mail, phone calls, and meetings are all forbidden. If the protected zone follows a period of stress, you may never get back to your best mental shape. Take occasional creative vacations when nobody can reach you. If this is too much, try it once. Perhaps you will see your entire life in a new context.
- **measure the day:** instead of measuring your distance to the goal, measure how much you have accomplished on a given day. If your goals are ambitious enough, most of the time they will be pretty remote far on the horizon. With your eyes on the horizon, you do not have a good sense of progress. If you focus on the jobs for the day, you will get a better sense of the positive motion. Do not wait for the great trophy. Let the little good deed be its own reward. Once you reach a higher level of satisfaction with little things, your brain may work on a higher gear and perhaps carry you beyond your original target.
- **simplify:** simple living is more fun. Simplicity is a great escape from the rat race. Some ideas: ride a bike instead of driving a car, give up some of electronic must-have gizmos, try to live without deadlines, make fewer promises (including yourself), turn off your cell phone, take a creative vacation (one job, one goal, no distractions), etc. If you work on too many projects, try to finish one before you begin another. Learn to say "no" or avoid situations in which you have to say "no". Learn to delegate. If you are overloaded with information or e-mail, dump it all to [SuperMemo](#) and prioritize.
- **creative work:** I believe that few things are as fulfilling as creative work for a good cause. If you can sacrifice lesser things for a major creative goal, do it each time you have a chance. In the long run, productivity of the mind is one of the best formulas for a happy and healthy living.
- **slow down:** if you always keep running out of time for doing things, you might be loading too much on your plate. This magnifies your stress levels, and gives you an excuse to delay sleep. It is good to be fast and efficient, however, this cannot stretch beyond a certain biological limit where you shortchange your life for today's minor accomplishments.
- **prioritize:** one of great ways to pile up stress in the long-run is to procrastinate or work on fun things while neglecting the rest. You need to always prioritize honestly and religiously execute by priority. There will always be a long bottom of the list that will need to be ignored. Ignoring the overload and focusing on top-priority jobs is a thing everyone needs to learn. One of the ways to prioritize effectively is to use [tasklist](#) sorted by priority = value/time. Dumping tasks on a tasklist is both stressless (you always hope to execute at some point) and efficient (you always work from the top of the list).
- **sleep:** even though we speak of sleep as a goal, sleep is also great for clearing up stress. However, this weapon is effective only if you can run your sleep free. This is due to the fact that stress itself may cause phase delays. This means that you may need to delay sleep slightly and get up a bit later. If you need to get up early, sleep is less likely to be your ally. If you get into an unsettling situation that spoils the day, you can always hope for some solid exercise followed by some solid sleep. Hang on to the comfortable thought that human biology will work for you. Stressful situations often seem much more stressful when stress adds up. Stress multiplies stress. Good sleep gives you a new, more honest perspective on today's worries.
- **be nice:** if you have something positive to say to someone, say it! Help others go through the day with a smile. If you have something negative on your mind, ponder if expressing it is necessary. Small things are not worth fighting for. When you are in a bad mood, remember that even if you force onto yourself a bit of niceness for others, you will see that niceness is infectious, you will get some back and a day will feel sunnier. If this advice does not work, perhaps you are in a wrong environment?
- **family:** family is a chief source of stress for many. However, it can also be the best form of stress relief. If you are just about to build a family unit, keep in mind that stress-free life in a long-term should be one of your chief goals. If your relationship is a string of worries with no light in the tunnel, perhaps it is not your best long-term investment?
- **nature:** sadly, many of us lost the ability to feed on the beauty of the natural world. For a stressed workaholic, a trip to the woods or the mountains feels like a waste of time that only magnifies the stress. However, the love of nature is atavistically dormant in everyone. It can be reawakened. It can be re-learned. Once it is restored,

contact with the nature is one of the best stress relievers. Needless to say, nature preserves should be mobile phone free zones!

- **contentment:** one of the best ways to boost one's resistance to stress is work on one's overall contentment. Research shows that contentment is primarily based on self-esteem, relatedness (relationships with other people), autonomy (being in control) and competence (being productive). To a degree, all these factors can be influenced. Contentment makes it easier to ignore minor annoyances and see the big picture and big goals.
- **avoid conflict:** go to battle only for major life-changing causes. Too much time on this planet is spent on battling for or against little things and/or minor principles. A great deal of conflict can be resolved by just ignoring it and focusing on more important things.
- **avoid bad people:** one of the chief sources of stress is other people. Some of them are good people that bring stress by virtue of their job, duty, good intent, ignorance, etc. Others are just plain bad people that would best be avoided. In your choices of a spouse, job, gym, friends, etc. make sure you stay away from people with a talent for spoiling your day. Those choices will determine your stress levels, your ability to sleep and your ability to focus on things that are important.
- **plan ahead:** when you wake up with a set goal for the day, your mind is taken away from stressful distractions and your productivity soars. Review your goal lists regularly to refocus the mind. You need separate goals for work, family, exercise, etc. They are all helpful in a smooth and productive sail through each and every day.
- **time-management:** solid time-management is essential for productivity. Low productivity begets low productivity. Once your efficiency drops, it will have a negative impact on your motivation undermining your progress even further. In terms of a nagging stress, few things are as bad as piling lists of things undone. Those nagging lists are best tackled with time-management (getting things done), and prioritization (getting rid of things than cannot be done). Consider [Plan](#) in [SuperMemo](#) for time-management, and [Tasklists](#) in [SuperMemo](#) to stresslessly cut the bottom of the to-do list.
- **health:** healthy lifestyle is vital. Healthy body makes stress management easier. Here sleep can be a part of a negative feedback loop (less sleep, more stress, less sleep), or a positive feedback loop (good sleep helps combat stress, stress management helps you sleep better, etc.)

For more, see this immortal text: [The Medical Basis of Stress, Depression, Anxiety and Drug Use!](#)

Positive stress

A degree of stress can also be a positive force. Some forms of stress are great energizers. I believe that when optimizing one's day for good sleep, good learning, and good creativity, it makes good sense to take into account the timing of stress. Stress before sleep will have a negative impact on sleep. Stress before creative work or learning will have a negative impact on the results of brainwork. A vast majority of people do not have much influence on the timing of stress. Stress seems to pervade all our lives. However, if you belong to the lucky few who can decide when to open a letter, read mail, make a difficult call, schedule a tough meeting, tackle a stressful task, you should try to employ stress to work to your advantage. I believe that the best and the only right time for tackling stressful situations is before or at [siesta](#) time. This timing spares the most creative morning period, and provides a sufficient time buffer before the night sleep. Moreover, it helps you sail through the less productive section of the day, including the mid-day dip in alertness (if you cannot afford napping). If you are a napper, adding exercise after the stress slot could pretty efficiently flush away the effects of stress. A dose of stress can actually improve the efficiency of exercise, and if exercise is not efficient enough to erase the effects of stress, you will be sacrificing only the lesser component of your daily sleep cycle: the midday nap.

Alcohol

Alcohol is a major enemy of a creative individual! In excess it is highly toxic to the brain! Even small doses can reduce the quality and the density of [REM](#) sleep. Alcohol also suppresses deep sleep, produces sleep fragmentation, and relaxes the upper airway muscles, which worsens snoring and severity of obstructive [sleep apnea](#). Apart from its negative impact on sleep, alcohol reduces cognitive powers, inhibits memory encoding, and should be particularly avoided at times of creative effort!

On the other hand, lots of research indicates that small doses of alcohol may benefit health. Actually, a drink a day may be the simplest known method of preventing arteriosclerosis, heart attack, and cerebrovascular disease. There are reports that moderate beer drinking, or perhaps even alcohol in general, may reduce the incidence of Alzheimer's (Breteler et al. 2002^[66]) (beer belly or aluminum in beer cans will have an opposite effect). In smaller quantities alcohol can improve the blood lipid profile, while, in contrast, excess drinking is associated with hypertension. Some physicians recommend daily alcohol in very small quantities (not more than a drink per day).

To a highly creative individual, alcohol poses then a health-vs-brain dilemma. Certainly it should be avoided 3-5 hours before sleep. It should also be avoided altogether before intellectual work if there is no intervening sleep period in between. This would leave place only for very moderate drinking in the early evening (assuming you do not do any brainwork later on) or at [siesta](#) time (assuming that this is the time you take a break from intellectual effort to take a nap).

[Exercise](#) is known to reduce drinking, possibly through its impact on the reward centers. However, it should also provide some protection against the toxic effects of alcohol on the brain. Exercise accelerates circulation and speeds up the conversion of alcohol into [acetyl-CoA](#) that can then be quickly used as a source of energy. This prevents a buildup of [acetaldehyde](#) that is the most toxic metabolite of [ethanol](#). Acetaldehyde is partly responsible for the hangover and may have carcinogenic properties. Exercise also helps you reduce the level of blood [triglycerides](#) that might increase as a result of chronic drinking. Regular moderate drinking improves the metabolic machinery used to neutralize alcohol. On the other hand, binge drinking is equivalent to destroying one's own brain. If you ever get to the point of slurred speech, or experience a hangover, you know that bad things happen to your brain! The younger you are, the more damage you can expect!

You should never drink before sleep. Alcohol is quickly metabolized, and will produce an acetaldehyde rebound effect that will greatly increase chances of waking up during the night. This effect keeps alcoholics up at nights, deprives them from [REM](#) sleep, and may actually be responsible for [delirium tremens](#) (and perhaps even [Korsakoff psychosis](#)). Even moderate amounts of alcohol will have a noticeable effect on the quality of sleep! **Make sure that alcohol is out of your system before your night sleep!** A book before sleep may be as effective as a glass of wine!

You should never drink before creative work or learning. Even a gulp of beer can affect your performance. Some users of [SuperMemo](#) claim they enjoy moderate drinking while learning in the evening. This is understandable if the function of evening learning is fun and relaxation without great expectations as to the learning effect itself. I am not sure if this worsens or alleviates the impact of memory overload on the [hippocampus](#) and the adjoining networks. However, I know for a fact that the memory effects will be greatly reduced due to the descending evening circadian slope and due to alcohol itself.

Some drinking rules you might consider:

- alcohol in the blood before the night sleep will seriously reduce the quality of sleep
- alcohol suppresses creativity
- alcohol makes learning ineffective
- hangover is bad for the brain and indicates excess
- slurred speech or balance problems indicate excess
- if you violate the excess rules (above), take a month-long break from alcohol to prove to yourself that you are not on the way to addiction
- try to balance each drink with at least one hour of accompanying exercise to protect the brain

Read more here:

- [Alcohol and the Brain](#)
- [Alcohol: Health Benefit or Hazard?](#)

Caffeine

Caffeine is the number one drug used against sleepiness! 90% of Americans use it in some form. It can be found in coffee and coke, as well as in smaller quantities in tea and chocolate. It is addictive and acts via similar channels as [amphetamines](#) and [cocaine](#). It also affects the reward centers (including the [nucleus accumbens](#) (Goldberg et al. 2002^[67])). As [caffeine](#) has a profound effect on the central nervous system by blocking [adenosine](#) receptors, it is widely used to tackle drowsiness. However, majority of people little realize that it works well in your struggle with the adenosine-related [homeostatic component of sleepiness](#), while it is quite inefficient in overcoming [circadian sleepiness](#)! Moreover, used against the latter, it can actually be quite unhealthy! If you abuse [caffeine](#) or use it at the time when your [body clock](#) tells you bedtime, you will only experience the symptoms that gave [caffeine](#) all the bad rap. These include: [heart arrhythmia](#), irritability, overwhelming tiredness, depression, increased risk of miscarriage, and a typical coffee abuser's "sickness in the stomach". No wonder the popular myth says that coffee is bad for health and can contribute to a heart disease.

Surprisingly, the research on the health effects of [caffeine](#) does not seem to confirm its harmfulness. Considering the way coffee is manufactured, it may seem surprising that its carcinogenic effect is insignificant. Some publications even indicate a positive impact of coffee on health and longevity. If the research seems contradictory, it probably comes

from the fact that some people drink coffee at the "right time", while others try to compensate for [sleep deprivation](#) or to mask [circadian](#) sleepiness. The link between coffee and heart disorders is weak, may depend on individual genetic ability to metabolize caffeine, and may be attributed to [caffeine](#) abuse in the form of excess doses or wrongly timed doses. Some research has even found that 3-5 cups of coffee are optimum for lifespan. The same research was criticized for failing to notice that coffee is more popular in well-to-do households that favor longevity. There have also been reports of positive impact of [caffeine](#) on memory. [Caffeine](#) increases the levels of [BDNF](#) in the hippocampus, and might perhaps boost neurogenesis. It was found to be modestly preventive against the Alzheimer's disease. You can then assume that [caffeine](#) is rather harmless in smaller 200-400 mg/day quantities (equivalent of 2-4 cups of coffee). Note that 50% of Americans take more than that. **For [caffeine](#) to be harmless, it must be taken at the right time!**

Caffeine tends to drive many people into a vicious circle: you drink it, you get a boost in [epinephrine](#), you feel more energetic, you get a boost in [dopamine](#), you feel better, you feel you can stay up late, you sleep less, you are more sleepy on the next day, so you need more caffeine, due to downregulation you get less boost per cup, you wonder why it does not work this time, you increase the dosage, and the vicious addiction circle continues. Coffee drinkers may occasionally experience migraine-like headaches. These are caused by an increased activity of adenosine receptors on days when the supply of [caffeine](#) is less. This results in the dilation of blood vessels in the brain. Vasodilation or activation of [purine receptors](#) on sensory neurons produces the headaches. Half a normal dose of [caffeine](#) should help. Conclusion: **if you want to go straight on coffee, do not go cold turkey.** Allow of a couple of days for your body to gradually fight off the addiction. A rational approach to [caffeine](#) is: use it as a [circadian](#) enhancer! Even though I always advise to avoid using substances in regulating sleep, you can use [caffeine](#) to accelerate your transition from sleep to full mental alertness. Small dose in the morning will shoot your alertness slope up and the regular intake will produce mild addiction that should help you fall asleep in the evening. This approach should be largely neutral to your health, to your sleep architecture, and positive to your alertness (at least very early in the day). **Never use caffeine to cover up for insufficient sleep!** Current knowledge about [caffeine](#) supports the recommendation for a cup of coffee in the morning in otherwise healthy individuals. As black coffee can be irritant to the stomach lining, coffee should rather be drunk with milk or cream. In regular nappers who do not battle [insomnia](#), the [circadian](#) rhythm should yet permit drinking coffee immediately upon waking up from an afternoon nap.

As an arousal drug, [caffeine](#) may induce insomnia. This is why it should never be taken later than 6-7 hours before sleep. [Caffeine](#) half-life is about 6 hours for a healthy individual, but can vary substantially from person to person! Taken too late, [caffeine](#) will suppress [REM](#) sleep with detriment to the quality of sleep and its effect on memory. At the same time, when taken regularly early in the day, it may actually produce mild withdrawal effects and promote sleep. Its impact on sleep structure should also be minor if administered early enough, however, even a morning intake will reduce deep sleep in the night (Dijk et al. 1995^[68]). [Caffeine](#) cannot serve as a weapon against [sleep deprivation](#). Only a sufficient amount of night sleep can play that role. [Caffeine](#) should also not be used against the [circadian](#) sleep component. As argued throughout this article, [circadian](#) rhythm should best be left alone to run its course!

Some sleep experts recommend coffee before a nap to shorten its duration and/or to ensure waking during Stage 2 [NREM](#). This may be ok in case you need a quick restorative nap in a hurry, e.g. in case of a drowsy driver. However, an optimum nap in a free running cycle will naturally last no more than 30 minutes, esp. in conditions of stress. The effect of napping may be short-lived if the nap is artificially cut short with a cup of coffee.

The only good time for drinking coffee is in the morning! (or after a nap in habitual nappers)

Never drink coffee to overcome circadian sleepiness!

Dr Stickgold says: *"In all likelihood, the vast majority of people drinking coffee in the morning are doing so, consciously or unconsciously, to correct from sleepiness due to inadequate sleep quantity or quality"*. It does not need to be the case. Even after a good night sleep, without sleep deprivation, coffee can crank up the creative powers of the brain. However, it most likely does so at the cost of attention. It may then help in creative problem solving, but it might also reduce one's attention during a morning lecture or magnify the effects of a stressful situation. **Ultimately, you need to be your own judge and see if this is really your best morning drink.**

Sleeping pills

Michael Jackson was a genius. He obsessively cared about his health. He wanted to be immortal or at least live past 150. He even contributed to a rumour that he slept in an [oxygen tent](#) to combat aging. And yet he committed a cardinal mistake of sleep hygiene: he used medication to control his sleep. This is why he died at 50. He could afford the best medical advice, and yet the genius of pop died of ignorance.

Millions of people on this planet take [benzodiazepines](#) to get themselves to sleep. Others [drink](#) themselves to sleep. Yet others take a puff of [marijuana](#). Inevitably, the outcome is the same: unrefreshing sleep and daytime tiredness. [Dr Kripke](#) showed in his [research](#) that people taking sleeping pills die younger. Why then do so many people make the mistake of medicating sleep? For many, unrefreshing sleep is better than no sleep at all. More importantly though, as society, we have lost the true sense of what a refreshing night of sleep can do to our brains and bodies! All this damage is done at a time were very little is needed to get great sleep in a majority of healthy people:

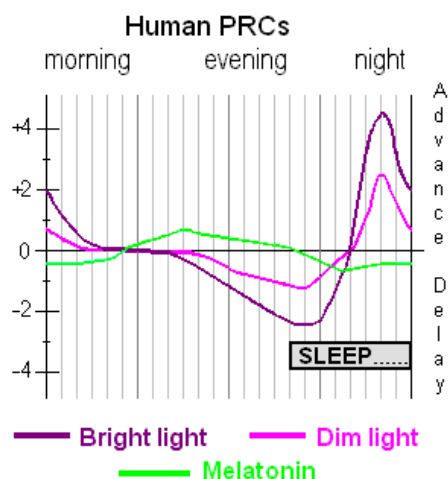
1. sleep at the right time, and
2. sleep until you wake up naturally (for more see: [Formula for good sleep](#)).

Wherever possible, avoid sleep inducing medication. Even a seemingly natural product, [melatonin](#), is not without its downsides. Read about [free running sleep](#) instead.

Melatonin

Melatonin is the only proven natural sleeping pill with few documented side effects. No wonder it is getting more and more popular. In addition, its antioxidant properties have sparked interest in [melatonin](#) as an anti-cancer agent. In the wake of such interest, there is always a wave of cheap counterfeit drugs hitting the market, esp. via the Internet sales. Those may contain no [melatonin](#) whatsoever.

Melatonin is a natural sleep hormone synthesized in the [pineal gland](#) from [serotonin](#) by [acetylation](#) catalyzed by [serotonin N-acetyl transferase](#) to form [acetylserotonin](#) that is later methylated with participation of [SAM](#) to [melatonin](#). [Melatonin](#) is released during that part of the [circadian](#) cycle that corresponds with the period of darkness in both nocturnal and in diurnal animals. Diurnal animals, like us, are those that are active during the daylight period. However, [melatonin](#) is only an intermediary in the complex process of sleep onset. It can accelerate the onset, and can slightly advance the sleep phase, however, it cannot produce sleep on demand, and the sleep it can trigger will often differ in structure from a normal healthy sleep. Melatonin's impact on sleep structure is probably the reason why many people who use [melatonin](#) as a sleeping aid report feeling less refreshed in the morning. The explanation of its limitations may be in the fact that [melatonin](#) is produced downstream from the [SCN](#), and as such cannot be considered a universal sleep hormone that affects the root of the sleep onset mechanism. [Melatonin](#) produces phase shifts along its unique [PRC](#):



However, it is not clear to what degree the phase shifts induced by [melatonin](#) are a result of the direct impact on the SCN where most of the receptors for [melatonin](#) reside, and to what degree it is a result of the phase shifting impact of the arousal in earlier waking (in evening administration). Whatever the answer, sleep induced with [melatonin](#) is not likely to be physiologically equivalent to natural sleep due to the bypassing of some of the stages of the [circadian](#) control. I guess it might be compared to sleeping in a slightly earlier phase with corresponding changes in the sleep structure.

Doses of up to 0.3 mg raise the serum [melatonin](#) to its natural nocturnal level. The half life of [melatonin](#) is around 40 minutes, which is important to know when timing [melatonin](#) administration to induce a [circadian](#) phase shifts. Side effects of high dosage of [melatonin](#) (above 1 mg) include cognitive impairment, drowsiness, nausea, headaches as well as troubling dream imagery. It is not clear if the negative impact of [melatonin](#) on cognition is caused by its effects on sleep structure or a direct effect of [melatonin](#) on the brain and/or other tissues. High doses might be counterproductive as they could produce phase delays caused by prolonged action on the delay side of the [PRC](#) that

begins pretty early in the [subjective night](#). Needless to say, for the same reason, additional administration on a sleepless night would act in opposition to the desired effect as compared with a timely evening use.

Melatonin can be used to remedy phase shifts in [DSPS](#), however, it cannot be considered a cure. For its effects to continue, it requires continuous administration. The withdrawal might actually worsen the symptoms due to various downregulation issues and suppression of the endogenous release. Total sleep time does not increase while the subjective alertness may actually drop (Sack et al. 2007^[39]). [Melatonin](#) has also been considered for morning administration in [ASPS](#), however, considering its impact on cognition, this application would almost certainly prove highly controversial.

For a creative individual, **melatonin should only be used when absolutely necessary** (e.g. in order to generate phase shifts needed to maintain a schedule needed to function in society). The timing and dosage are essential for the therapeutical effect. Those must be consulted with a qualified professional!

Nicotine

Smoking destroys sleep, destroys health and kills many good people all too early. Do you think Obama is a cool and rational customer? Note that he is in a powerful grip of nicotine addiction. Even though he claims to have quit just in time to be president, rumour says he still takes a secretive puff from time to time.

For the sake of good sleep and good health, quit smoking now!

Did you hear of a great method for quitting smoking called the "**incremental withdrawal**"? Probably not. I coined the term on the spot. However, I saw many people succeed using this method. This is how it goes:

1. Count exactly how much you smoke per day. Let's call that number *Baseline Count*
2. Take 95% of the *Baseline Count* and call it your *Current Count*
3. Every morning, make sure you put your *Current Count* into a cigarette box. Plan it as you wish, that box must be all you smoke on that day!
4. Do you feel any better on your 95% level? Do you feel you could sustain this indefinitely? If you feel strongly about those questions, reduce your *Current Count* by one.
5. Stick with your *Current Count* until you are really in a mood to make another step forward. Remember that reducing *Current Count* by more than one is risky to your resolutions. Remember that it makes sense to go through a whole constellation of days in your schedule (e.g. workdays vs. weekends) before you reduce your *Current Count*. Don't leap ahead before you are sure.
6. Go back to Step 3 and stay in this cycle until your *Current Count* drops to zero. Remember that the key to success is always feeling great about the procedure. You need to sense progress, and enjoy it without suffering too much of withdrawal consequences.

I like the incremental withdrawal method because it increases the chances of success. In addition, cold turkey is not without risks. Quitting is always great for your cardiovascular system. However, withdrawal can put a tremendous stress on that system. It can actually kill you! I favor methods that fiddle less with dangerous aspects of human physiology. If you really want to prove your strength, go fast through the incremental procedure instead of quitting instantly. Quitting cold turkey is not only risky, it also increases the chances of a relapse. This is due to the immortal maxim: Easy come, easy go. Some more tips: [How to quit smoking?](#)

If you still cannot live without nicotine, [Nicorette](#) chewing gum may be the simplest over-the-counter way to tackle the addiction without the carcinogenic effect of cigarettes. Obama swears by *Nicorette*. Still *Nicorette* may even be more addictive than cigarettes on their own, and the short half-time of nicotine may result in overnight craving that disrupts sleep!

Remember that smokers usually experience a shallow and unrefreshing sleep. Smokers get less [REM](#) than non-smokers! Even though nicotine make you feel more creative, without [REM](#) sleep, your creativity and problem solving capacity will inevitably drop. Don't get fooled by the transitory effect of nicotine injections! You will be less smart in the long run! Nicotine will improve your alertness by acting on cholinergic receptors in arousal areas including an important sleep center, [basal forebrain](#) (see: [Why do we fall asleep?](#)). However, it will also cause night time withdrawal effect that often results in premature awakening. Do you often wake up after just 2-4 hours of sleep? If you quit, you might leave those premature awakening behind.

Interestingly, only 4% of users of [SuperMemo](#) are smokers ([source](#)). In addition, users who smoke spend much less time on learning with [SuperMemo](#) (an average of about 10 minutes per day as compared with the usual average of around 30 minutes). This is more related to the hormonal balance in the brain of a smoker than to smoking itself.

Smokers simply do not have the patience for [SuperMemo](#) and are less likely to be in-depth learners. Yet there are strong indications that those who quit smoking show improvement in their perseverance in learning! That is one more reason to quit!

Exercise

Exercise is good for sleep

If employed skillfully, exercise is a blessing for sleep. Exercise is good for health, and whatever is good for health is also good for sleep. Exercise is known to enhance deep sleep and promote the nocturnal release of [growth hormone](#), which has been found to stimulate memory [consolidation](#) via its impact on [protein synthesis](#). Exercise, deep sleep and GH have all been linked with neurogenesis (i.e. brain growth). A good night sleep following exercise causes an increase in release of [BDNF](#) and an increase in nerve cell proliferation (for example see: [Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus](#) (Van Praag et al. 1999^[69]), [Sleep deprivation reduces proliferation of cells in the dentate gyrus of the hippocampus in rats](#) (McGinty et al. 2003^[70])). In other words, exercise builds both muscles and the brain! (Gambelunghe et al. 2001^[71]).

Sleep, learning and exercise are the best friends of a smart brain!

What is the best time to exercise?

There are different forms of exercise: the type, the intensity, and the timing will affect sleep. The number of possible permutations is huge. It would take another article to list them all. Read about your favorite form of exercise, and experiment on your own! I tend to favor exercise at the descending slope of the [circadian](#) curve, either before lunch or dinner, or in the early evening. This choice is dictated by the wish to preserve the period of highest alertness for creative work. In addition, peak alertness times are not necessarily peak physical performance times that come at a slightly later phase. Metaphorically, the brain wakes up faster than the cardiovascular and, most of all, musculoskeletal system. Exercise before a siesta-time meal can deepen the mid-day nap as long as there is sufficient "cooling" period. Late afternoon exercise might be best for exercise's sake. Endurance and strength tend to peak at that time while the chances of injury are lowest (one theory says that it is due to the least catabolic [testosterone/cortisol](#) ratio). Early evening exercise, if not too intense or injurious, will do wonders to the quality of night sleep. Moreover, evening exercise seems like a good filler for the time when the brain is already winding up its capacity for mental effort. Exercise may increase the demand for sleep even more than learning. However, high adrenaline, competitive, emotionally charged, or injurious exercise that comes too close to the [subjective night](#) sleep could be disruptive and reduce the quality of sleep. Also, with some exceptions, it might not be as healthy as exercise at a more suitable [circadian](#) phase. Late exercise may increase the risk of injury. It can also result in contradictory signals for the cardiovascular system that is also supposed to wind down for the night. Exercising before sleep is little less contradictory than exercise after a meal. This way a late evening marathon should be discouraged, while some calisthenics or moderate body building might be encouraged. Again, your own experimentation is essential. If your way of exercise feels great, and your creative work does not suffer, and you sleep great, chances are you are doing all things right, and you are more likely to persist in your exercise regimen for psychological reasons. Early morning exercise is great for people who battle with sleep phase problems. If you find it difficult to fall asleep early enough and need to resort to an alarm clock due to oversleeping, early jogging in bright sunshine can help you shift the sleep phase. Exercise and light are powerful zeitgebers. Naturally, this practise will also contribute to your running out of mental energy earlier in the day, which, at times, is exactly what you need to remedy sleep phase problems. Republican presidential candidate [Ron Paul](#) confessed that the best time for exercise for him is the very early morning. He regularly takes long walks at the start of the day. This may work for him as walking is not injurious and can indeed be taken on very early in the morning. Moreover, for a politician, this exercise does not need to quarrel with his creative regimen. Walking is great, for example, to reiterate main talking points for an evening debate. Paul's example shows that there is no one-for-all cookie cutter rule for everyone. Late evening exercise, for example, tends to delay the sleep phase and might be helpful in people suffering from [ASPS](#).

Formula for best exercise

If you anticipate your exercise with enthusiasm or even euphoria, you know that you chose the right type, timing and intensity. If you feel pleasantly exhausted, if you fall asleep fast, and if your sleep is deep, you know that you are doing things right. If you cannot drag yourself for a jogging, try walking, or swimming. If water is too cold, perhaps try swimming in an indoor pool. If swimming is not challenging enough, try the adrenaline of team sports. Or perhaps a social setting of a gym will suit you better. If exercise worsens your [insomnia](#), try it earlier, change the intensity, or the

type of exercise (e.g. to one that is less injurious). Read relevant exercise tips (rehydration, preventing injuries, etc.). Exercise can be and should be addictive. Many people hate exercise because they never tried it properly. If you are one of those, try again, perhaps with a personal trainer (for a while). People hate exercise only if they do not know how to exercise!

Listen to your body! Exercise should make you enthusiastic before, and contented afterwards. If that's the case, you are almost certainly on the right track.

Sleep is good for exercise

It is well-known, at least amongst body builders, that sleep is necessary for muscle growth and repair. If you do not get enough sleep, your body building effort will be ruined. The muscles need sleep, but we do not sleep because of the muscle needs. For the organism to cope with muscle regeneration, there is no need to shut off the [central nervous system](#), and make one unconscious for a third of one's life. If REM paralysis was to play this role, it could be enforced at the level of the [medulla oblongata](#) without making us unconscious. If growth hormone secretion was to play a role, it can also be upregulated in abstraction from the state of the central nervous system. There are many other benefits of sleep for muscular regeneration but none will require the state of unconsciousness on its own. For evolution, using sleep for muscle regeneration would be as sensible as shutting down the government in order to fix a highway. The universal belief that sleep evolved to promote rest and regeneration comes from the feeling of being "broken down" and "unrefreshed" once you do not get enough sleep. However, you do not feel crushed after an all-nighter because of the [damage inflicted by the lack of sleep](#). Your state is simply your body's own defense against not getting enough sleep. You can cheat those defenses to a limited extent. One night of good sleep, and your body seems to be back to shape. The only true damage inflicted by [sleep deprivation](#) is to the fabric of memory. Unfortunately, this damage is imperceptible, and the universal perception is that sleep is cheap and can easily be dispensed with. Whether you sleep for the sake of your memory or for the sake of your muscles, sleep is good.

Sex and exercise differ

Someone noticed that I contradict myself recommending sex before sleep and saying that exercise directly before sleep is not recommended. One only needs to observe that hormonally sex and exercise differ like chalk from cheese, the degree of stress in sex should be negligible (at least in a stable and harmonious relationship), chances of injury are not too high, etc. This kind of exercise before sleep I wholeheartedly recommend.

TV

Many sleep experts say that a bedroom should only be used for sleep and sex. They also imply that there should be no TV in the place where you sleep. However, this advice seems to stem from a futile battle against [sleep-onset insomnia](#) that is so often caused by sleep phase problems. If you go to sleep very early, and you are not sleepy enough, it is quite natural that a TV or radio could provide a distraction or even wake you up prematurely (e.g. with an annoyingly loud advertising). The effect of a TV sound may be quite different when you sleep in the right phase (e.g. in [free running sleep](#)). In those circumstances, you go to sleep when you are really ready. If you run a pre-recorded material, and set the timer to turn the TV off in 5-15 min, you might be actually doing your sleep a good service. An important thing for a good night sleep is to leave all issues of the day behind. Even pleasurable thoughts related to your life can keep you up and excited. At the same time, repetitive news from foreign lands or a moderately interesting science program can effectively lull you to sleep in 2-4 minutes, which should be your healthy target. Some TV or radio news for an adult can be compared to soothing music for a newborn or a fable that mom reads to a child before sleep. This has even become a part of [bibliotherapy](#). Many people read themselves to sleep, which is a good idea (as long as passionate reading does not go on till morning hours). An audio-book might also be effective in a different way. It is a very personal issue. You need to test it for yourself and avoid the dogma. If you need to wake up early and you have problems with falling asleep, you may follow the conventional advice. However, if you can afford to run your sleep free, you should go to sleep only then when you are truly sleepy. In those cases, to TV or not TV, is really not a question. You can get those 2-3 min. of news, or just fall asleep in absolute silence. It is up to you.

Cannabis

Marijuana is a well known sleep "remedy". It is particularly popular among [DSPS](#) sufferers who claim it helps them go to sleep earlier. Unfortunately, research seems to indicate that cannabis changes the structure of sleep (e.g. reducing the proportion of [REM](#) sleep (Feinberg et al. 1975^[72]; Fujimori and Himwich 1973^[73]), which can also be expressed by particularly lucid dreams in withdrawal). This results in lesser sleep efficiency and possible premature awakening after the administration of cannabis. Due to the suggested impact on the release of melatonin, soporific effect and

possible premature awakening, cannabis might seem like a remedy that might stabilize the [circadian](#) cycle in DSPS. However, this stabilization would be achieved at the cost of quality of sleep and productivity. Subjective sleepiness reports seem to indicate that indeed marijuana smokers do wake up much less refreshed. Moreover, they experience unusually high energy levels and rich dreams in withdrawal, which is an indication of the negative impact of the drug on the quality of sleep.

In abstraction from other potential negative health effects of smoking marijuana, it should definitely be avoided in the "protected zone", i.e. in the hours preceding sleep. In that respect, it is not much different from alcohol or [benzodiazepines](#), which are also well known to affect the sleep structure and the efficiency of sleep. The same rule applies in all these cases: **treat your brain before sleep no worse than you treat your brain before creative work**. Whatever is bad for creativity is likely to be bad for the quality of sleep.

Dr [Buzsaki](#) spoke in an [interview](#): *"Timing and network synchronization are the essence of all cortical computation, and the timing ability of cortical networks is reflected in the rhythms they produce. We have shown that [deterioration of synchrony of hippocampal assemblies](#), e.g., induced by the active ingredient of marijuana, is reflected quantitatively by the field rhythms. In turn, the degree of impaired hippocampal oscillations is correlated with the deterioration of memory performance. [...] Oscillations constitute a robust phenotype that reliably 'fingerprints' an individual and expected to alter in most psychiatric disorders. Often such changes are most pronounced in sleep".*

Sex

Sex is good for sleep, however, using sex as a "sleeping pill" may not be too good for sex itself. For [circadian](#) reasons, morning sex should be best (in [free running](#) condition). [Testosterone](#) peaks in the morning. However, sex is a powerful hypnotic, and morning sex may undermine morning alertness. On the other hand, sex before sleep is likely to help you fall asleep faster. Evening sex may be less "efficient". You are more tired and perhaps not in a mood. But sex is a great soporific! Sex is a very personal thing, but I believe that creative people perform better if they sexercise before sleep or at [siesta](#) time.

If you practice sex without procreative intentions, positive influence of sex on sleep may be your number one excuse for sticking faithfully to your conjugal duties. Here is also a recommendation to stick with a single partner. Longevity studies show that healthy stable monogamous sex life is one of powerful life expectancy determinants (even though, in this case, monogamous should stand in opposition to promiscuous rather than to polygamous). While monogamous sex is generally good for sleep, sex with your new great love may actually disrupt sleep. Apart from a healthy dose of [endorphins](#), it will also raise your [catecholamines](#) that may fragment sleep cycles. For the same reasons, promiscuous sex may also fail to play the expected hypnotic role.

Many highly creative people opt to sleep in beds that are separate from their partners. This approach may undermine family cohesion and sex life, however, it is pretty understandable, esp. in people who love to burn the candle at both ends. Co-sleeping is probably a better choice healthwise as long as it does not affect the quality of sleep. In addition, both partners should sleep in similar hours and forgo the alarm clock. This is a hard personal choice that needs to balance a healthy tradition with the quest for productivity. I do not think I can recommend one choice over the other. It is too complex and too personal.

Diet

Foods that we eat affect our alertness, and our propensity to sleep. However, the role of foods is largely overappreciated. For example, it is very difficult to significantly affect the [circadian](#) cycle with basic foodstuffs. It is the timing of meals that may matter more. [Homeostatic](#) sleepiness can be enhanced with some foods, esp. when consumed in larger amounts. However, this is highly individual. For example, your glucose tolerance will determine the effect of glucose-rich foods. Your ability to metabolize [alcohol](#) or [caffeine](#) will determine the degree of the effect of these two frequently consumed mind-altering substances. Your food intolerance and food allergies can have a big impact as well. Your current satiety status, rehydration, caloric needs, etc. also play a role. Ages old recommendations, such as "a glass of warm milk before sleep" will only play a marginal role in helping you sleep well. It would take a separate article to describe all nuances and possible interactions and synergies. I will therefore limit this section to the following basic rule-of-the-thumb mnemonics:

- whatever is good for health is also likely to be good for your sleep (at least in long-term). Healthy body will ensure healthy sleep. Consult your favorite healthy diet book or website. Keep learning! You need to virtually memorize an encyclopedia of foods to truly understand all nuances of different diet choices.
- if you are on an obese side, avoid meals in the last third of your waking day. For hormonal reasons, this will help you keep your weight in check, and help you sleep better.

- even if you are on a weight loss program, before creative work you need foods that will gradually release glucose into the bloodstream while you work in high gear
- avoid alcohol and [caffeine](#) in the last third of your waking day

Your best diet for good sleep is roughly the same diet that is good for your health and longevity.

Variations in the healthy diet are unlikely to have a major impact on your sleep. You may only want to watch caffeine, alcohol, exotic herbal products, toxins, and all substances with a substantial effect on the nervous system. Otherwise, the diet should have only a minor impact on the demand for sleep, [circadian](#) patterns, [homeostatic](#) sleepiness (with a major exception of [caffeine](#)), progression of sleep stages (with a major exception of [alcohol](#)), or neural efficiency of sleeping. The reason for this is the same as in many other cases of homeostasis: the organism is striving at retaining the [homeostatic](#) balance throughout all systems. Rare foods, herbal preparations, pharmacological intervention, etc. can always change or unbalance internal equilibria, but a standard healthy diet is far less likely to do so. It takes an extraordinary nutritional error to stop the human heart. It is even harder to stop the [gene-based body clock](#).

Vegetarian diet

Lots is being said about vegan or vegetarian diets in reference to sleep. It is not true that herbivores sleep less, as there are many exceptions to the rule (there are herbivores that sleep three times as much as short-sleep carnivores). There is, however, a correlation, which says that the decrease in sleep time is faster with the increase in weight in herbivores than it is in carnivores. In other words, heavy herbivores, like giraffe, indeed sleep very little. This correlation may be explained by changes in metabolism, but it could also reflect a different lifestyle. A predator may eat once and then spend many hours on digestion, an elephant keeps munching all day long to sustain its energetic needs, while a gazelle needs to maximize vigilance to ward off an attack from a long sleeping lion. The correlation between the diet type (herbivore vs. carnivore) and the length of sleep links sleeping habits with eating habits of a species, not with eating habits of an individual. While humans are omnivorous, you won't become an herbivore, and allegedly a short sleeper, by enforcing new eating habits.

Sleep and glucose metabolism

While changes to a healthy diet do not have much impact on the quality of sleep, sleep has a powerful impact on the metabolism. [Sleep deprivation](#) research tells us that adequate sleep is particularly important for healthy glucose metabolism. Sleep deprivation, shiftwork and jetlag all facilitate obesity and the development of [type II diabetes](#). The possible reason is that [sleep deprivation](#) decreases [leptin](#) and increases [ghrelin](#) for the same caloric intake (Knutson et al. 2007^[74]). Those two hormones control the appetite and affect the [homeostatic](#) set point for the body fat level. In [sleep deprivation](#) we tend to eat more and achieve satiety at a point which will increase the body fat percentage. In caloric terms, those changes can be pretty dramatic. Halving one's sleep might increase the demand for food by 1000 kcal per day. There are also indications that the appetite switches to substantially favor high carbohydrate foods. This only magnifies the problem. Last but not least, [sleep deprivation](#) simply makes you lazy. You are less likely to expend those extra calories.

Getting sufficient sleep helps you stay slim!

For more see: [The Dream Diet: Losing Weight While You Sleep](#).

Fasting

Most nutritionists will tell you that weight loss is easier if you avoid larger meals in the last third of your day. Others claim this is a myth. Epidemiological studies, as always, do not provide a clear cut confirmation. [Ramadan fasting](#) seems to favor weight loss despite nighttime eating. Controlled studies also provide seemingly contradictory outcomes depending on the design. The conviction that evening fasting might be beneficial probably originated in the 1970s when weight loss programs were shown to prove more effective when meals are eaten in the first half of the day, as opposed to the second half (for a discussion see: [Weight Loss is Greater with Consumption of Large Morning Meals and Fat-Free Mass Is Preserved with Large Evening Meals in Women on a Controlled Weight Reduction Regimen](#) (Keim et al. 1997^[75])).

I believe that if you try evening fasting for yourself, you will quickly discover that it can do wonders to your sleep, its restorative powers, your weight loss targets, your morning energy, etc. Unless you are in this ravenous group that cannot sleep without a nighttime trip to the fridge or at least an evening snack, you will also notice that for circadian and psychological reasons, evening fasting is pretty easy to sustain once you get the hang of it. Fasting promotes the

release of [ghrelin](#) (Bloom et al 2000^[76]), which contributes to the overall nighttime increase in the release of [growth hormone](#) (Norrelund 2005^[77]). Most of growth hormone release occurs in deeper stages of NREM sleep early in the night. This nighttime release is partly responsible for the anabolic mode of early sleep that helps you avoid abdominal obesity, strengthen your bones, rebuild your muscles, tendons, ligaments and other tissues subject to daytime wear and tear. Hormonally, evening fasting produces effects similar to those of overall calorie restriction, which has been shown to prolong life in mice. Older people seeking their youthful past may resort to growth hormone injections. Evening fast combined with a healthy free running sleep is definitely a healthier and simpler option. Try it for yourself, and if you have any doubts, please [write to me](#).

If you are an [insomniac](#) or suffer from [DSPS](#), you should also consider evening fasting as a factor that might help you maintain a healthy sleep schedule. See: [Curing DSPS and insomnia](#). On the other hand, if you are troubled by early awakenings and short nights, you might defy a conventional nutritionist advice and listen to [Seth Roberts](#) who says the reverse. Roberts found that skipping breakfast helps him maintain a healthy sleep phase (Roberts 2004^[78]). Thousands of people follow Roberts' advice without realizing that a majority of them are likely to be at the DSPS end of the phase disorder spectrum, and his advice, while well researched and ideally suited for him, may have the opposite effect in their own case. Remember therefore that your fasting choices as well as other lifestyle changes that affect your sleep must be chosen to fit your [chronotype](#).

Combating jetlag with diet

There is some evidence that rats can entrain their cycles to food with the help of the [DMH](#), however, using starvation to combat jetlag is only a theoretical concept. The [SCN](#) rhythm is not maleable beyond minor phase shifts, and losing synchrony between the SCN and the DMH, if at all possible in humans, is not likely to be a good thing for health, esp. that humans do not seem to have evolved a mechanism to subject sleep to the timing of the availability of food. If you happen to have any success in combating jetlag with the timing of meals, please let me know.

Learning

Few things can be as tiring before sleep as a dose of heavy learning. However, a leading sleep expert, Dr Dement, in his guide to better sleep suggests: "*Avoid heavy studying or computer games before bed, they can be arousing*". This advice needs a slight amendment. There is no doubt that computer games are arousing and should be avoided. However, "*heavy studying*" may have many forms. If you study for an exam, and this brings stressful images of the exam itself, it can indeed be arousing. If you study a fascinating subject that monopolizes your thoughts, it can be arousing as well. Similarly, learning in a brightly lit room may slow down the descent to sleep. However, if you extract the pure learning process devoid of stressful associations, light, social aspects, etc., you will come to a different prescription.

Learning should help you sleep

The more you learn on a given day, the lesser your capacity to learn more (see: [Learning overload](#)). For that reason, the more you learn, the faster you will get seriously sleepy. However, you will not be able to sleep well until [your circadian subjective night arrives](#). This means that you can advance your bedtime only slightly, e.g. by 20-60 min. You cannot generate multi-hour [phase shift](#) with learning!

Learning is associated with the homeostatic component of sleepiness, and can promote sleep.

If you want to use learning as a form of getting tired for sleep, and you do not mind the learning process to be less efficient, here are the suggestions:

1. select some unexciting learning material (e.g. your French vocabulary could pass the test, unless you plan an exciting trip to Paris)
2. subtract the high priority material (learning in a drowsy state can negatively affect the learning process in that subset)
3. make sure that your monitor and your room are not too bright. Otherwise you may impact your sleep phase that will make sleep harder on the next day

Remember that learning in a sleepy state is actually a violation of the learning hygiene. Science has not yet conclusively answered the question if this is good or bad for your memory in the long run (Wozniak 2002^[79]).

Does learning increase total sleep?

Even though you may hear from me often that learning increases the demand for sleep, I have not been able to demonstrate the fact with [SuperMemo](#) data! I simply repeat what other scientists keep saying. Learning should indeed increase the demand for [neural optimization in sleep](#), however, this may as well be done by increasing the intensity of processing (e.g. by increasing the density of [REM](#) sleep). Heavy learning may not necessarily increase the length of sleep. Learning may also be like exercise, it does not contribute much to the baseline demand. If you do not learn with a textbook, you still keep learning by noticing things, by thinking, by talking to people. If you do not exercise, you still burn lots of calories. It seems easier to prove that heavy exercise results in longer sleep than to prove that heavy learning increases total sleep. I have been able to show that [learning contributes to homeostatic sleepiness](#). As such, it should contribute to earlier bedtimes and longer sleep. However, I still have no data to show it. For more see: [How learning affects sleep?](#)

Sleep and learning

Sleep length

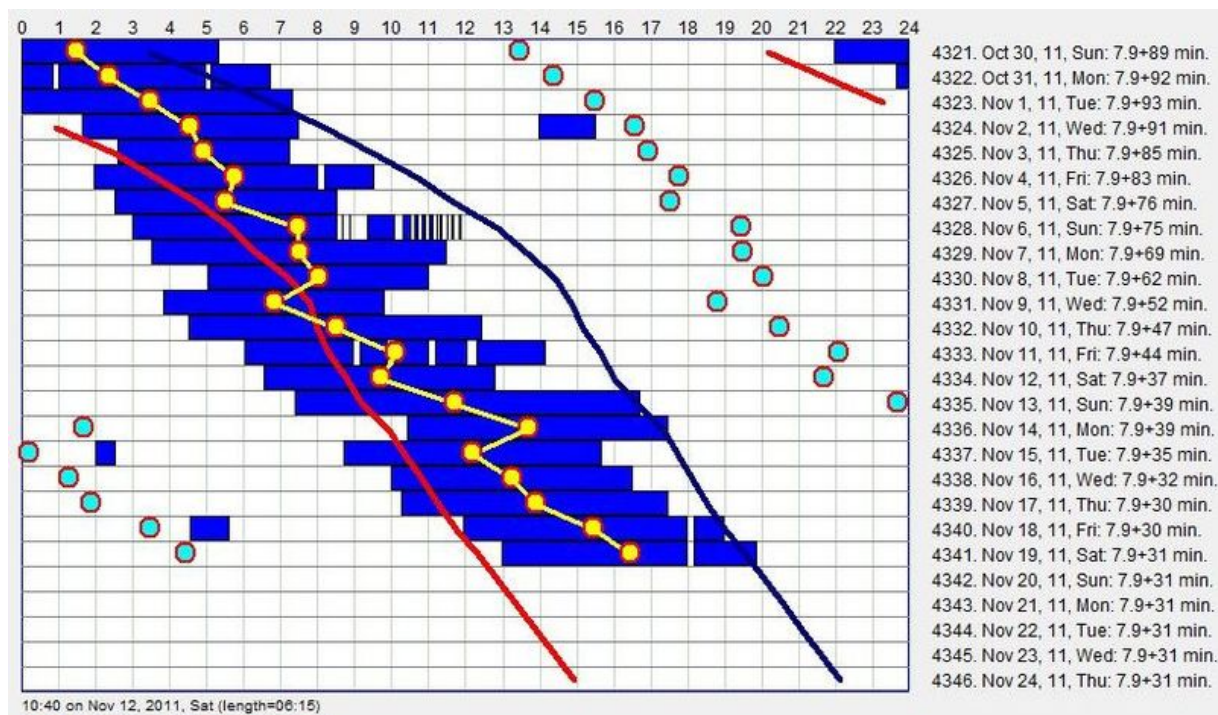
Optimum length of sleep

In this busy modern world, every minute of time seems precious. For some people, the bottleneck resource is time (not money, material resources, people, etc.). Time becomes a limiting factor, and everyone looks for ways to decongest one's life. As sleep takes a third of our lives, a widespread ignorant solution is to cut down on sleep to economize more time for work. This might work in a short run for someone who needs his legs or arms more than his brains. It will definitely backfire for those who use their brains as the primary tool. Even for someone who believes he accomplishes more on limited sleep, life must feel like a race without the rays of happy sunshine. In terms of global value, a [single creative insight produced by a refreshed mind can equal to thousands of man-hours in backbreaking labor](#). Millions of young lives wasted on the fronts of World War I must have equalled to less of a meaningful contribution than a few hours of programming on the part of [Tim Berners-Lee](#). Imagine all those lives spent on more productive pursuits! By cutting down on sleep, you undermine your chances of a meaningful creative contribution (unless, naturally, your worthy mission could not have been accomplished without some sacrifice in sleep).

Recommended 8 hours of sleep

Sleep researchers often look for a recommended amount of sleep. Using surveys or lab sleep data, they often come with a recommendation of 8 hours of sleep per night. However, this recommendation opens a minefield of problems. To get their 8 hours, some people may wish to go to sleep too early and thus exacerbate their [insomnia](#) and related [stress](#). The 8-hours-per-night recommendation is also scorned by some researchers who promulgate the false claim that [sleep is like food and we will always want more even if we do not need it](#).

Energy conservation theory of sleep is patently wrong. Benefits of sleep, unlike the benefits of food, cannot be accumulated in advance and there is no evolutionary advantage in getting more sleep than necessary. An all-nighter will be as painful after a month of oversleeping as it is after just 2-3 nights of good sleep. Conservation of energy is minimal, and the brain may actually use more oxygen during some sleep stages than when working on a complex task. Even though lions might sleep 20 hours per day when there is shortage of food and water, humans, in normal circumstances, can only binge on sleep after periods of sleep deprivation, or when sleeping in a wrong [circadian](#) phase, or when they experience health problems. In theory, [neural network optimization](#) could benefit from some additional sleep, however, the brain does not seem to crave that extra optimization. Its control mechanisms are set to make sleep last for a limited period of time each day, even if we tried hard to get more sleep. Not only there is no advantage, there are huge costs to sleeping too much: we are most vulnerable and defenseless in sleep. Even though sleep can be compressed, proving it is not perfectly efficient, [there are no natural and healthy methods of sleep compression](#). The best sleep is accomplished when all circadian, homeostatic, genetic, and neural mechanisms run in synchrony at the right time on a prescribed course. This can only be accomplished with [free running sleep](#). With dozens of [SleepChart](#) submissions, I can demonstrate easily that once a regular sleep schedule is adhered to, the total amount of free sleep drops and becomes pretty steady. In the exemplary graph, a DSPS subject runs her sleep free and gets on average the same regular recommended 7.9 hours of refreshing sleep per night even though, before running free, she was convinced that she needed 9 hours, and that, even on 9 hours, she would still be tired throughout the day:



Saving time with polyphasic sleep

[Uberman sleep schedule](#) was proposed with a view to gaining more hours in a day. Polyphasic schedules are very appealing in theory, and many people tried them out just to give up within a week or a month (depending on the ability to suffer through the mental misery). Those who try to adjust to any unnatural schedule will suffer an unspeakable torment of the mind. Polyphasic sleepers regulate their sleep with an alarm clock until they reach the breaking point. Human self-experimenting guinea pigs collapse into a sound life-saving 5-8 hour sleep towards the breaking point and then resume the polyphasic schedule with a sense of guilt. That sense of guilt is calmed with exculpatory terminology such as "*weekend break*", "*re-energizer*", "*bonus sleep*", etc. Polyphasic experimenters may happen to sleep less but their intellectual performance will be dramatically undercut. Some [polyphasic sleep](#) theories are based on the false premise that the body can adapt to any sleeping rhythm. Researchers tried to find a natural polyphasic rhythm that would minimize the pain of sleeping little. For that purpose they have studied the [phase response curve of the circadian rhythm](#), where the impact of various sleep affecting factors is shown to move the sleeping schedule forward or backward. The obvious conclusion is that we can rather painlessly move the major [circadian](#) sleepy time little by little in a desired direction. However, a healthy normal individual will not be able to chop the rhythm into a desired number of pieces. [Monophasic sleep or biphasic sleep](#) are the norm in healthy individuals. [Biphasic sleep](#) is rarely composed of two major sleep episodes. Usually it has a form of a major episode (nocturnal sleep) and a minor episode (siesta). Great catnappers nap when they feel they need to. Often, they can accurately predict when and how much they will need to nap. If you want to minimize time spent sleeping and maximize your learning results: free run your sleep. [Polyphasic sleep](#) is not the answer. [Get rid of the alarm clock!](#)

Minimizing sleep time

All forms of sleep control with an alarm clock will increase the overall demand for sleep. This means that:

If you use an alarm clock, either:

1. **you will sleep longer, or**
2. **you will feel more miserable.**

Artificial sleep schedules will dramatically reduce your mental capacity. A healthy individual in normal conditions will find it difficult to fall asleep 4 hours after the main sleep episode unless that episode was unnaturally cut with an alarm clock resulting in [sleep deprivation](#).

The shortest healthy sleep is accomplished with [free running sleep](#)!

In free running sleep, once you know your average sleep time and your optimum wake time, try to stick to it religiously. Use [SleepChart](#) to find your optima in case your sleep is irregular. Plan your day in such a way so as to be sure that if sleepiness comes earlier, you can hop in to bed in a wink, and while sleepiness does not arrive in time, you

can get busy with some low-priority sleep-conducive activities that will tire you until the right time for sleep comes.

Inefficiencies in the sleep control system

[There are many factors that might increase the demand for sleep](#) (e.g. [learning](#), [exercise](#), etc.), or shift the sleep control balance to favor sleep over wakefulness (e.g. brain injury, infection, poisoning, hypothermia, etc.). The impact of external factors can be used to illustrate a degree of inefficiency in the sleep control system. Since days are longer in the summer than in the winter we do tend to sleep a bit longer in winter. There does not seem to be an increase in the need for the neural function of sleep in winter. If we sleep more in winter and there is no biological need for more sleep, then it seems that we must be getting either more sleep than we needed in winter or less sleep than we need in summer. As sleep is primarily controlled by the [circadian](#) and [homeostatic](#) sleep propensity, and the circadian component is strongly influenced by light, variations in the levels of illumination will cause variations in sleep duration. It is conceivable then that we sleep less efficiently in winter (in terms of neural effects per unit time). Equally well, summer sleep might be less restorative. Eskimos cut off from civilizational influences sleep for a few hours more per day in winter. [Dr Jim Horne is right saying that in some circumstances we might sleep more than we really need to](#). However, he goes a step too far when he compares sleep to eating, which makes some people believe that sleep restriction might be beneficial (by analogy to calorie restriction). In conclusion, we need to realize that sleep control mechanisms are not perfect, however, we have not yet come with any artificial and certified ways of improving upon what we were given by the biological evolution. Natural [free running sleep](#) is still the best way to accomplish healthy, refreshing and shortest-lasting sleep.

Length of sleep among users of SuperMemo

A survey of users of [SuperMemo](#) (SuperMemo World 1994^[80]) revealed that the average speed of learning was 243 items/year/minute. **Those users who sleep less than 7.5 hours learned at the speed of 240 items/year/minute. Those who sleep more than 7.5 hours learned at 256 items/year/minute.** Amount of sleep, smoking and exercise were poorly correlated with the speed of learning. Students aged 28 years old or younger learned at the speed of 264 items/year/minute, while those above 28 years old learned at the speed 179 items/year/minute. Remember, however, that in another study it has been shown that [good students learn slower \(!\)](#) (Gorzalanczyk et al. 1998^[81]) because of their greater self-criticism in providing grades.

People who sleep less live longer?

"**People Who Sleep Less Live Longer**" screamed news headlines in February 2002. The reason for the uproar was a large-scale study by researchers from the University of California at San Diego who found that people averaging 8 or more hours of sleep per night were 15% more likely to die within the 6-year period of the study than those who slept seven hours. The study makes a valuable contribution to our knowledge of sleep habits but conclusions amplified by mass media are not only wrong, they are dangerous! If you decide to cut down your sleep today to live longer, you will certainly achieve the effect opposite to the one desired. It is your body (actually the brain) which knows best how much sleep you need. This might be five or it might be nine hours. We differ a lot in that respect. There are no noteworthy benefits of cutting down your sleep with an alarm clock, and the dangers are well documented. The erroneous conclusions media drew from [Dr Daniel Kripke](#) team study come from a typical cause-effect relationship confusion. It is not that long sleep is detrimental. It is more that poor health may increase the demand for sleep. Driven to extremes, comatose and bed-ridden patients will bias similar statistics. People with poor quality apneic sleep are more likely to linger in bed and report long nights. On the opposite side of this spectrum are people with healthy and sound sleep habits that often feel refreshed with as little as five hours of sleep, and wake up naturally before the alarm time. In addition to having adverse health effects, [sleep deprivation is a major cause of traffic accident and causes immeasurable damage to nations' creative potential](#). Even a poorly designed alertness test is not likely to testify to your sleep's quality. This comes from the fact that stress hormones often mask [sleep deprivation](#). However, if you try to learn with [SuperMemo](#) after an artificially shortened sleep, you will see that your [recall](#) gets worse and stress hormones may improve your sense of alertness, but they will do so at the cost of focus and memory. You will achieve best health by getting as much sleep as your body calls for in conditions that eliminate stress, stimulants, anti-depressants, sleeping pills and the like. Once more, the mass media amplifier is likely to produce confusion and negative ripples that will keep on reverberating for years to come!

As always, some research seems to make headlines, while more thorough meta-analyses don't. In this case, it is probably the self-comforting thought "*even if I feel miserable in sleep deprivation, loss of sleep might actually prolong my life!*" If we review the literature on the association between the length of sleep and longevity, we are likely to notice that very short sleep, as much as very long sleep, correlate with shorter lives (Cappuccio 2010^[82], 2010^[83]). Professor Francesco Cappuccio puts it best saying: "[while short sleep may represent a cause of ill-health, long sleep is believed to](#)

[represent more an indicator of ill-health](#)". If you take an average of the optimum amount of sleep for all members of the population, you will arrive at a specific number that is meaningless for a specific individual. In sub-populations that sleep longer or less than the average, longevity may be diminished. However, for each single individual, the optimum number is the one that is suggested by the body needs. If it is 4 hours or 10 hours, it matters less as long as the number comes from the natural sleep that is not controlled artificially. Moreover, that number will differ from day to day, it will be less before an exciting date, and it will be more after a day of heavy exercise. No one should worry about sleeping 4 hours per day or 10 hours per day, as long as he or she sleeps naturally, wakes up naturally, and feels refreshed.

The optimum amount of sleep differs from person to person, from day to day, and is best determined by sleeping without artificial control such as an alarm clock, [sleeping pills](#), etc. You can best determine your optimum sleep needs by trying [free running sleep](#).

Epidemiological studies that focus on morbidity and ask "how many hours per night do you sleep?" ask a wrong question! They should rather ask: "*Do you artificially modify the timing and the length of your sleep?*" Only that kind of question would tell everyone that artificial control of sleep increases morbidity, while the actual length of sleep is largely irrelevant.

Investigating links between sleep length and longevity is not much more useful than my own failed attempts to connect the sleep length with the quality of learning. In case of learning, short sleep produces poor results because of the impact of [sleep deprivation](#) on attention, recall, and [consolidation](#). However, long sleep produces poor learning as well because it usually is an indication of something going wrong either with health or with the sleep control systems (e.g. sleeping in a wrong phase, or compensating for prior deficits). Asking about how much sleep we need is not different from asking how many calories we need: it depends on our size, our current fat level, our caloric expenditure, and many other factors.

Jim Horne and Daniel Kripke

Jim Horne and Daniel Kripke are two sleep researchers who seem to stand in opposition to the rest of the field in their prominent claim that sleep is like food and we can get too much of it. They even contemplate the concept that, as with caloric restriction, sleep restriction might prolong life! [I mentioned Dr Kripke's research that is often erroneously interpreted as "short sleep prolongs life"](#). It is not that long sleepers die earlier. The obvious interpretation of epidemiological studies is that sicker people often sleep longer. Drawing an analogy with calorie restriction is as weak as proposing a "wake restriction" that might have some unknown benefits, esp. that in the hormonal spectrum of glucose metabolism, wake restriction is more similar to caloric restriction. There is no evolutionary advantage to getting excess sleep due to the fact that sleep cannot be accumulated like fat can (see: [Excessive sleeping](#)). Metaphorically, if we compare sleep to garbage collection, there is no advantage in collecting garbage ahead of time. People on [free running sleep schedule](#) quickly reduce their total demand for sleep and sleep less than on various forms of regulated schedules. Their mental energy is naturally much higher despite sleeping less. I believe that comparing long sleep to overeating is particularly harmful. It sends wrong signals to teenagers and students for who their brain performance determines their future. Drs Horne and Kripke's main concern is that "scare tactics" employed by researchers who insist on the value of the proverbial 8 hours of sleep may worsen insomnia and stress related to not getting "enough" sleep. These are valid concerns, but these can easily swing the balance too far in the other direction, while there is a golden mean: [free running sleep](#) that helps people get exactly as much sleep as is needed. To seek some counterbalance, let me then nitpick at some of Drs. Horne and Kripke's statements and hypotheses to throw some light on sleep needs from the [free running sleep](#) perspective.

Dr Horne

Here are some of Dr Horne's statements that keep detracting from the value and power of sleep:

- "*The amount of sleep we require is what we need not to be sleepy in the daytime*". It is hard to disagree. However, I would upgrade that statement to an Information Age status: "*The amount of sleep we require is what our brain asks for*". This is a higher standard than just "not to be sleepy". After all, it does not take much sleep to feel well-energized for work in a field, or a walk in the park, or a basketball game. It takes more quality sleep to be at one's intellectual best for writing, programming, learning, research, etc.
- "*Sleeping continuously through the night is quite a modern invention*". That's plain false. Many species sleep for many uninterrupted hours. This most certainly has been the habit of early humans. Natural sleep discontinuities, like nocturnal awakenings or segmented sleep, are a far cry from the forced interruptions inflicted by alarm clocks. Waking up for a specific purpose might have been invented in pre-historic human societies, however,

there has never been a compelling need for a frequent use of that "invention". For centuries, even candles were available only for the rich. [Frederick the Great](#) might have been woken up by the firing of cannons in childhood, but his contemporaries, thankfully, did not have madly authoritarian military-obsessed fathers. Our ancestors never paid much attention to sleep. They just had plenty of it and it was never a subject of discussions or anxieties that now flood the forums for insomniacs. The true advent of alarm clocks and shredded sleep schedules and sleep problems dates back to the early days of electric lighting that disconnected the modern world from the natural cycle of daylight. Even though alarm clocks are not new, they only entered massive use in the last century.

- *"There's a lot of fearmongering about alarms. You hear some funny ideas - that we should be woken up "naturally" by light or at certain points in our sleep patterns".* Being woken by light is by far healthier than being woken by an alarm clock. Still, morning light is not necessary to accomplish top-quality sleep. [See a case of perfect sleep in the absence of morning light in an octogenarian.](#) Being woken at the lightest phases of sleep is by far healthier than being woken just 15-25 min. later when deep sleep sets in. Most people have experienced the difference and can easily list a couple of symptoms that are indicative of the negative impact of sleep disruption on health. If I am a "fearmongerer" in reference to alarm clocks, it is because I understand the physiology of sleep well enough to know that life without alarms should be a basic human right esp. at younger ages.
- *"Insomnia is not really a sleep disorder but a disorder of wakefulness intruding into sleep".* A typical cause of insomnia in an otherwise healthy individual is bad sleep timing. People who need to get up early, go to sleep too early in reference to their [body clock](#), and just cannot fall asleep. It is not wakefulness intruding into sleep, but a human wish to impose sleep onto wakefulness. These are modern schedules and expectations that are the root of the problem in a vast majority of cases.
- When criticizing psychological tests used in studying sleep deprivation, Horne says *"tests simply measure tolerance to boredom, which shortens with [sleep deprivation](#). Take the stimulation away and the animal will fall asleep"*. Creative work will not always provide sufficient excitement to combat [sleep deprivation](#). It is not the boredom that is the enemy of a sleep deprived creative brain. It is the mental effort itself. **No amount of boredom can put a well-rested brain to sleep.** However, mental effort in [sleep deprivation](#) may be tantamount to torture. Millions of students in the industrialized nations experience that daily. If we want to measure the impact of [sleep deprivation](#) on cognition, we need tests that are both stimulating, and tests that eliminate the excitement variable. Tolerance to boredom does not shorten with sleep deprivation! It is a fresh creative mind that truly abhors mental nothingness! It is our ability to stay awake in the absence of arousing stimuli that really gets shortened in [sleep deprivation](#). Boredom does not induce sleepiness. There is no known boredom nucleus in the brain that would start firing in response to lack of stimulation (other than via disinhibition of the natural sleep control system). Even if that nucleus was ever identified, it would rather form a part of an arousal system. Children, when deprived of stimulation, may become cranky or aggressive. Evolution made us smart because we seek action and low entropy states. **Boredom unmasks the underlying sleep deprivation.** Whoever nodes off at a boring lecture must have simply not gotten enough sleep in the night. A refreshed mind will instead drift to more interesting thoughts such as an exciting project, problems of the day, or an attractive classmate sitting nearby. My impression is that sleep researchers who bring up the effects of boredom on wakefulness must extrapolate from their own sleep deprived condition. Top quality creative brain does not need a whip of [adrenaline](#) or [dopamine](#) to stay focused on its creative pursuits. We should all aim at sharp and crisp minds, not just minds that are "not sleepy".
- Dr Horne brings up the Inuit as an example of human capacity to sleep in excess. The Inuit are able to sleep for up to 14 hours in winter. It is true that lifestyle and environment will affect the length of sleep. You can blame our biology for not doing its best of the available time, but nothing natural can be done about this, so we might as well enjoy a full night sleep. When irregular sleepers claim they need 8-9 hours of sleep per night, one might expect them clocking 10-11 on a free running schedule if the "wastefulness of sleep" theory was right. Instead, in [free running sleep](#) they often go down to 6-7 hours per night and claim feeling better than ever! As for the Inuit, part of those excess hours might come from the documented wish to minimize the exposure to cold in winter months. Much of that "sleep" might be Wehr's [segmented sleep](#) (Wehr et al. 1992^[26]). So we would need to employ polysomnography to see how much of that bedtime actual sleep is. On the other hand, sleeping little in summer can easily be explained by the fact that it is not easy to fall asleep at midnight in bright light, and there is a pressure from the other end of sleep to get up early for a hunt with a stress of possible oversleeping. We know that the sleep control system is imperfect and the actual need for sleep may be masked by arousing stimulation. Inversely, Arctic night might be conducive to leisurely sleep that may exceed the actual needs of the organism. However, we cannot state with certainty that it is the lack of stimulation that makes Inuit wastefully sleep longer. We know for sure though that extra summer stimulation makes Inuit get less value from sleep than they otherwise get in winter days. To settle the issue we would need to apply appropriate cognitive tests in summer and in winter, and compare the two. In particular, I would be interested in comparing the [circadian](#) peaks of [recall](#). This is more important than just the [recall](#) average as I believe that creative people change the world

primarily in their moments of peak mental strength, i.e. shortly after waking up from a refreshing night of dream-rich sleep. In my own work, I did not find much correlation between the length of sleep and the quality of learning. [Free running sleep](#) might be slightly longer in winter, however, shorter sleep in summer is often compensated by longer naps. On average, cognitive performance seems to be comparable. [SleepChart](#) logs emphatically contradict Dr Horne's claim that we like to sleep wastefully. [Free running sleep decreases the total sleep as it increases its efficiency!](#)

- "Researchers in America tend to take a different view. They assert that because most of us can extend our daily sleep, we must need to do so. This would mean that people who seem content with seven and a half hours of sleep a day during the week but enjoy nine hours at the weekend are, unknowingly, chronically deprived, and actually need nine hours every day. Evidence for this is said to come from the many people who are sleepy in the daytime, and the numerous reports of people falling asleep at work and, worse, while driving". Dr Horne's annoyance with the 8-9 hour sleep recommendation is understandable. After all, people have different sleep needs, and the recommendation might compound [insomnia](#). However, sleeping more on weekends than on working days is a clear indication of [sleep deprivation](#). Stress or passion associated with work can easily mask deprivation. That mask falls off on weekends. It is hard to say if 7.5 hours on workdays and 9 hours on weekends equals to a 7.8 hour optimum, or perhaps an 8.5 hour optimum, esp. than those numbers will change from day to day even for very regular sleepers. Everyone should determine his or her needs on their own in free running condition. This condition cannot possibly be approximated by sleep on weekends due to the sleep debt carried from the working week.

Dr Kripke

Here are some statements from Dr Kripke which undervalue the importance of undisturbed sleep:

- "Nobody seems to know exactly where the idea that we should sleep eight hours came from. I guess it was just passed down from somebody's grandmother". The "8 hour myth" does not come from grandmothers but from surveys in which many people claim that they function best once they get their 8 hour sleep. The actual perfect number may be less because of a common misperception. People who do not get enough sleep during the working week often compensate on weekends when they do sleep more to make up for various sleep deficits. That weekend sleep may be 8 hours or more, but it does not imply that this is what is actually needed. The same people on a free running schedule may be surprised to discover that they actually need just 6-7 hours. It is not uncommon to go down to 4-5 hours per night on a biphasic schedule, where the remaining sleep needs are met with a well-timed [siesta](#) nap. My small-sample estimation seems to indicate that people overestimate their sleep needs by 10-15%. Dr Carskadon's research shows that 8 hours may be a good estimate for teenagers who clearly have increased sleep needs. My own analysis of [SleepChart](#) submissions also indicates that for teenagers, 8 hours is a solid recommendation! The figure also often shows in other publications (Dinges et al. 2000^[84]). When a software glitch in the first two days of 2011 kept iPhone alarms silent, thousands of people realized their capacity to oversleep. Not by just 10-30 min. Some angry bloggers clocked extra 6 hours of sleep illustrating the monstrous degree of [sleep deprivation](#). When grannies suggest 8 hour sleep, they are not that far off the mark!
- Kripke in his editorial in Sleep (February 2004) wrote: "The results [of epidemiological studies] falsify the widely-circulated hypothesis that it is best to sleep at least 8 hours". All epidemiological studies contribute to our knowledge one way or another. However, a study that focuses on morbidity and mortality that asks "how many hours per night you sleep?" is a waste of time! Like a study of the impact of height on mortality, we know ahead of time that it will provide U-shaped results with no bearing on our lifestyle recommendations. The correct question would be "Do you cut your sleep short with an alarm clock?", or "Do you delay sleep despite being sleepy?" or "Do you try to sleep early even if you are not sleepy?" In short, those questions should ask: "Do you artificially modify the timing and the length of your sleep?" Those studies would tell everyone unequivocally that artificial control of sleep is deadly. Length of sleep is largely irrelevant! For more see: [People who sleep less live longer?](#)
- Kripke: "Recent results from the Hordaland study in Norway showed that working people who reported sleeping less than 6.5 hours a night did not suffer any significant increase in disability. Those who reported more than 8.5 hours were more than twice as likely to become disabled as those who slept 6.5-7.5 hours. The suggestion from this study was that, if anything, spending more time in bed might tend to increase disability". We already know that on average people live longest if they spend a certain number of hours asleep, or if their height is somewhat above average. But the statement seems to suggest a reverse causality. Trying to spend less time in bed would be as good for longevity as trying to shrink people who grew beyond a certain height. **Healthy people sleep less, but those who shorten their sleep are less healthy!**
- Kripke: "We know that we do not suffer some horrifying loss of intelligence or memory every time we get less than eight hours of shut-eye. We make deliberate choices to sleep seven hours or six hours, feeling that the practical benefits of having the extra time outweigh whatever sleepiness might result from sleeping less than eight or nine hours". It really amazes me to hear a sleep researcher accepting a practice of trading sleep for "practical

benefits"! Loss of IQ might not be horrifying, but the death toll on the roads definitely is. [There is a neural and health cost to trading sleep for "practical benefits"](#). An irreplaceable physician or a firefighter might do the trade. However, they should always remember that they sacrifice their own creativity, brain and health for others!

- In a [debate with Dr Stickgold organized by the Economist](#), Kripke countered Stickgold's claim that insufficient sleep is the cause of traffic accidents: *"People claim that daytime sleepiness causes road accidents, when the fact is that the sleep-related road accident rate goes up late at night. It is driving late at night, which causes most sleepiness on the road. People who stay up unusually late, such as physicians called to duty at night, have extra driving risk and risks of mistakes, but that does not prove that the regular sleep patterns of the general population are too short."* When two great researchers disagree on a fact that can easily be verified, I can always suspect professional or personal prejudice. Could it be that early riser Kripke feels most impaired when driving in the evening, while owlish Stickgold feels out of sorts in the morning? I had a peek at the statistics and noticed that overwhelmingly the accident rates follow the average of the human [circadian](#) sleep propensity. This would mean that both doctors have a point. It is probably a [chronotype](#) that will determine the difference in accident chances at different times of the day on average. The circadian phase while driving would be even a better determinant. My guess is that whatever impairs [recall](#) or [memory consolidation](#) in the waking day will also impair driving. In other words, alertness graphs plotted in [SuperMemo](#) could easily be used to determine the probability of a traffic accident while driving at any time of the day. An interesting difference shows up when investigating accident rates across different ages. There is a huge spike in accidents at 6-7 am in middle-aged people. That would contradict Kripke's claim. However, for younger ages, the rates are very high throughout the night. For retirees, who do not need to get up early, and do not need to drive insanely long into the night, the peak aligns with their [siesta](#) time. Whatever the truth, Dr Kripke is definitely wrong when using his statement to defend short sleeping. According to [National Sleep Foundation](#), [people who sleep less than 5 hours per night are four times as likely to be involved in a crash than those who sleep 8 hours or more. Even those who sleep 6-7 hours double their risk.](#) Obviously, as argued throughout this article, it is not the length of sleep but its quality that matter. Those who get 5 hours in [free running sleep](#) need not worry.

My own prejudice

Early risers find it difficult to understand the problems of evening type people. They are prejudiced by their own condition. Scientists frequently divide into fiercely opposing camps that are often based on serious prejudices coming from trivial sources. That's good. Discoveries benefit from passions even if they often and inevitably cross rational boundaries. I am seriously prejudiced too. So are those magnificent scientists who I dare to criticise. I bet that when Drs. Horne or [Siegel](#) read about new ideas coming from Drs. Stickgold or Walker's camps, they might be mumbling to themselves *"Oh no! Not again..."* If they ever come to read the presented text, they might exclaim *"Who's that [bleep] Wozniak [bleep]!?"* That's healthy. I would be honored if they bothered to read.

I bet that some researchers who are short sleepers or early risers themselves tend to extrapolate from their own position to a wider population. Having seen hundreds of [SleepChart](#) logs, I know that some individuals definitely need 9-10 hours of sleep and feel bad when they do not get it. Could there be an underlying health problem? Perhaps. However, most of these are teenagers that seem otherwise pretty healthy and good students. I have also seen logs of those who need just 4 hours per night and occasionally feel great on just 2-3 hours! Both extremes are in minority. Most of people do well on 6.5-7.5 hours in free running regimen.

When standing against alarm clocks and short sleep, I must then delineate my own prejudice. I have used alarm clocks pretty sparingly in my life. 12 years ago I decided to get rid of alarm clocks altogether. I got absolutely in love with my uninterrupted sleep and want to share the fun with everyone, esp. with the young generation. Against the claims of Dr Horne, despite running my sleep free, I am rather a short sleeper. As I write these words my trailing nighttime sleep length is 5.7 hours, which is well below the population average. It used to be more before I started strictly running my sleep free over a decade ago. It used to be far more before I started sleeping [biphasically](#) nearly 20 years ago (see: [the impact on napping on nighttime sleep and total sleep time](#)). I have never noticed a tendency to sleep long just because of conducive circumstances (long nights, cold weather, rainy weather, etc.). Just the opposite, the more religiously I adhere to the rules of good sleep, the shorter my sleep is and the better the quality of my learning (as measured with [SuperMemo](#)). Even though this observation is definitely my natural and unavoidable [cognitive anchor](#), the same correlations I noticed in dozens of [SleepChart](#) submissions.

My love of free sleep does not imply that I do not know how serious [sleep deprivation](#) feels. I [recall](#) a time at [SuperMemo](#) World, in the early 1990s, when working as a programmer against a deadline, I had to go for some 72 hours without sleep. I did not feel brain dead because of the stress and excitement of the job. However, the outcome was near-to disastrous. A CD-R with the finished product was on its way to Germany for mastering and production when a disastrous bug was spotted in testing. That [sleep deprivation](#) and the deadline could have been very costly.

Had I not tried free running sleep, I might have been pretty skeptical of Dr Stickgold hyperbole: "*sleep deprivation makes you fat, sick and stupid*". In the 1980s, when I was in a constant battle for quality sleep, pulling a dozen of all-nighters annually, and nearly always late to bed, I was actually pretty healthy, very skinny (mostly as a result of coming from a poor household), and I ended up graduating with honors. Neither fat, nor sick, nor certifiably stupid. However, my views changed drastically now that I have tried [free running sleep](#) for over a decade. I am now much healthier than 20 years ago, and I learn much faster (even though most of that acceleration is due to technology and experience). I might still be in a daily battle to maintain a healthy level of body fat, however, that battle was by far hardest in the early days of [SuperMemo](#) World, some 20 years ago, when my sleep hygiene was at its lowest. I believe strongly that [free running sleep](#) improved my health and creativity. I believe that it was [free running sleep](#) that helped me eliminate the problem of colds and influenza, even though winter swimming might also have been a strong contributor. Most of all, I love to have nearly forgotten how [sleep deprivation](#) feels. Nothing undermines creative work as effectively as a bad night sleep. In the light of my own experience, let me then take liberties and reword/soften Dr Stickgold's claim:

Sleep deprivation will make you fatter, sicker and dumber!

Robert Stickgold, PhD, Associate Professor of Psychiatry, Harvard Medical School (paraphrased)

I admit! I am severely prejudiced! Having tried good sleep, I cannot possibly think of sleep restriction or artificial sleep control. You do not need to trust my judgement though. If you are not sure, apply Pascal's Wager and treat sleep like God. Your intellectual strength is at stake!

Good sleep is a key to the treasure of good life. Don't let anyone rob you!

Effects of sleep duration and sleep phase on learning

I started my investigations of the impact of sleep on learning in the early 2000 from the simple intuition that short-night sleep is bad for learning on the next day. After collecting two years of data with SleepChart, I tried to show the link between the length of sleep and the quality of learning. However, that attempt was not successful. My problem was that I used my own sleep and learning data. I am a religious adherent of [free running sleep](#) (i.e. sleep where all forms of sleep control, esp. the alarm clock, are forbidden). Upon closer inspection, it appears that in free running sleep, short night sleep is often an indicator of hitting the optimum sleep phase, while long sleep may result from going to sleep too early, heavy exercise, ill health, and other factors. The interpretation is analogous to [Dr Kripke's research](#) showing that people who sleep less live longer. That research led many to a wrong conclusion that keeping one's sleep short is healthy. In Kripke's and my own investigations, the confusion comes from the fact that it is the naturally short-night sleep that is an indicator of good health, correct sleep phase, or good prospects for long life. Using other people's data, I could later show that [short sleep caused by the use of alarm clock has a negative impact on learning](#). One can expect the same effect of alarms on longevity. It is now obvious that the length of sleep cannot be used as an indicator of sleep quality in [free running sleep](#).

In [free running sleep](#) there is little or no correlation between the total sleep time and the learning performance. This correlation emerges only when the length of sleep episodes is controlled [artificially](#).

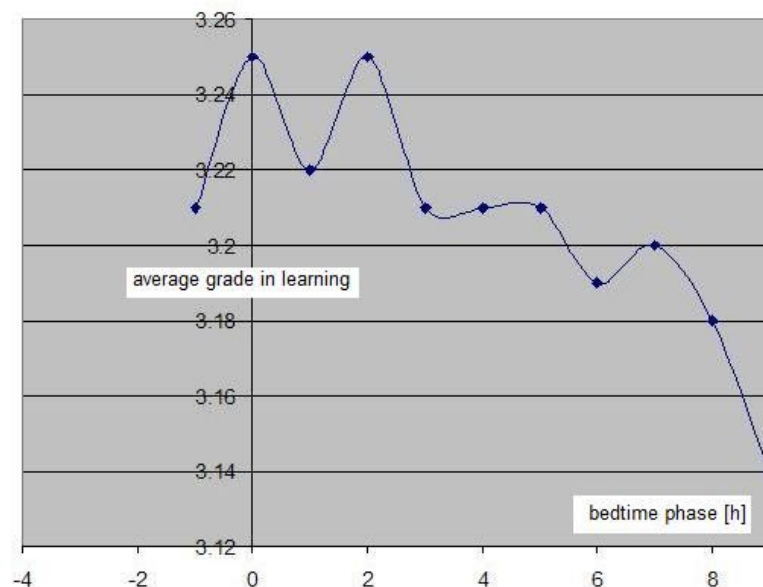
The relationship of bedtime and the sleep phase is more important than the total amount of sleep. We should always sleep at the time when the body clock says it is the beginning of the [subjective night](#). There is more benefit in 2-3 hours of sleep at the right time (subjective night), than in 8 hours of sleep at a wrong time (e.g. when jetlagged in Japan). Obviously, it may be pretty hard to get 8 hours during the subjective day without a serious prior [sleep deprivation](#).

While doing my preliminary investigations with my own sleep data, I concluded that I could use sleep phase as a much better indicator of sleep quality. [SleepChart](#) makes it possible to analyze the data and approximate the optimum time of bedtime. Those predictions are very rudimentary and can be explained by the following reasoning: if you went to sleep at 5 am yesterday, and the lateness was natural, not forced, do not hope that you can fall into quality sleep at 2 am today. In free running sleep, tiredness is always the ultimate judge that tells you when to go to sleep. However, [SleepChart](#) can warn you when the tiredness is likely to be [homeostatic](#) and an "unreliable predictor" of the optimum sleep time. If you got to sleep too early, your sleep will be excessively long, not fully refreshing, and carrying a risk of premature awakening. If you go to sleep too late, your sleep will be unnaturally short and carry a risk of shifting the sleep phase (i.e. going to sleep even later on the next day). Those observations provide a solid suspicion that the sleep phase could affect the quality of sleep and the quality of learning on the next day. The sleep phase here is the difference between the optimum bedtime (e.g. as predicted by SleepChart) and the actual bedtime. However, when trying to correlate the sleep phase with the quality of learning, I was to be disappointed again. I could not find a

correlation between the sleep phase and the quality of learning (e.g. as expressed by grades in SuperMemo). There were two major weaknesses in that preliminary effort:

- **SuperMemo** uses the concept of midnight shift that allows of registering repetitions executed after midnight with the previous learning day. In other words, in older SuperMemos it was not possible to say if the repetition executed on May 11 took place on May 11 or in the early hours of May 12
- **SleepChart** used to use simple statistics in predicating on the optimum sleep phase. It did not use a two-process model of sleep regulation. Just plain old averages. It did not even use the phase response curve to register block shifts that can affect the sleep phase. In other words, **SleepChart** was strong only when **free running sleep** was not disturbed by factors such as forced delays, exercise, health problems, sunlight, etc.

Both **SuperMemo** and **SleepChart** have been vastly improved since. **SuperMemo** registers the timing of each repetition, while **SleepChart** relies on a phase response to predict the circadian **acrophase**. With improved data gathering, I was able to have a preliminary peek at the relationship between the bedtime phase and the learning performance:



*Relationship between the bedtime phase and the learning performance. The bedtime phase is defined as the difference between the actual and the optimum bedtime. Learning performance is measured by the average grade obtained while learning with **SuperMemo**.*

As expected, delaying sleep resulted in a gradual decrease in performance. There is far less data on the "advance" side due to the fact that in free running sleep, early bedtime hardly ever results in early sleep, and is more likely to simply entail some unproductive wake time in bed.

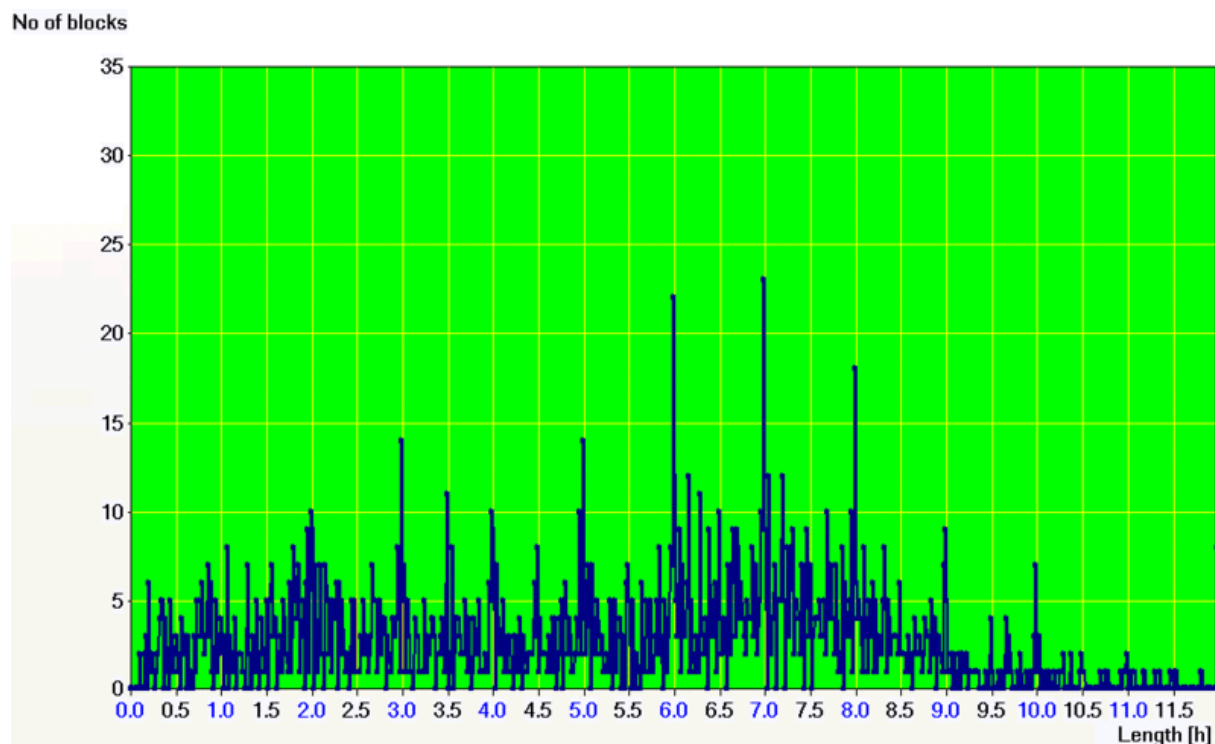
Sleeping in the wrong phase (i.e. too early or too late), will result in a degraded learning performance.

SleepChart has become an integral part of **SuperMemo** as of **SuperMemo 14.0** (2008). Some of the findings based on the data collected with those two applications are listed in later sections of the present article.

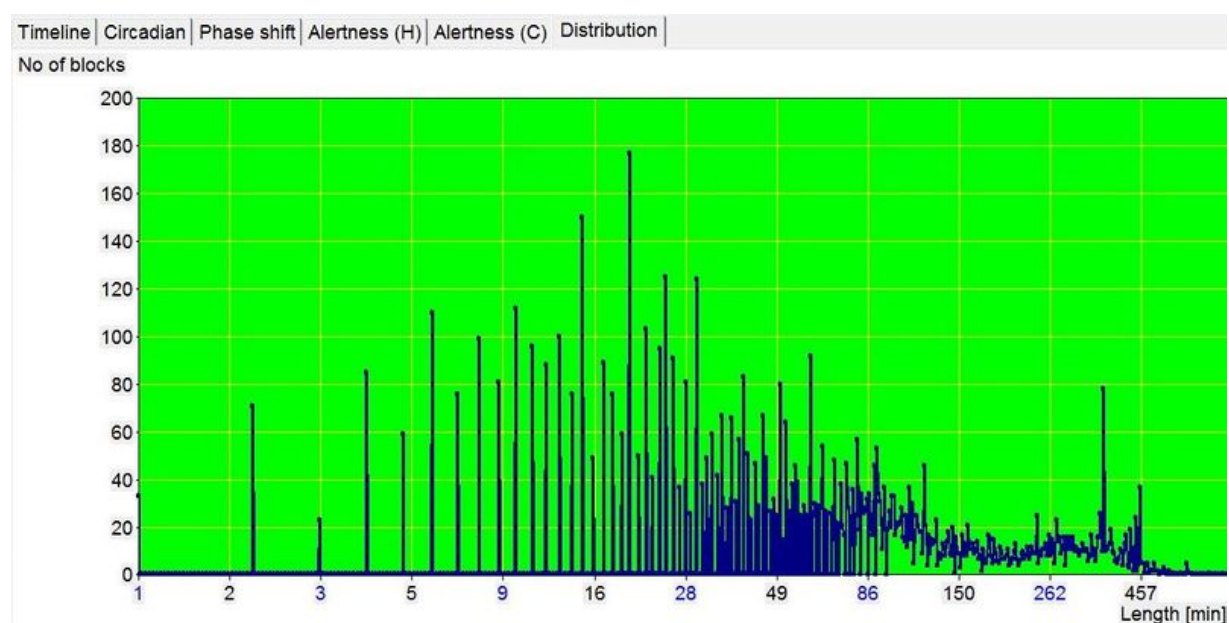
Sleep block length distribution

NREM-REM sleep cycles take roughly 90 min. A popular myth says that the length of a healthy night-time sleep episode will therefore always be a multiple of 90 min. Another myth says that it is ok to interrupt sleep after a multiple of 90 min. A variant of both myths says that sleep is supposed to last a multiple of a period that is specific to a given individual.

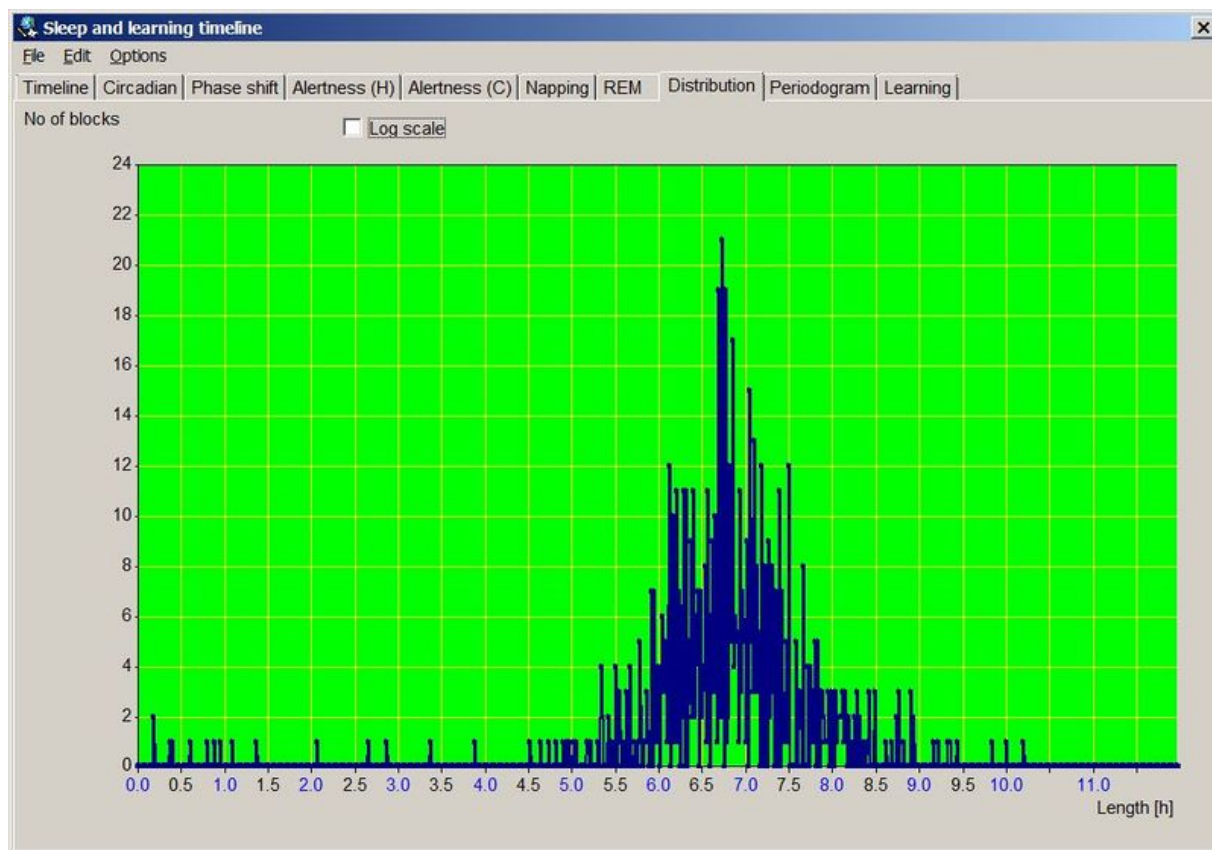
SleepChart displays the distribution of the length of all sleep episodes. That distribution can be used to invalidate the claim that sleep blocks cluster in multiples of 90 min. In the presented example, sleep block length distribution in a monophasic sleeper indeed shows clusters at: 1, 2, 3, 3.5, 4, 5, 6, 7, 8, 9, and 10 hours. However, upon closer scrutiny, this clustering comes only from inaccurate logging by the subject (it is easier to mark 3.0 hour block than 2.95 hour block). There is no 90 min. trend discernible, however, one might be tempted to notice a multiple of 60 minutes.



Here is then yet another example that uses a semi-log scale, which is better for visualizing short sleep blocks of a **habitual napper**. In this case, a biphasic sleeper shows only one significant cluster at 7 hours of sleep. This cluster was again caused by imprecise logging.



Finally, a sleep block distribution of a regular 7-hours-per-night monophasic sleeper. There are a few peaks discernible, however, no regular sleep length multiple. In particular, no peaks around the expected 5.5 and 8.5 hours.



How sleep affects learning?

Why is sleep important for learning?

If I was to bet on the top two factors that hinder learning in industrialized nations, these would be:

1. [Stress](#) which takes away your focus, stifles creativity, saps motivation, and which can contribute to poor sleep
2. **Sleep** which is needed for [optimizing memories](#). Without sleep, you cannot even experience the sense of a "good day"

Health is important too, but, statistically, it is stress and bad sleep that affect nearly everyone, and take the largest toll. Reduce stress and improve sleep, and you might see a society changed beyond recognition!

For healthy people, all other factors in learning seem to be somewhat secondary. Self-discipline improves greatly if you are rested and happy. The fun of learning follows. The way you approach learning, tools and techniques, the way you [represent knowledge in your mind](#), and other factors can all be improved gradually and consistently. If you are on a steady path ahead, success is nearly guaranteed. Metaphorically speaking, **your brain comes with a solid warranty of progress that you can easily void with stress and/or poor sleep.**

Given the importance of sleep, unless you are a "natural" and rarely get a bad night sleep, you should understand the basics of sleep physiology and the impact of your sleep habits on learning. Moreover, even if you sleep well today, you are always in danger of ruining your sleep patterns through the use of computers, Internet, mobile phones, SuperMemo, etc. In short, the human brain has not yet got enough time to evolve and adapt to the stimuli of the modern lifestyle. That's why we witness an epidemic of sleep disorders in industrialized nations.

In the following sections, I will try to show that the impact of sleep on learning goes far beyond the simplistic concept of "rested mind".

Sleep and learning research

Everyone knows that without a good night in bed, the next day can be ruined. When sleepy, you can easily shovel the garden in fresh air, but if you try some creative work in front of your computer in a warm room, your brain will tend to switch off and stifle any creative progress.

It is quite evident that cognitive functions and learning are the primary victims of [sleep deprivation](#). Scientists have

for long suspected that the main function of sleep is related to learning and memory. Even in the 17th century, [John Locke](#) campaigned for good sleep for kids for those reasons. However, only recent decades and years brought an exponential increase in evidence demonstrating the role of sleep in memory. There are still [prominent sleep researchers that dispute the link](#). Some insist that only a conscious brain can be involved in memory. Others claim that sleep is like eating, [if you can get more, you will always want to get more](#). Outside the scientific community, sleep is held in an amazing disregard. Many people do not want to waste time on sleep to economize more time for work and "creativity". Others try to get "best" sleep in minimum time (see: [Polyphasic sleep](#)).

The worst part of that disregard is that little kids worldwide are woken up early in the morning to [go to school to "learn"](#). Not only does their learning suffer, or even becomes futile; not only do those kids get stressed and cranky; their health can be affected. Their immune systems undermined. Their long-term development stunted. Some sleep researchers try to battle the establishment for more rational school schedules (hats off to [Dr Mary Carskadon](#) and [Dr Amy Wolfson](#); see [interview](#)). At the same time, the ever-present rat race produces forces in the US, in Europe, and beyond, that insist on even earlier school hours. That comes from both parents and from the authorities. They all bring up a spurious and biologically untenable excuse: the kids can just go to sleep earlier.

In this gloom and doom scenario, there is still a ray of hope though. Science is slow to percolate into social awareness; however, in the end, it wins most of the time (except where it needs to combat stronger forces; e.g. intelligent design theories still keep doing well with the backing of religious doctrinaires). My optimistic prediction is that, sooner or later, governments, school authorities, and parents will realize that **the use of an alarm clock to rip kids from their beds contradicts the goals of education!**

Studying sleep and learning with SuperMemo

For three decades now, I have been interested in the negative impact of modern lifestyle on sleep and learning. I have suggested that a large proportion of sleep disorders can be remedied with simple techniques such as chronotherapy, free running sleep, etc. The first step towards a solution to a sleep problem is the understanding of one's own sleep patterns. For that reason, I have encouraged people with sleep problems to collect their sleep data with [SleepChart](#) freeware that was released in 2003 ([download](#)). When [SleepChart](#) was created it was not clear what benefits it would bring. I have suggested that [SleepChart](#) might in the future be used to investigate the links between sleep and learning, and that [SleepChart](#) could become a tool for the optimization of learning, esp. when used in conjunction with [SuperMemo](#). One of beautiful things about [SuperMemo](#) is that it keeps a detailed record of memory performance while you learn. If that record could be combined with measurements of sleep quality before and after learning, an ocean of research opportunities would emerge. It was the [SleepChart](#) application that provided the missing link. With [SuperMemo](#) and [SleepChart](#), we can collect data that can provide answers to a virtually infinite set of questions about sleep and learning. However, my suggestion that [SleepChart](#) and [SuperMemo](#) be integrated, raised a lot of opposition, primarily from users of [SuperMemo](#) who have always complained that the program fell into an endless spiral of mounting complexity and that few users will ever need or make use of the new functionality.

Long sleep results in poor learning?

As of 1996, [SuperMemo](#) makes it possible to keep a detailed record of all repetitions. You can check which piece of knowledge was reviewed, when, and with what outcome. As of January 2000, I kept a detailed record of my own sleep timing. I was always curious how sleep affects learning and how learning affects sleep. With learning and sleep data at hand, I could look for correlations between the two. My first, most atavistic and raw intuition was that it should be easy to show that short sleep produces poor learning. "*Does more sleep help learning?*" I took my own sleep-and-learning data to quickly investigate such a correlation. However, nearly a reverse relationship could be demonstrated. In retrospect, the paradox is very easy to explain: in [free running sleep](#), which I practise religiously, there is a correlation between the quality of sleep and its length: the better the alignment of the sleep episode with the [circadian](#) rhythm, the shorter the sleep, and the better its quality. **Unless they are sleep deprived, healthy people sleep long only if they sleep in a wrong phase. Optimum sleep is usually very short. In other words, length of sleep is no measure of sleep quality.**

Learning reduces the demand for sleep?

An analogous question to ask was "*Does learning increase the demand for sleep?*" When I tried to investigate this mirror question, I was equally unsuccessful. Again an inverse correlation could be noticed. This time, the reason for that surprise was that **insufficient sleep discourages learning**. This way, less sleep means less learning, and longer sleep on the following night to repay the sleep debt. In other words, lots of learning would paradoxically be followed by little sleep! For more details see: [Impact of learning on sleep](#).

Those failure made it apparent that little evidence can be garnered on the relationship between sleep and learning without considering the **circadian** timing, i.e. the time in which learning takes place in reference to the sleep phase (e.g. as determined by the natural waking hour).

Approximating the sleep phase

In the next step, I was hoping to see a correlation between learning and the disparity between sleep time and sleep phase. However, for this correlation to be computable, one needs a good estimation of a **circadian** rhythm phase. **SleepChart** uses a rough heuristic algorithm that attempts to do just that. However, this algorithm was too weak to interpret major disturbances in the sleep rhythm caused by delayed sleep, stress, exhausting exercise, etc. That algorithm was replaced in **SleepChart** 2.0, which uses a recursive phase response curve (**rPRC**) to estimate the **circadian acrophase**. **rPRC** is a variant of a phase response curve that is based solely on the outward expression of the circadian rhythm as documented by sleep logs, and whose only phase shifting stimulus is the delay in bedtime (in reference to the optimum bedtime).

Timing of repetitions

Another stumbling block in further research was a feature used in **SuperMemo** called **Midnight clock shift**. It makes it possible to use **circadian** time for repetition record as opposed to clock time. For example, if the student keeps working after midnight, repetitions are recorded for the previous day, not the new calendar day. That could cause misalignment of sleep and learning data by an entire day. Sadly, earlier versions of **SuperMemo** kept only the date of the repetition, not its precise time. This was changed only in **SuperMemo 13** (2006), in which the clock time of each repetition is recorded. This makes it possible to compute the exact **circadian** timing of each memory **recall** act. At last, it was possible to correlate sleep data with learning in precise time frames! I had the alpha release of **SuperMemo** 2006 available as of July 17, 2006. This means that, as of this writing, we have passed the fifth anniversary of data collection, and the data set is getting bigger and more meaningful with each passing day. The circle of people logging their sleep in **SuperMemo** is increasing.

The impact of SleepChart

The application of **SleepChart** in **SuperMemo** surpassed all expectations in its value and is now a unique tool for investigating sleep and learning. As of the release of this article (winter 2012), this is the only tool in the world that makes similar investigations possible. The employment of **SuperMemo** in this research is essential as it effectively aims at the same level of knowledge retention at each review. This provides for a steadier comparison platform between different levels of **circadian** and **homeostatic** sleep propensity. Developers of other spaced repetition applications have never expressed much interest in investigating sleep. Moreover, the extra accuracy of the newest **SuperMemo** Algorithm SM-15 provides for extra sensitivity that should yield faster clarification of trends and correlations even for smaller datasets.

[You can also join the research effort!](#) In **SuperMemo** 15, you only need to log in your sleep and send the data with just one button push. More details on the functionality of **SleepChart** in **SuperMemo** can be found [here](#).

Recall vs. Consolidation

In studying the impact of sleep on learning, we have to separate two important measures of memory: **recall** and **consolidation**.

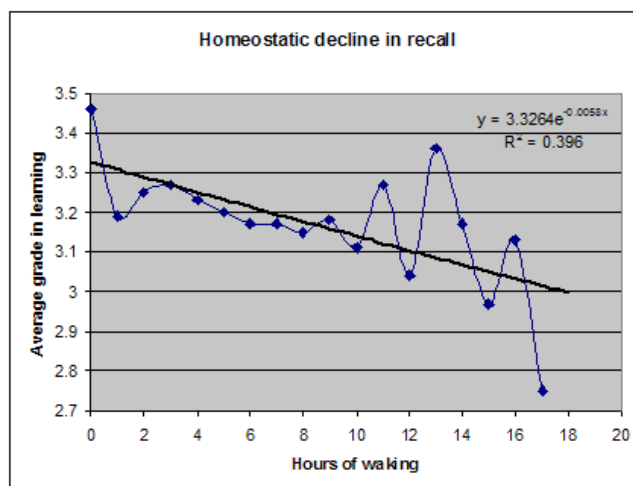
Recall measures the proportion of pieces of information that can be recalled from memory at any given circadian time. In **SuperMemo**, **recall** can be simply measured as the average grade received in learning within a selected subperiod of **circadian** time. Grades can be converted to percent recall, or can be used as an equivalent measure of **recall**. The conversion to **recall** may be of all-or-nothing type (successful **recall** is treated as 100% recall, while a **recall** failure is treated as 0% recall). The conversion can also rely on the expected and/or estimated forgetting index in **SuperMemo** to provide a more precise reflection of **recall** difficulty. The conversion that uses the forgetting index may be based on the correlation between grades and the expected forgetting index, or can use a heuristic based on the subjective estimated forgetting index assessment (note that the estimated forgetting index, unlike the expected forgetting index, is not part of repetition history in **SuperMemo**). That latter, seemingly less precise approach, provides sharper contrast between **recall** levels and is accomplished by depressing the **Exp FI** button in alertness graphs in **SleepChart**.

Consolidation measures how well we consolidate or re-consolidate memories with repetitions executed at any given circadian time. **Recall** measurements are fast. We get our data on the day of learning. We instantly know if we

can or cannot answer questions at the selected time. However, **consolidation** data may take years to collect. We may review an item today, and need to wait several years before the outcome of the review (consolidation) can be verified. As sleep-and-learning options in **SuperMemo** are relatively new (timing of repetitions is collected as of 2006), only very large sets of data collected over the periods of many years provide a basis for meaningful **consolidation** measurements. For that reason, memory **consolidation** graphs are currently not part of data analysis in **SuperMemo**. The plan is to introduce those options in a few years when they become usable for a larger proportion of long-term users of **SuperMemo**.

Recall

Data collected with **SuperMemo** show that **recall** decreases rapidly with waking time.



*Exemplary illustration of the speed in which **recall** drops during a waking day. In this example, the average grade drops from 3.3 early in the day to less than 3.0 after 16 hours of waking.*

As the day goes on, our ability to **recall facts from memory is getting worse and worse.**

Interestingly, even a short nap seems to bring the **recall** back to the baseline level. In other words, there seems to be a direct link between **recall** and alertness. **Recall** seems to be inversely correlated with the **homeostatic** drive to sleep. A slight increase in **recall** around the 12th hour of wakefulness is a reflection of the **circadian** component of alertness. The waviness at later waking hours seen in the graph comes from the scarcity of data as learning at later hours makes less sense (of total 31,000 repetitions used to plot the graph, only 684 fell beyond the 10th hour of waking).

Newer versions of **SuperMemo** make it possible for everyone to see the relationship between their **circadian** cycle and their **recall**.

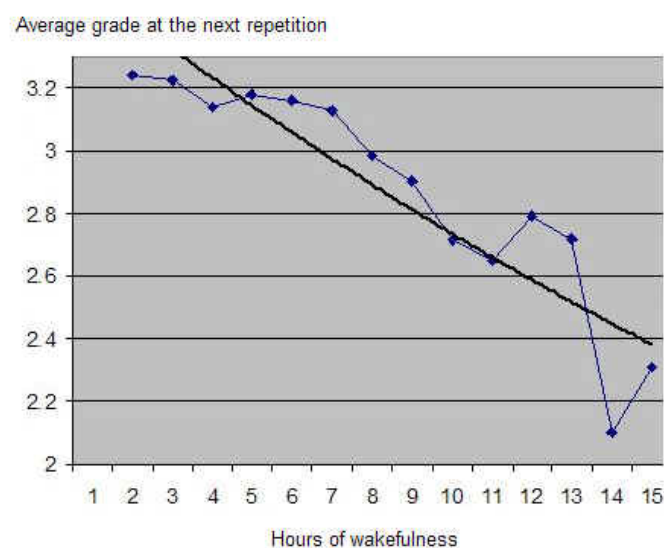


An exemplary *recall* graph displayed by *SleepChart* shows the decline in grades scored in learning during a waking day. This graph also shows a slight increase in the grades in the second half of the day due to *circadian* reasons.

Note that both graphs above show a similar [time constant](#) of 178 and 172 respectively ([half-life](#) of 124 and 119 hours). For calibration reasons, half-life becomes meaningful only when actual *recall* percentage data is used (in SuperMemo, grade 3.0 is a sharp border between *recall* success and *recall* failure).

Memory consolidation

The decline in the ability to consolidate memories during the waking day follows a curve that mirrors the decline in the ability to *recall* things from memory!



Exemplary relationship between the circadian time (hours from waking) and the ability to consolidate memories (expressed by an average grade scored in the next repetition)

As the day goes on, the ability to store facts in memory declines. A repetition in *SuperMemo* is a single effort to *recall*

previously learned information from memory. The graph has been constructed by correlating the **circadian** time of one repetition (in reference to waking time), and the grade scored in the successive repetition of the same piece of information. The successive repetition often takes place months or years after the repetition for which the **consolidation** time was registered. Again, short naps seem to restore the memory **consolidation** power to baseline. As much as recall, **consolidation** seems to be inversely correlated with the **homeostatic** drive to sleep. A slight increase in the quality of learning can also be seen around the 12th hour since natural waking (in the presented case).

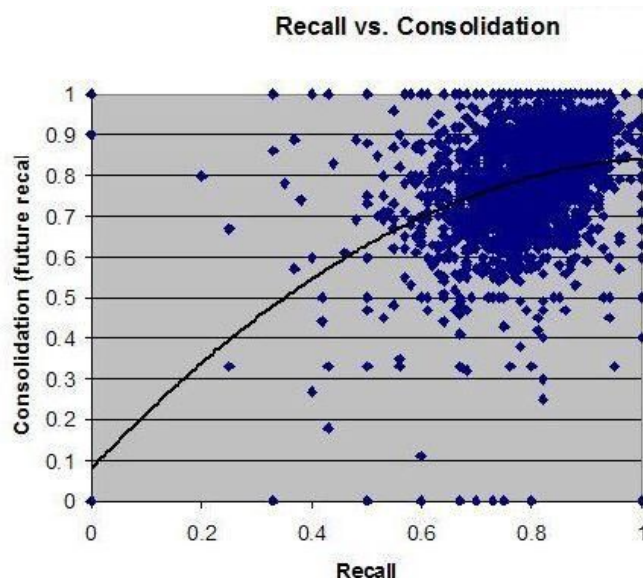
The conclusion is that in **free running sleep** (i.e. primarily in the absence of an alarm clock), **we can get best learning results if we learn early in the morning**. The same holds for exams. The **recall** and exam results will be best if the exam is held in the morning even though some time for pre-exam cramming may skew the outcome.

Correlation between recall and consolidation

The fact that both **recall** and **consolidation** curves seem to follow a very similar course during a waking day seems to indicate that they both may depend on the same underlying mechanism. This conclusion is amplified by the fact that **recall** is a passive process, while **consolidation** is an active process of forming new or reconsolidating old memories. We can hypothesize that the underlying mechanism is therefore not molecular. The decline in **recall** and **consolidation** might simply be caused by a decline in operational efficiency of the neural networks involved in learning. That efficiency, expressed as alertness (see: [Alertness in SuperMemo](#)), depends on both **homeostatic** and **circadian** components of the sleep drive. The **homeostatic** component determines an overall decline in network efficiency over the course of a waking day, while the **circadian** component allows of a small bump in the second half of the waking day, presumably due to a neurohormonal impact of the **circadian** cycle on the overall function of the central nervous system.

Good learning days

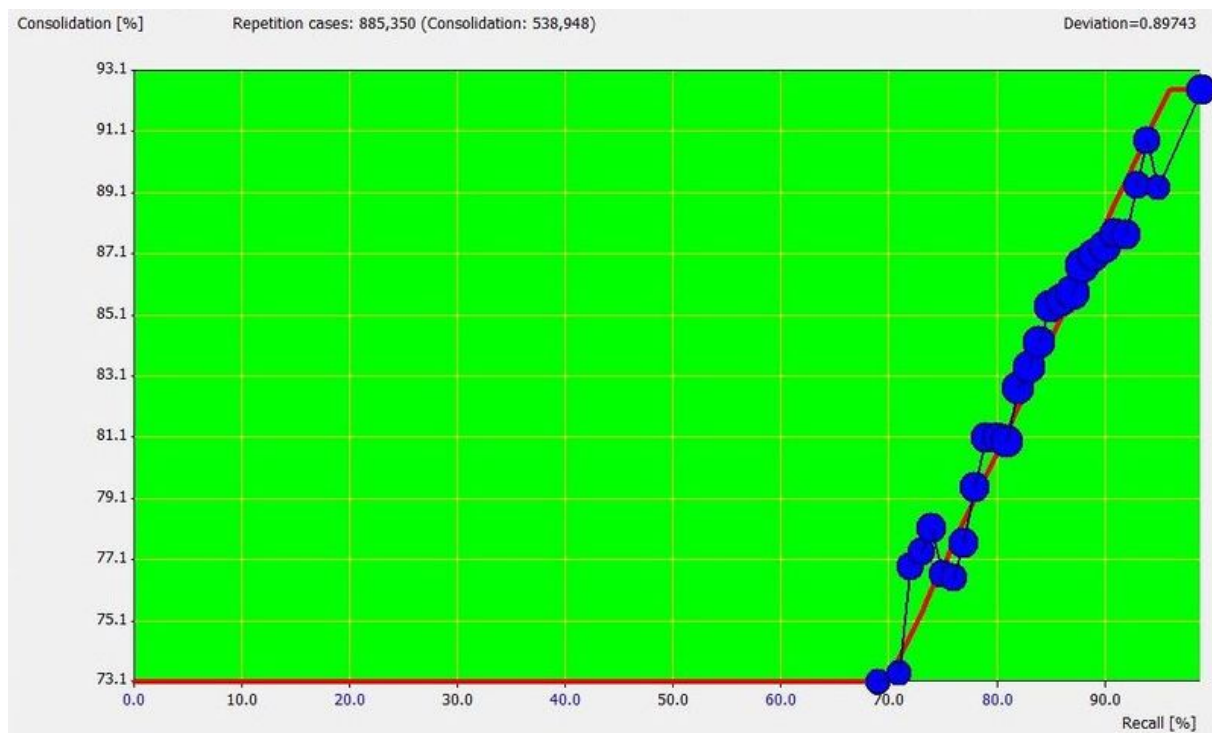
The correlation between **recall** and **consolidation** can also be seen in abstraction from the **circadian** time. If the overall **recall** and **consolidation** data are taken from individual days of learning process, they correlate pretty well too:



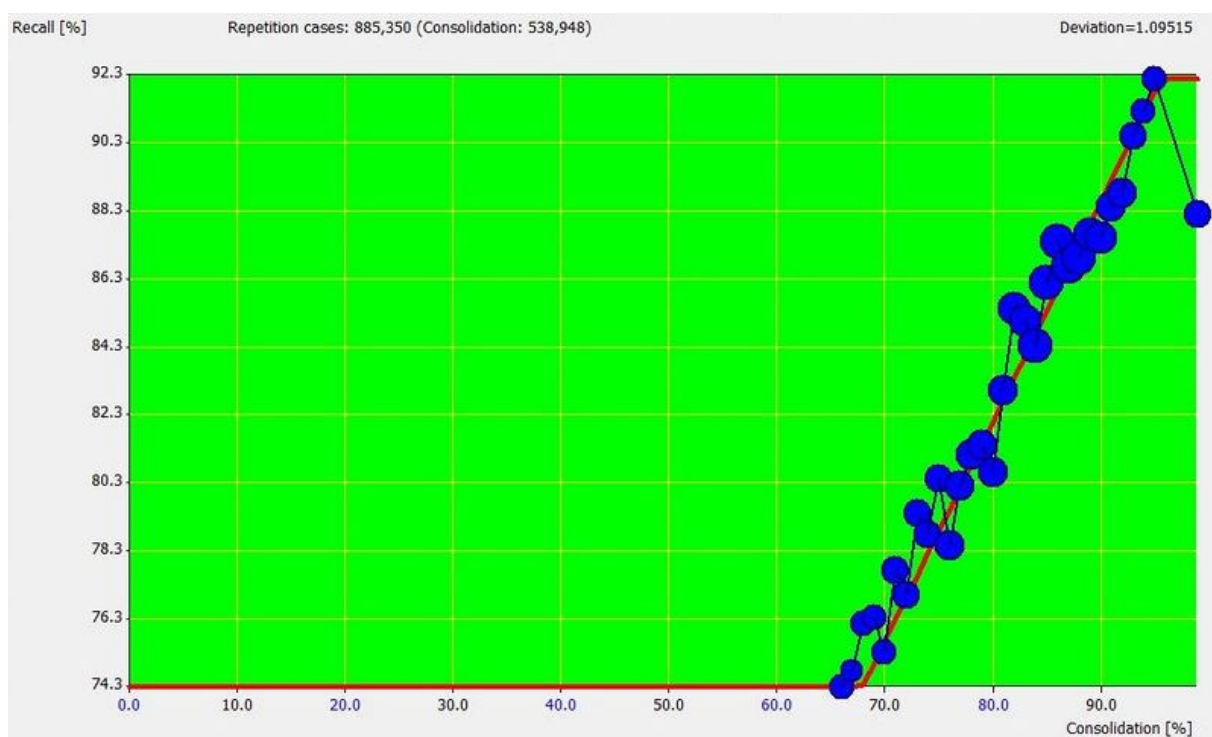
*Exemplary graph that shows that learning days that are good for **recall** are also good for memory consolidation. **Recall** is expressed as a fraction of correct answers on a given day. Consolidation is expressed as a fraction of correct answers on the day of the next repetition that follows the one on the day for which the consolidation is measured.*

We can conclude that good learning days are equally good for **recall** as they are for **consolidation**. A more general conclusion is that successful **recall** is essential for **consolidation** of memories.

In future versions of SuperMemo, the user will be able to see the strict correlation between his or her own **recall** and memory consolidation:



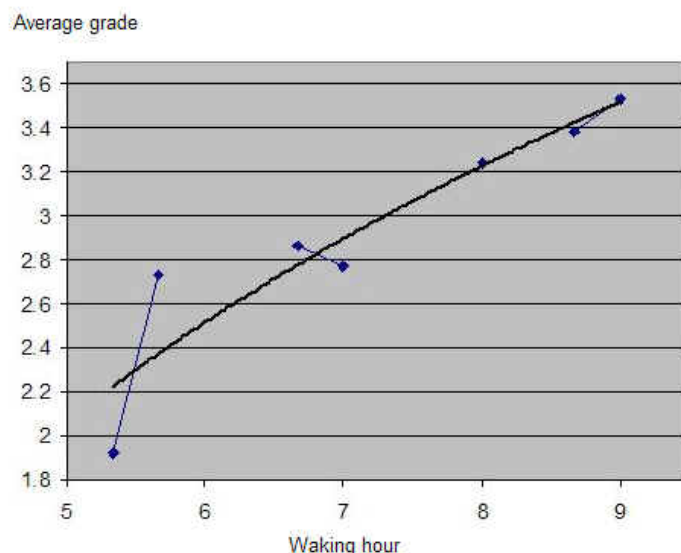
Exemplary graph showing how good memory *recall* improves memory *consolidation*. The relationship between *recall* and *consolidation* is nearly linear. The graph was plotted using over 800,000 repetitions in SuperMemo, with 538,000 of these contributing their data to the *consolidation* estimates. *Recall* levels with fewer than 3000 data points have been omitted from the graph. The **Deviation** parameter says how well the linear fit matches the data (the less the deviation, the better the fit). The deviation is computed as a square root of the average of squared differences between the approximation and the data.



Exemplary graph showing the average recall for days producing a given level of memory consolidation. The relationship between consolidation and recall is nearly linear. The graph was plotted using over 800,000 repetitions in SuperMemo. Consolidation levels with fewer than 3,000 data points have been omitted from the graph. Lowered recall for consolidation of 100% comes from the fact that this consolidation level is overrepresented by small sample days where lucky perfect recall in just a few items may result in perfect consolidation reading without actually saying anything about the recall on the day the consolidating repetition took place. Sufficiently large number of such cases will let consolidation category of 100% pass the 3,000 data points outlier limit set for this graph, and result in a recall level that is much closer to the average level.

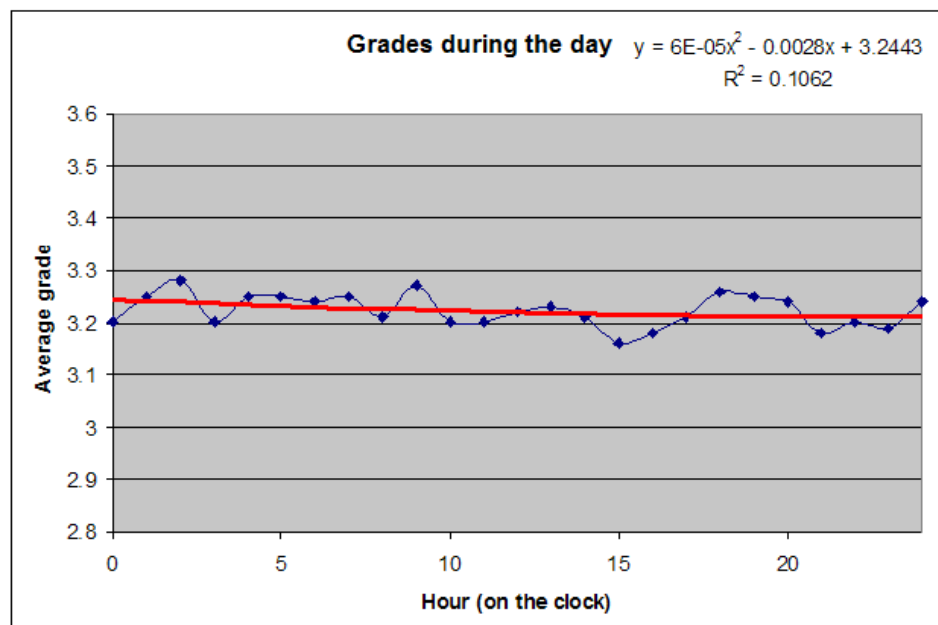
Alarm clock vs. learning

There is an urgent need to collect sleep data from subjects who disrespect healthy sleep in various ways. The most interesting area for further investigation is how poor sleep hygiene affects learning. As an example, let's have a peek at an interesting graph showing the average **recall** of a teenager who often needs to get up early for school, far ahead of his natural waking time. If grades are converted to the forgetting index, we can see that this student forgets 53% more on schooldays when he needs to get up early. This is a very preliminary sample that should not be used to draw far-reaching conclusion (for example, more learning occurred in earlier hours on days free from school), however, it is my hope that with more data pouring in, we can tangibly demonstrate the disastrous impact of early school times on learning. In other data sets, it has also be found that later waking time (after 11 am) often correlates with lower grades as well (perhaps as a result of weekend late "partying" that results in poorer sleep and later awakening).



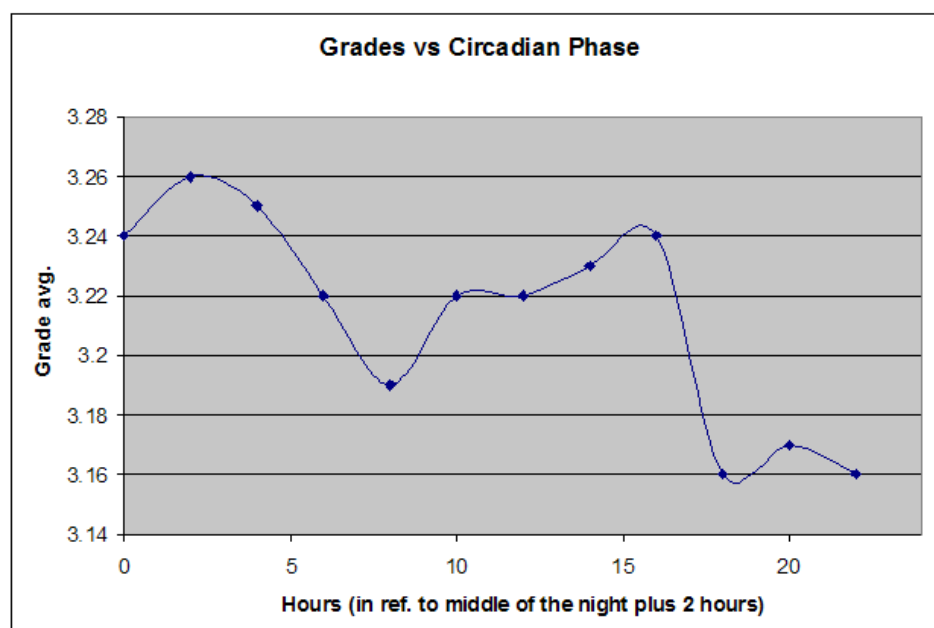
Learning in free running sleep

Everyone has his or her own optimum learning hours that depend on the **circadian** rhythm. For most people, optimum learning occurs in the morning and after a **siesta**. Non-nappers also improve their learning in the evening due to a **circadian** upswing. However, the exact timing of those optimum periods can only be determined on an individual basis. The disconnect between the optimum learning time and the absolute clock can be seen in a regular **free running sleep** rhythm as in the analogous graph below that does not show any hours (on the clock) in which learning is more efficient:



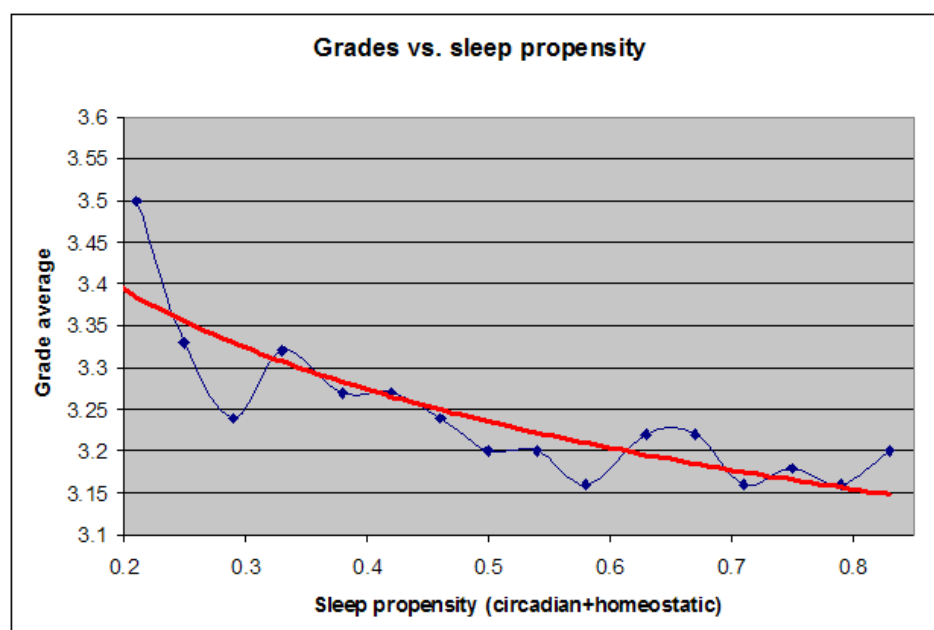
However, when the **free running sleep** data presented in the graph above is processed using the **circadian** time rather than the clock time, a typical two-peak circadian pattern re-emerges with good grades in the morning, **siesta** dip, and

an evening upswing. The circadian phase estimations have been generated with [SleepChart](#). The peak learning times are usually separated by 10-13 hours:



Alertness multiplier

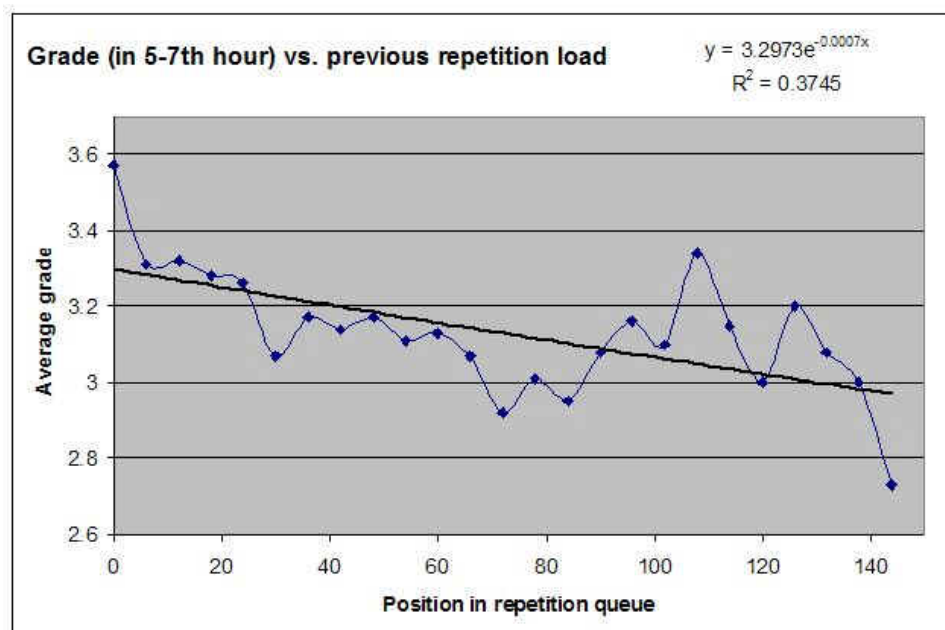
It is obvious that alertness improves learning. However, it is worth noting that even marginal improvements to high alertness can yield major benefits to learning. In other words, it is not enough to be alert. Crisp alertness might substantially improve learning as compared with just being ok. In the presented graph, sleep propensity has been estimated with [SleepChart](#) using the [two-component model](#).



Learning overload

The more time we spend learning on a given day, the lower our learning capacity is. [Recall](#) decreases along a [homeostatic](#) increase in sleepiness. However, it decreases much faster when the learning process continues. In other words, **learning increases sleep propensity**. That observation agrees nicely with the complementary encoding theories that explain how the [brain copes with catastrophic forgetting that occurs in artificial neural networks](#). Those theories speak of secondary memory systems used to redistribute knowledge originally stored in low-interference short-term networks. The act of storage redistribution is hypothesized to occur during sleep. In other words, as you keep loading your memory with knowledge, your brain turns on a defense mechanism, makes you drowsy, and sends you to an earlier sleep. This is why, against conventional advice of sleep experts, I recommend [SuperMemo](#) to

[insomniacs](#) (if they must go to sleep early). Except where the [circadian](#) component of sleepiness is missing, learning is a good tool for boosting [homeostatic](#) sleepiness. Obviously, it will not work in cases like learning before an exam, which may subconsciously be associated with stress.



Average grade in learning with SuperMemo depends on the position of the tested item in the learning queue. Later items receive lower grades. To eliminate the impact of the homeostatic sleep propensity, all repetitions studied took place in the hours 5-7 of the waking day.

Sleep might be the chief anti-overload protection mechanism. The hypothesis says that sleep helps unload separated neural representations from the [hippocampus](#). It optimizes the long-term neocortical overlapping representation. Learning with a fresh mind after a good night sleep will then be recommended. Learning in condition of [sleep deprivation](#) or mental fatigue would then be a mistake (unless employed as an anti-insomnia tactic).

Robin Clarke who hypothesized that too much learning can cause Alzheimer's (Wozniak 2002^[79]) writes: "*Natural selection will favor further mechanisms, which enable local matrixes nearing overload, to signal their lack of spare capacity, thus activating diversion to other locations*". This sounds exactly like the job of NREM-REM sleep interplay. Optimizing the storage is the simplest defense against memory interference. Sleep may act as an anti-overload and anti-interference mechanism that does not show the same destructive powers as forgetting. The signal on the "*lack of spare capacity*" might simply be adenosine-based [homeostatic](#) component in the [two-process sleep model](#). See also: [Neural optimization in sleep](#)

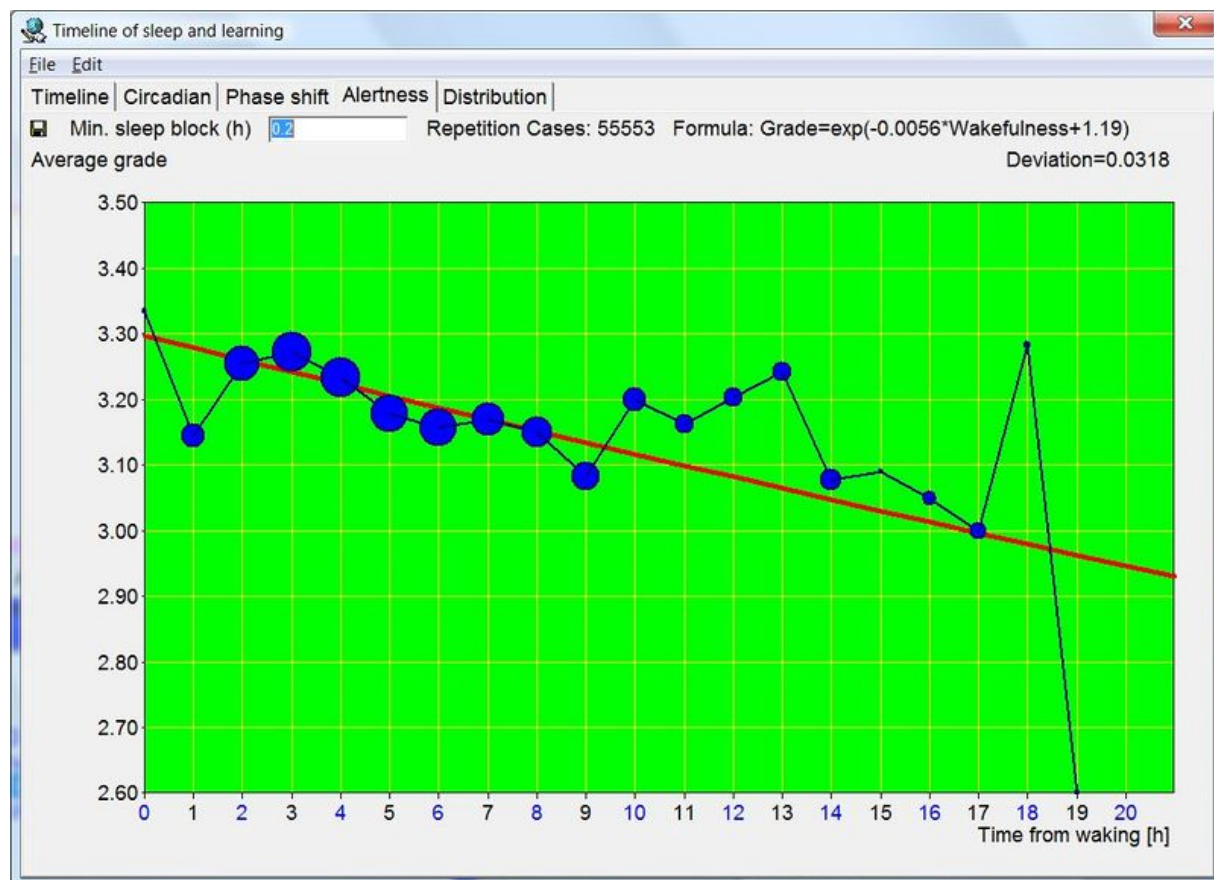
Alertness vs. learning

As shown in the preceding sections, in healthy individuals who are not sleep deprived and who sleep in the correct phase, the best learning results are obtained early in the morning. This easily reproducible observation was an incentive to introduce two options in [SuperMemo](#) that help users of the program study their alertness throughout the learning day. The term alertness, in SuperMemo, is used interchangeably to describe two different measures of cognitive function: inverse of sleep propensity (or sleep drive) as derived from the [two component model](#), and the average grade in learning with [SuperMemo](#) which corresponds with memory [recall](#). Both expressions of alertness are closely correlated. [SuperMemo](#) measures alertness as well as attempts to predict changes in alertness in two different time frames intended to separate the [homeostatic](#) and [circadian](#) components of sleep propensity. Both approaches require a sleep log for the measurements and for the predictions to be possible. To demonstrate the [homeostatic](#) changes to alertness, [SuperMemo](#) measures the learning performance since the last sleep episode. To demonstrate the [circadian](#) changes to alertness, [SuperMemo](#) measures the learning performance in reference to the [circadian](#) time (i.e. time measured since the optimum natural waking hour) in periods that may or may not include intervening sleep episodes. As it can be seen in the enclosed pictures, it is not possible to fully deconvolve the impact of [homeostatic](#) and [circadian](#) sleep propensity on learning. [Homeostatic](#) graphs will always include a small [circadian](#) bump related to post-siesta learning, while [circadian](#) graphs will be affected by sleep habits that are closely correlated with the circadian cycle, esp. in [free running sleep](#).

If you have already collected your sleep data with [SleepChart](#), you can see your wake-recall correlations with the

newest **SuperMemo**. Note that only repetitions executed with **SuperMemo** 13.0 (2006) or later will be included in the graphs as earlier SuperMemos did not store precise time of repetitions in repetition history.

You can see how fast your alertness, **recall** and grades drop during the day by inspecting **the Alertness (H)** graph in **SuperMemo**. In this graph, you can see the time that has passed since the last sleep block, and how your **recall** changes in waking:



Alertness (H) graph makes it possible to visually inspect how recall decreases during a waking day. It also shows the impact of **circadian** factors with grades slightly lower immediately after waking and slightly higher in the post-siesta period (i.e. in the 10-13 hour bracket). The **Deviation** parameter displayed at the top tells you how well the chosen approximation curve fits the data (in the picture: negatively exponential recall curve). The lesser the deviation, the better the fit. The deviation is computed as a square root of the average of squared differences (as used in the method of least squares).

In **Alertness (H)**, the minimum length of a sleep episode in consideration is determined by **Min. sleep block (h)** box (0.2 hours, or 12 min. is the default minimum). Shorter sleep blocks are disregarded in plotting this graph. **Homeostatic** alertness half-life (in hours) tells you when your learning capacity drops by half after waking. You can modify this parameter to look for a better curve fit in your case (the **Model** button must be depressed). See **Deviation** to evaluate the fit. This half-life can differ between individuals. Notably, it is very short in narcoleptics, and very long in natural non-nappers.

The **circadian** changes in alertness can be seen in the **Alertness (C)** graph, which plots alertness throughout the day in reference to the circadian time measured from the actual waking time or from the optimum natural waking time:



Alertness (C) graph showing the powerfully [biphasic nature](#) of the human circadian cycle. The horizontal axis shows the circadian time, i.e. the time that elapses from phase 0, i.e. the predicted "end of the night" time (if **Model** is depressed). The prediction comes from the [circadian](#) model employed in SleepChart, and is derived from the sleep log data. The yellow line is the predicted circadian alertness derived from the same sleep log data using the [two component model of sleep propensity](#) developed for the purpose of sleep optimization in SuperMemo (inspired by similar work by [Alexander A. Borbely and Peter Achermann](#)). The overall alertness, not shown in the graph, is the resultant of the status of the two components of sleep propensity: the [homeostatic](#) component and the [circadian](#) component. The blue dots are recall data taken from the learning process in SuperMemo that correlate well with overall alertness

How learning affects sleep?

Impact of learning on sleep

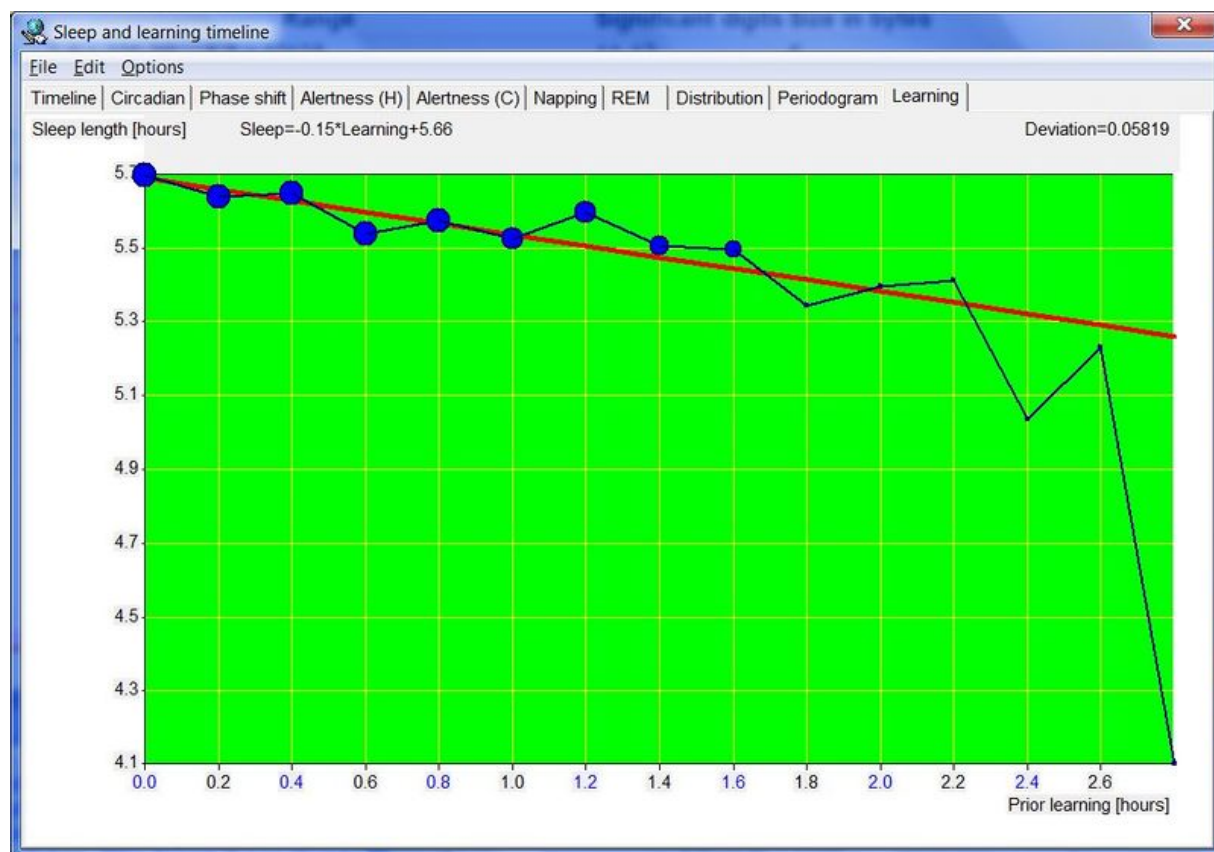
There are many indications that heavy learning increases demand for sleep and increases the density of sleep, esp. its [REM](#) phase (DeKonick 1989^[85], Smith et al. 2004^[86]).

In [Learning overload](#), I showed how learning inhibits further learning and how it contributes to the [homeostatic](#) drive to sleep. In that sense, learning does increase the demand for sleep.

In many of my older articles I often mention the fact that learning should increase the demand for the total sleep time. I read about the impact of learning on sleep yet in the 1980s. I have since lived with the conviction that this is a science fact that is as obvious as the fact that sleep is essential for learning. However, when I tried to prove the claim with data collected with SuperMemo, I discovered that it was not as easy as I thought.

When I tried to see if prior learning increases the length of sleep, I found the opposite. Again I started with my own sleep and learning data, which is rare in its size and the fact that the free running condition applies to both sleep and learning. I explained [free running sleep earlier in the article](#). By "learning at libitum" I mean learning that, for the sake of efficiency, is more intense and long lasting on good learning days, and less intense on worse learning days. Good and bad learning days are primarily determined by the quality of sleep, and not, for example, availability of time. I thought that the free running condition is essential for such investigations, esp. sleep should not be controlled artificially so that to make sure that increased demand for sleep is reflected in total sleep obtained.

It appears that **in a free running condition, the days with lots of learning were followed by less sleep in the night!**



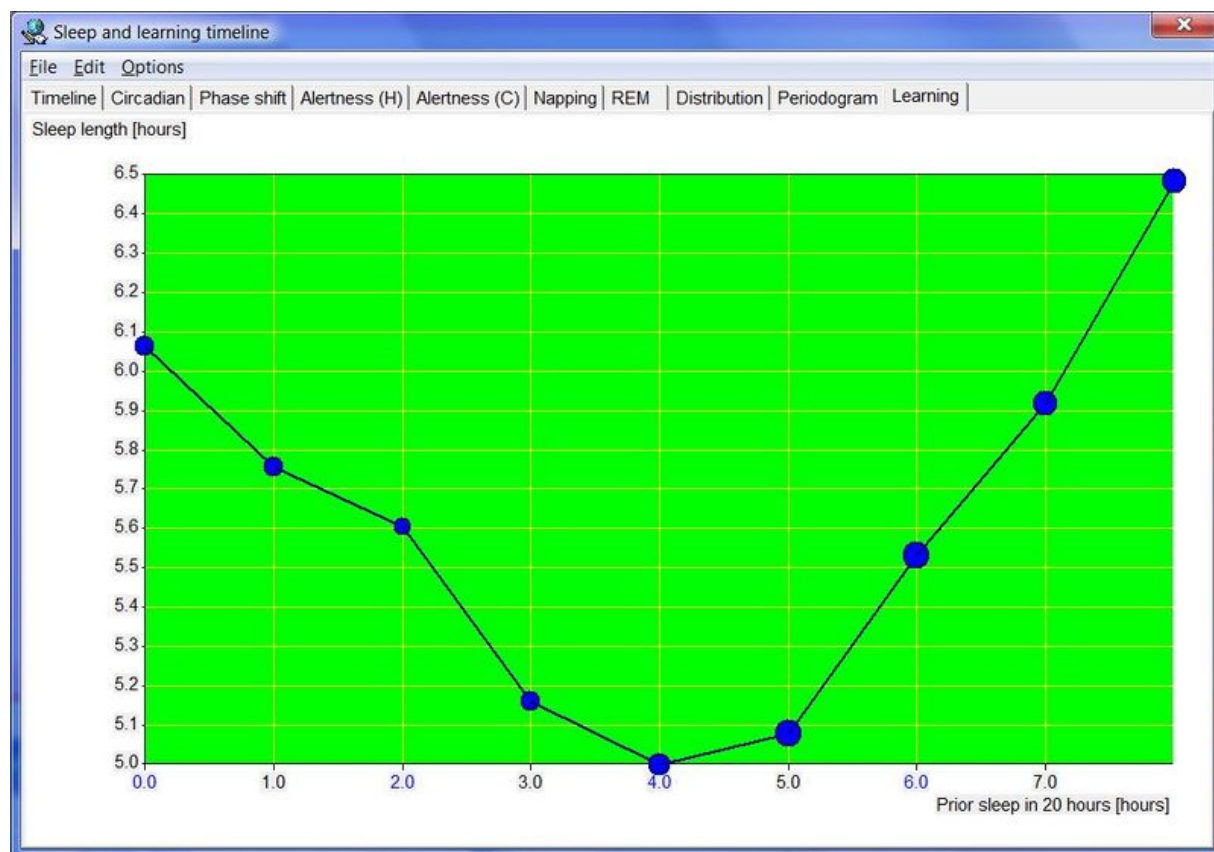
The amount of sleep obtained in the first 11 hours from bedtime as a function of the amount of learning in the last 8 hours preceding the bedtime.

Upon a closer inspection, it appears that the reason for this surprising outcome is that if learning is done on demand, i.e. more learning on good learning days, prior quality of sleep determines both the amount of learning and as well as the total sleep on the following night.

In a free running condition, where both sleep and learning are taken ad libitum, good learning days are followed by less sleep due to the fact that they correlate with minimum sleep debt.

I tried to correct for prior total sleep to get a better picture. You may [recall](#) from the section devoted to [napping](#) that the amount of napping correlates well with the prior night's total sleep (the less sleep, the more napping). If I could find a similar neat relationship between the sleep on two successive nights, I could perhaps correct for sleep debt and reveal if more learning entails more sleep.

However, the relationship between total sleep on two successive nights is also pretty surprising. For example, the following U-shaped relationship shows the amount of night-time sleep depending on the total sleep in the preceding 20 hours.



Exemplary U-shaped relationship of total sleep and sleep on the preceding night. Total sleep on the vertical axis is taken as the consolidated night-time sleep (i.e. sleep in which short-lived nighttime awakenings are ignored).

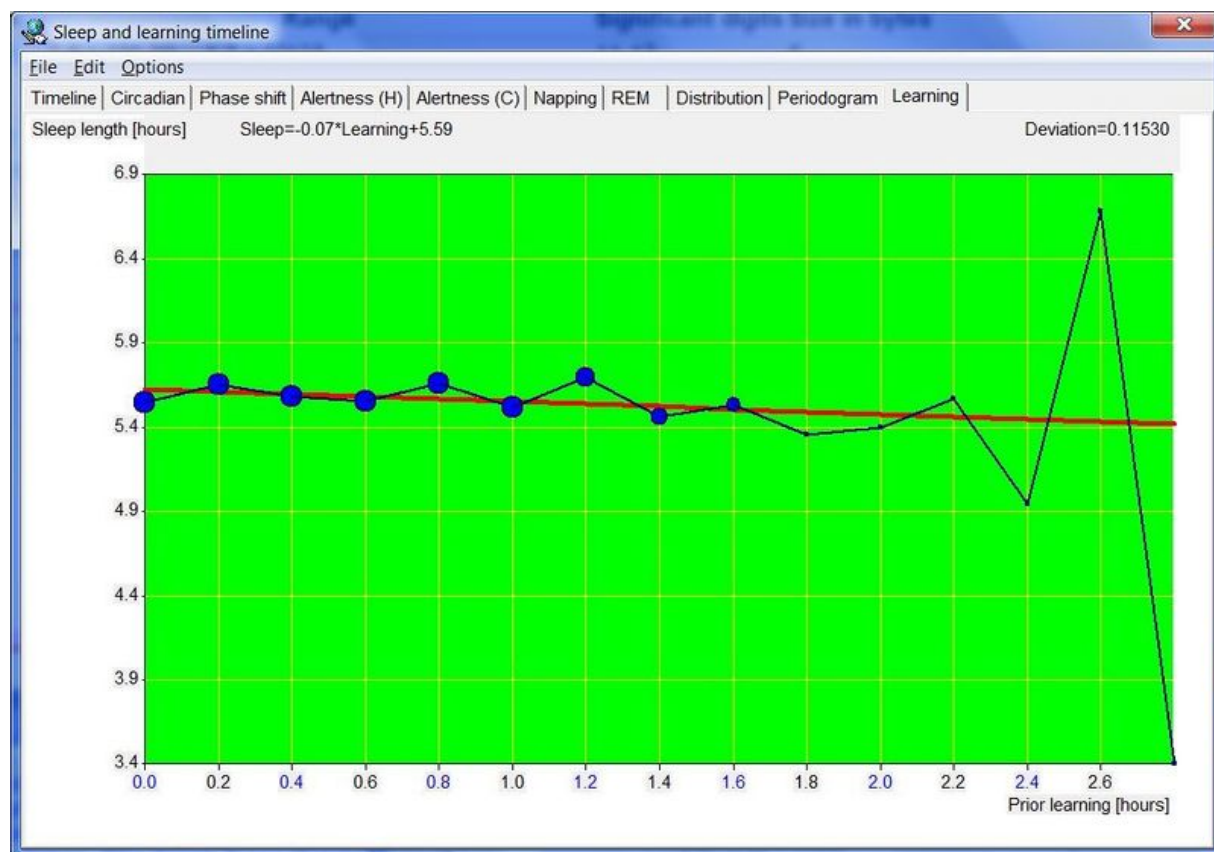
The horizontal axis represents total sleep whose termination point is embraced by the 20 hour margin preceding the bedtime in consideration. This margin was chosen to capture the preceding night sleep as well as follow-up naps without reaching into areas of sleep that should be considered two nights away from the period of interest.

The U-shaped graph shows that a simple sleep debt formula cannot be used to correct for sleep demand after a day of learning. However, a subset of normal-length nights could be used to filter out for varying sleep debt conditions.

As for the explanation of the U-shape obtained, it might be a combination of three main causes:

1. Most obviously, short sleep on one night will often result in longer sleep on the successive night (e.g. as with total sleep from 0-3 hours on the preceding night).
2. Some factors that determine the length of **free running sleep** may span over periods longer than a single day (e.g. health status, season, humidity, availability of sunlight, etc.). Those factors will result in a positive correlation between total sleep on successive nights (e.g. as seen in the graph in total sleep spanning 5-8 hours).
3. Extremely long days, with more than 20 hours of wakefulness, will result in failing to register the preceding sleep on the graph (i.e. the preceding night sleep will equal zero).

Using data on the relationship between the length of sleep on two successive nights, we can apply a "band filter" on the data used to generate the [first learning-vs-sleep graph](#). If we eliminate short-sleep nights by choosing only data points with total preceding sleep equal to five or more hours, we can reverse the downward trend and produce a nearly flat linear relationship between learning and the follow-up sleep:



If sleep on the preceding night is above 5 hours, then the amount of learning has nearly no impact on the follow-up sleep

If the "bandwidth" is narrowed to 5.0-6.5 hours, we get a perfectly flat line (slope=0.00). This data seems to indicate that **an increase in learning does not increase the total sleep on the follow-up night**.

As there are many lines of evidence that learning does affect the follow-up sleep, there could be many explanations of that conclusion. Sleep density might change instead of the length of the night sleep episode (as it is the case with REM density (Smith et al. 2004^[86]). In an active lifestyle, learning may not increase the demand for sleep much above the baseline. Last but not least, the result may differ between students. Some students can swear that more learning requires more sleep in their case. I am yet to receive an appropriately large set of data that could demonstrate this fact. As much as **free running sleep** makes it impossible to prove that short sleep is bad for learning, learning on demand may make it impossible to prove that lots of learning increased the demand for sleep. As much as alarm clocks can be helpful in showing their own bad impact on learning, forced learning may also be a more grateful research subject. Forced learning may be more costly for the brain and show a more pronounced impact on the density and length of sleep. Perhaps learning needs to be heavy enough to notice the effect due to the fact that all our waking experience is a form of learning, even if we do boring repetitive activities. A mere thought process, e.g. recalling a relative, will form new memory traces in the brain. These will be processed in sleep. For sleep demand to come well above the baseline, learning must come above its own baseline as well.

Sleep and school

Schools have changed the world for the better. Literacy is on the increase worldwide. However, there is one huge factor that holds schools back: sleepy kids!

Sleepy kids learn little!

Modern lifestyle results in an epidemic of **delayed sleep phase disorder** in the adolescent population. Millions of families nowadays struggle with putting their kids to sleep early enough, and to have them wake up fresh in time for school. It seems like we are losing this battle worldwide. Kids seem to be getting less and less quality sleep! Drs Amy Wolfson and Mary Carskadon study sleep in teenagers. They were horrified to find out that **sleep latency** during school hours was lowest for 10th graders and was a shocking 1.8 minutes^[87]! This latency is lower than the value a good sleeper usually achieves at bedtime! In other words, kids are more ready for sleep at school than a normal individual is ready for sleep in the night!

Learning in such sleep deprived state is worth little more than zero!

This is an alarming situation that can undermine the future of education as well as **the physical and mental health of the next generation**! Some sleep researchers ring the alarm bells, others look for remedies. I do not have a prescription for the problem. Hereby I would only like to appeal for more tolerance and understanding on the part of parents and schools. All my life I have worked for the purpose of better education for everyone. However, there is no learning without sleep. Sleep is important enough to often take precedence over the education itself! My appeal is:

It is better to miss a class or two than to go to school sleepy!!!

The premise of this appeal is very simple. Waking up a semi-conscious kid for school implies a day that is practically wasted for learning, or literally crossed out from a young life's calendar. Adding those extra 2-3 hours of sleep means that the kid will only miss a class or two, with many additional productive hours left in the day! It is by far better to spend an hour on productive learning than to spend 8 hours on comatose "survival through the class". It amazes me how little this simple truth is appreciated! When I speak to parents, they always excuse early waking with "there would be consequences for missing the class"! There must not be any consequences! [Sleep deprivation shrivels the brain](#)! Sleep is the fundamental human right of a developing brain. If someone threatens the kid with "consequences", you need to combat that attitude. Sadly, for many parents, the timing of the early morning schedule is determined by work and other obligations that cannot be worked around.

Excessive school workload

One of my favorite journalists, Fareed Zakaria, spoke in his GPS program about his prescription for better education: *"Some elements of the solution seem obvious. The writer Malcolm Gladwell says it takes 10,000 hours to get really good at anything. It's really just another way of making Thomas Edison's famous point that genius is 1 percent inspiration and 99 percent perspiration. Now if our kids spent two years less in school than in many other countries, they will find themselves behind in many areas. We don't have to go to the lengths that South Korea has gone to lengthen the school day and the school year, but we can't do the least work and hope for the best results"* ([source](#)).

The problem with this "Korean solution" is that it fails to account for a dramatic difference between good learning and bad learning. Given a shortage of good teachers, good funding, good methodology, etc. we might as well pump up school hours in hope of converting quantity into quality. However, a good hour of self-learning or a good hour of customized one-on-one tutoring is worth more than 10 hours of boredom in an average classroom. Perhaps Finnish schools with their reliance on excellent teachers would show a better ratio. If we added just two factors to our school systems: (1) **good sleep** and (2) **spaced repetition**, we could safely cut school hours to 1-2 classes per day and still get better results!

A good hour of self-learning is worth more than 10 hours of boredom in an average classroom!

School hours and homeschooling

Due to a well-documented sleep **phase shift** at adolescence, teenagers find it more and more difficult to solve the problem of **sleep deprivation** by just going to bed earlier. Instead of providing for longer sleep, early bedtimes may result in **insomnia** and a multitude of psychogenic sleep and emotional problems. Teens are simply unable to fall asleep at designed early time, and trying to force them to do so may actually backfire. Even a mild degree of **sleep deprivation** might be better than hours of tossing and turning, or nocturnal awakenings. Return to a **farmer's lifestyle** would remedy the problem of teenage body clock, however, this would mean many hours of physical work in the field from the early morning. Sitting in a school bench just won't do. Heavy load of schoolwork on its own contributes to the late sleep phase lifestyle!

When schools experiment with later class hours to accommodate the adolescent body clock, they get better learning results (Wahistrom 2002^[88]). Traffic accidents among young drivers on the way to or from school also drop (around 25% for a mere one hour shift clockwise). However, it appears that kids just tend to adapt and stay up later in the night. Later school hours are an imperfect remedy, esp. that kids differ by **chronotype** and each will have its own optimum window for the best learning performance. Callan (1998) reported that in high school, less than 10% of kids preferred the early school hours, while 15% preferred evening hours. Reported preference is often confused by the misalignment of **circadian** cycle with the waking period, which often makes evening types claim evening is better for learning, while in free running sleep, the same kids would prefer the subjective morning hours (with "morning" coming as late as mid-day). Moreover, as the kids get older the predominance of eveningness starts becoming more pronounced.

I do not know a universal solution, however, all parents should consider [homeschooling](#), which could make a world of difference. Not every parent is qualified, and not everyone can afford it. Amazingly, some modern and progressive countries banned homeschooling altogether. It is hard to believe, but two leaders in the adoption of rational and scientific social solutions, Germany and Sweden belong to that group! In fear of dangerous ideologies, some governments block a return to a tradition that is as old as the human race. A tradition that could remedy many weaknesses of the school system: tutoring one-on-one under the supervision of the most loving people in existence: own parents or other family members. Homeschooling makes it easy to employ the most efficient of the learning methods: self-paced self-directed exploration based on passion and curiosity. This ideal solution solves the problem of matching learning hours with the [circadian](#) cycle.

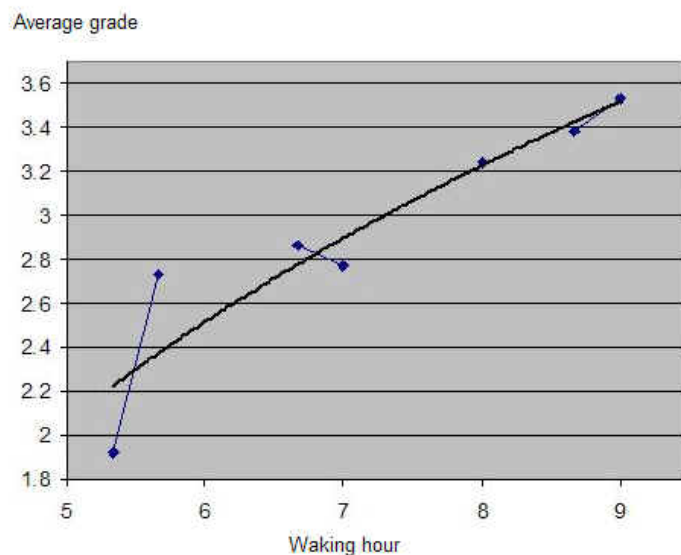
Sleep deprivation in kids

Most kids wake up earlier than they would prefer to. This results in [sleep deprivation](#) and a set of negative consequences:

- **bad learning:** cutting down on sleep dramatically impairs learning. Some groups of schoolchildren show [sleep latency](#) of just 1-2 minutes at the time when they sit in the class. This is **catastrophic**! This is a latency that many would be envious of at evening bedtime! Kids should learn at a time when sleep initiation is near-to impossible! In free running sleep, that would be the first 3 hours of the waking day! After that, learning is impaired and PE classes and lunch could come in. Lots of kids sleep in the class, or are solely preoccupied with "surviving".
- **bad emotions:** [sleep deprivation](#) results in irritability. Without the neural network cleanup executed in sleep, the brain quickly gets overloaded and overwhelmed with the stimuli. This could be learning stimuli, or minor annoyances, such as a colleague's jokes. Bad temper follows even in otherwise well-mannered kids. Comraderie and social interaction are replaced by bullying, fighting, aggression, and sheer meanness. Over many years this can lead to psychological problems, depression, aggression, suicide, and the loss of ability to harmoniously integrate with the rest of society.
- **hate of school:** by the age of 10, most kids universally hate school! One of the first questions I ask any kid I meet is about his or her fondness for school and learning. If they claim to like school, it is often because of the chance to interact with friends or simply to break free from parental supervision or leave the home environment. Vacation countdown becomes a daily preoccupation. This has disastrous effects on the efficiency of school education, and long-term choices such as going to college. Universal hate of school shapes a generation and the way society copes with challenges of the modern world. And it all begins with the malignant device: an alarm clock!

Poor recall on schooldays

To illustrate the impact of school hours on learning, see the following exemplary graph. A 16-year old high school student logged his sleep patterns in [SleepChart](#) and his learning results in [SuperMemo](#). By combining the two we can see the relationship between the waking time and the average grade obtained in learning with [SuperMemo](#). The waking time for school was always ahead of the natural waking time and the teen compensated by sleeping longer on weekends:



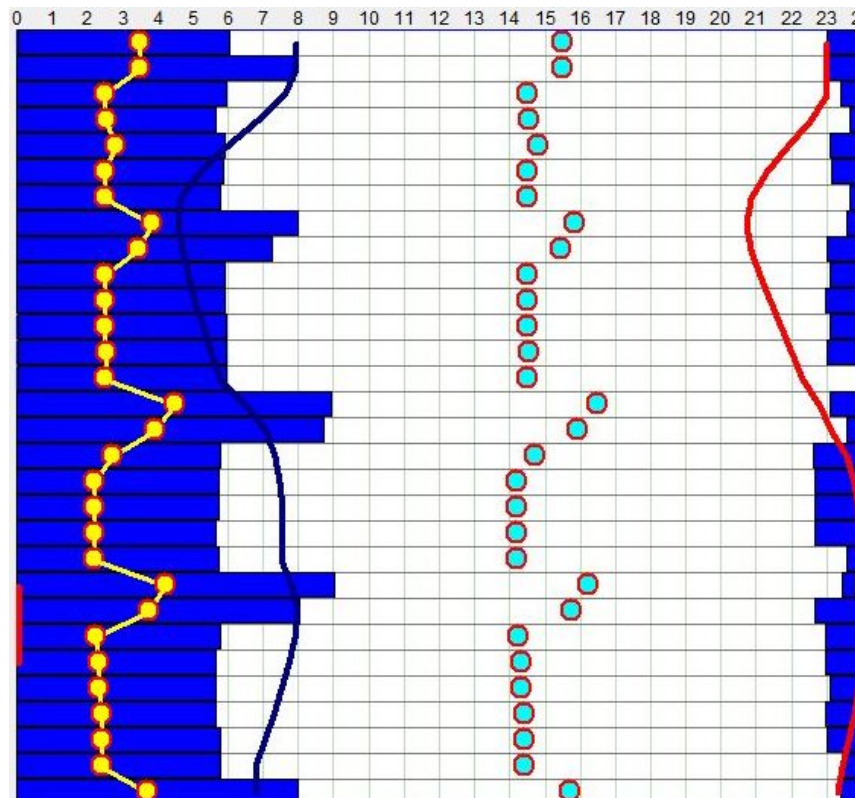
Despite a decline in the learning performance on schooldays, the teen would do great at school, do his best learning

during weekends, and would later get admitted to an Ivy League school. The dramatic impact of **sleep deprivation** on learning can be seen when grades are converted to the forgetting index. In this case, the students would forget 53% more on schooldays when he needed to get up early. Clearly, **sleep deprivation** is not likely to deprive someone of a chance to get to the Ivy League. However, it does affect the performance and undermines a young man's potential. At younger ages it may also have a significant impact on the brain development. Interestingly, in other data sets, I have also found that later waking up (after 11 am) often correlates with lower grades too. Perhaps that is a result of weekend late "partying" that results in poorer sleep and later waking?

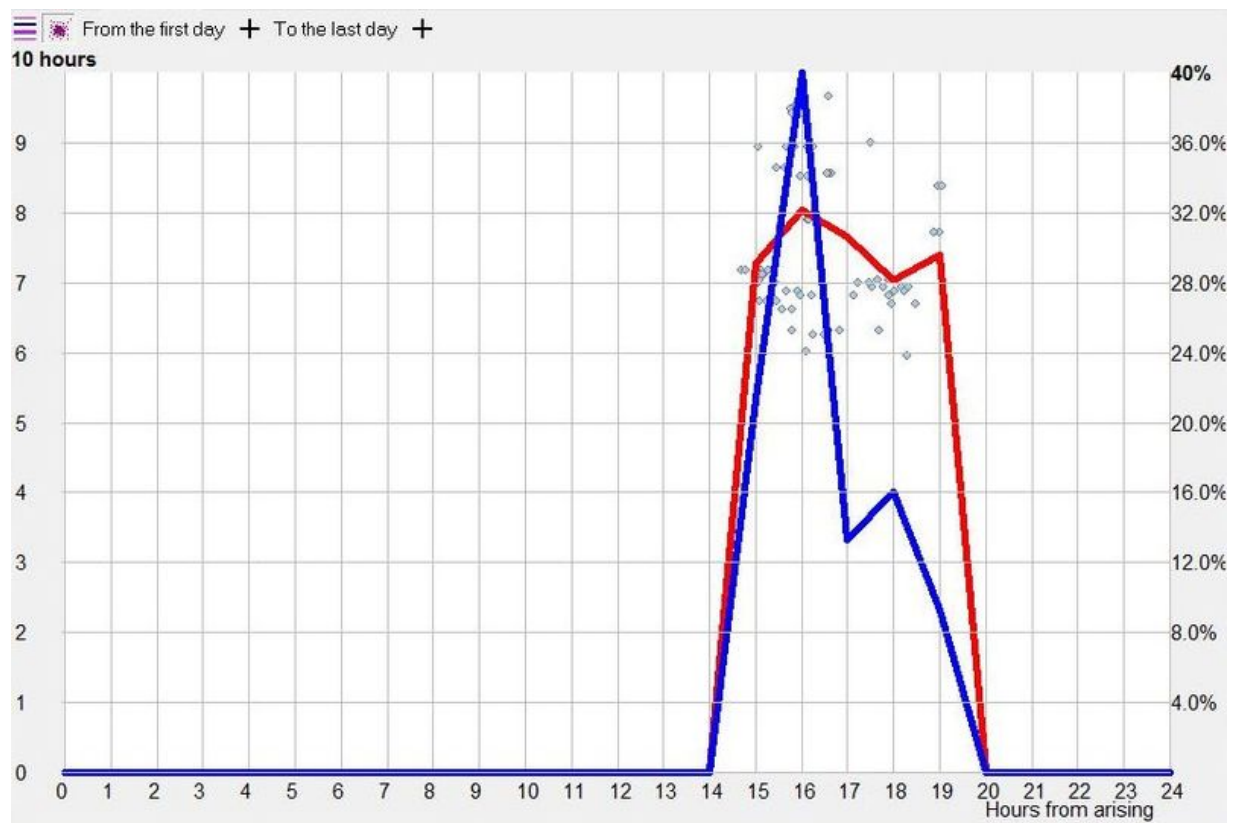
Examples

Example #1: Long weekend sleep

A typical sleep pattern with short weekday sleep and long weekends sleep is shown in the following sleep log and the corresponding circadian graph.



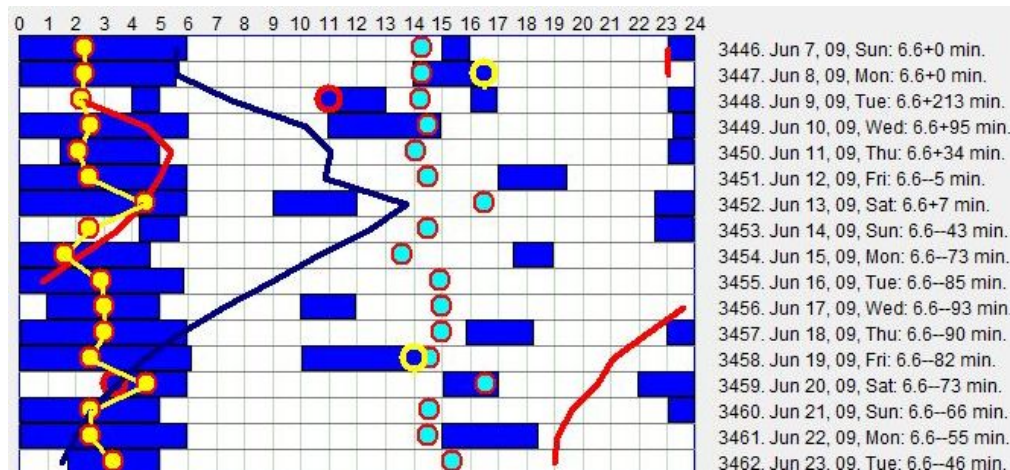
Exemplary sleep log with weekday sleep deficits and longer sleep on weekends. Typically, Saturday morning sleep is longer than the Sunday morning sleep.



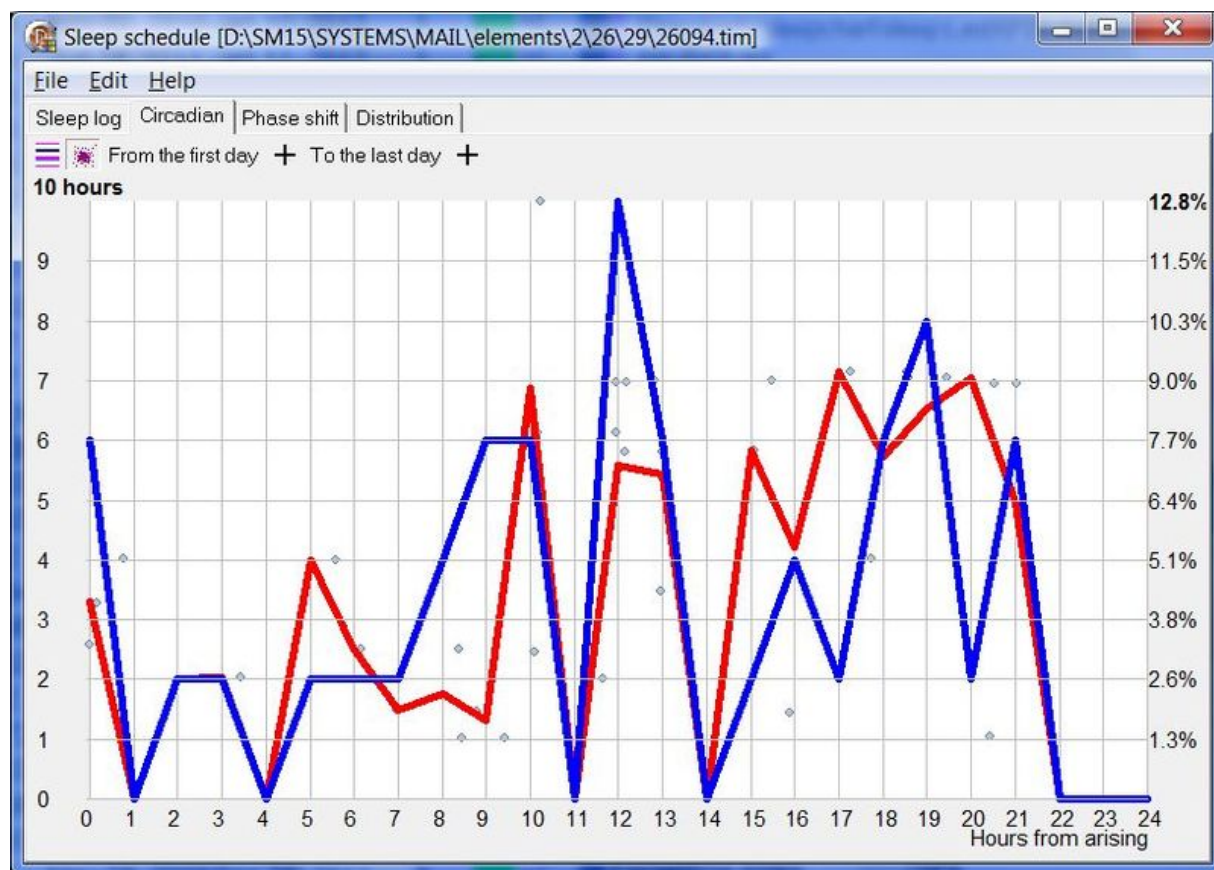
Circadian graph for sleep with weekday sleep deficits and longer sleep on weekends. The graph shows that a day of 16 waking hours and 8 hours of sleep would probably make the desired optimum. Instead, the 7 hour night causes an accumulation of sleep deficit with sleep cut short by one hour per day on weekdays.

Example #2: Phase 12 napping

A more troubling example shows a fragmentation of the sleep schedule caused by short night sleep episodes, and frequent [Phase 12 napping](#). Here a student attempts to sleep in the exactly same brackets, i.e. 23:00 - 6:00:



Exemplary sleep log where irregular napping is used to compensate for sleep deficits.



Circadian graph for short night sleep with irregular napping. Naps are taken ad hoc in various phases. Early naps are short and do not cover for sleep deficits. Late naps cause a delay in night sleep, and possibly a phase delay that compounds the problem of sleep deficits.

Learning in alpha state

There are learning gizmos and contraptions out there, which are marketed as based on learning in a relaxed state. Proper cognitive environment is paramount to learning. However, for clarity, we should rather use the term concentration instead of an all-inclusive relaxation. Concentration in learning should be maximized by taking into account the following factors:

- being cut off from all sources of interference in learning (telephone, e-mail, conversation, radio, and perhaps even one's favorite music)
- finding the [optimum circadian timing for learning](#) (e.g. early in the morning in [free running sleep cycle](#), late in the evening in DSPS individuals who cannot afford free running sleep, etc.)
- all aspects of mental and cognitive health (e.g. avoiding stress, substance abuse, etc.)

The concept of relaxation is often associated with alpha wave learning which has attracted lots of companies that are more interested in their bottom line than their customers' actual success in learning. EEG measurements can be used to roughly determine the current state of the brain in the same way as you could detect bustling activity in a major city by scanning the surrounding electromagnetic field. The usefulness of alpha wave scanning in learning can be compared to the usefulness of electromagnetic field scanning for social life of a city. You need to focus on the causes rather than on symptoms. Alpha waves appear primarily in the absence of visual processing and other intense mental processes. This is why they cannot dogmatically be considered a desired learning state. After all, the drowsy alpha state that precedes falling asleep is exactly the worst moment for learning during the day.

In evaluating the "relaxation products" you need to differentiate between the relaxation effect and the actual learning effect. The number of companies making false claims in this field is astounding. It is very easy to fall for a simple solution to a learning problem (e.g. get 10Hz [binaural beat](#) difference and your learning problem will go away for life, and perhaps your sex drive will improve at the same time, you will sleep better and you will look younger). The easy learning solution explains why false claims related to "learning in relaxation" are so hard to extinguish.

At the same time, if you need to cope with [stress](#) or [insomnia](#), many products in the field may have a legitimate application. Customers of the Polish Sita system jokingly claim that the company would do better if they marketed

their product as a napping system. A worthy application on its own. In the 1990s, I appealed to users of [SuperMemo](#) to let me know of relaxation products that might be worth mentioning as an effective help in learning. I do not think I have received any credible suggestions until now.

Learning during sleep

When Soviet researchers made a claim of sleep-assisted instruction, they started a powerful meme that could never be reproduced and is now pretty hard to extinguish. You may have heard of sleep tapes that offer effortless learning during sleep. They are a direct follow-up of the Soviet claims and only a part of the whole series of products for learning in sleep. Your investment in tapes for learning in sleep will not be money well spent. **Attempts at learning during sleep should be discouraged!** It is possible to occasionally [recall](#) a fraction of the material presented during sleep. Information may reach and register in memory during short periods of awakening or transition from [REM](#) to shallow sleep. There is also ample evidence that some circuits in the brain can be conditioned during [REM](#) sleep. However, the connection between the senses and the brain in sleep is rather focused on awakening in danger rather than on processing complex information.

Whatever you might gain from your sleep tapes will by far be offset by damage to the quality of sleep. If the learning stimuli do not reach a certain threshold, they will simply be ignored. However, past a certain value they may prevent the progression of [NREM](#) sleep toward stages 3 and 4. They can also shorten [REM](#) sleep.

Interestingly, memories acquired minutes before falling asleep do not get consolidated! Even a few minutes of sleep leave a short window of waking time that is totally erased from memory. Luckily, we rarely learn mission-critical information shortly before dozing off.

Counter-recommendation for learning during sleep, does not imply that [falling asleep with TV or radio turned on should be discouraged](#). If you would like to get a dose of education yet before falling asleep, be sure your tapes, TV or radio meet these conditions:

- they turn off automatically no later than in 10-20 minutes
- they have no ability to wake you up from a properly timed sleep. If you wake up in the initial minutes of sleep you may experience a [dramatic drop in homeostatic sleepiness that would delay the sleep onset](#). Awakening may also indicate that you went to sleep too early in reference to your [circadian](#) cycle
- they do not include highly emotional content, distressing messages, shrill sounds like doorbells, phones, timers and alarm clocks, as these all have been designed to most effectively interfere with sleep for the purpose of interrupting it

Moreover, if you find it difficult to fall asleep due to the [stresses](#) of the day, subtle news channel may actually help you fall asleep by keeping your mind away from the thoughts that might trigger the release of [ACTH](#), [cortisol](#), [catecholamines](#), or other alertness hormones.

TV, radio or tapes in the morning are OK too, on condition you turn them on manually (i.e. they should not work as an alarm clock substitute). If you wake up slightly ahead of your expected waking time, turn on the news and stay in bed. Test your brain for signs of sleepiness. Occasionally, you may still be able to fall asleep and go through one cycle of sleep that will be beneficial to your intellectual performance.

Lucid dreaming

Some self-help personal power gurus keep bringing up the concept of lucid dreaming as a tool for enhancing learning and creativity. Terms such as super-consciousness or hyperreality are tossed around. Polyphasic sleepers often claim that the [Uberman sleep schedule](#) helps them achieve lucid dreaming and an enhanced experience of reality. There might be a grain of truth in that claim. Read about the [polyphasic rollercoaster](#) to understand why polyphasic sleeper might experience euphoric highs that seem even higher due to the periods of total zombification. Lucid dreaming is as useful for learning and creativity as [LSD](#). Striving at lucid dreaming is rather likely to disrupt the healthy sleep and negatively affect learning. During [REM](#) sleep, the prefrontal cortex should normally be de-activated. Hobson's AIM model of 3D sleep-wake space (Hobson et al. 2000^[89]) can be used to illustrate the state corresponding to lucid dreaming as a partitioning, in which the cortex and the rest of the brain occupy different points in the AIM space. Such partitioning is likely to interfere with the physiological function of [REM](#) sleep. It can be compared to eating your lunch while jogging (i.e. the situation where contradictory targets are fed to the nervous system). Using auto-suggestive tricks to change the AIM state may affect neural processes occurring in sleep with unpredictable consequences that are not likely to be positive. As for creativity, it is conceivable that LSD (and less so lucid dreaming) might boost non-specific creativity or help understand the creative process. However, most of the mankind's creative breakthroughs occur

when a healthy refreshed mind focuses on solving a specific problem. Hallucinatory haze is not helpful in directing creativity towards a useful purpose. Creativity is a game of chance. You should look for ways of consciously directing the creative process rather than to increase its randomness indiscriminately (Wozniak 2001^[90]).

Physiology of sleep

Why do we fall asleep?

Initiation of sleep

We fall asleep when two signals are generated in the brain:

- (H) "*too much waking*" signal and
- (C) "*it is the usual sleep time*" signal.

The "*too much waking*" signal is called the **homeostatic signal**. While "*time to sleep*" signal is called the **circadian signal**. The **homeostatic** signal is a reflection of network "tiredness". The more you learn, the more you think, the more you process information, the more tired you get mentally. This generates **homeostatic** sleep propensity. However, **homeostatic** sleepiness is not enough to fall asleep. You may be dead tired of too much waking or too much learning, but you may still be unable to get a wink. This is where the circadian sleepiness comes in. Circadian sleepiness is maximum during the **subjective night** period. There is also a mid-day slump in alertness that also has **circadian nature**. When you are sleepy in both **homeostatic** and **circadian** sense, you can finally fall asleep.

Homeostatic signal

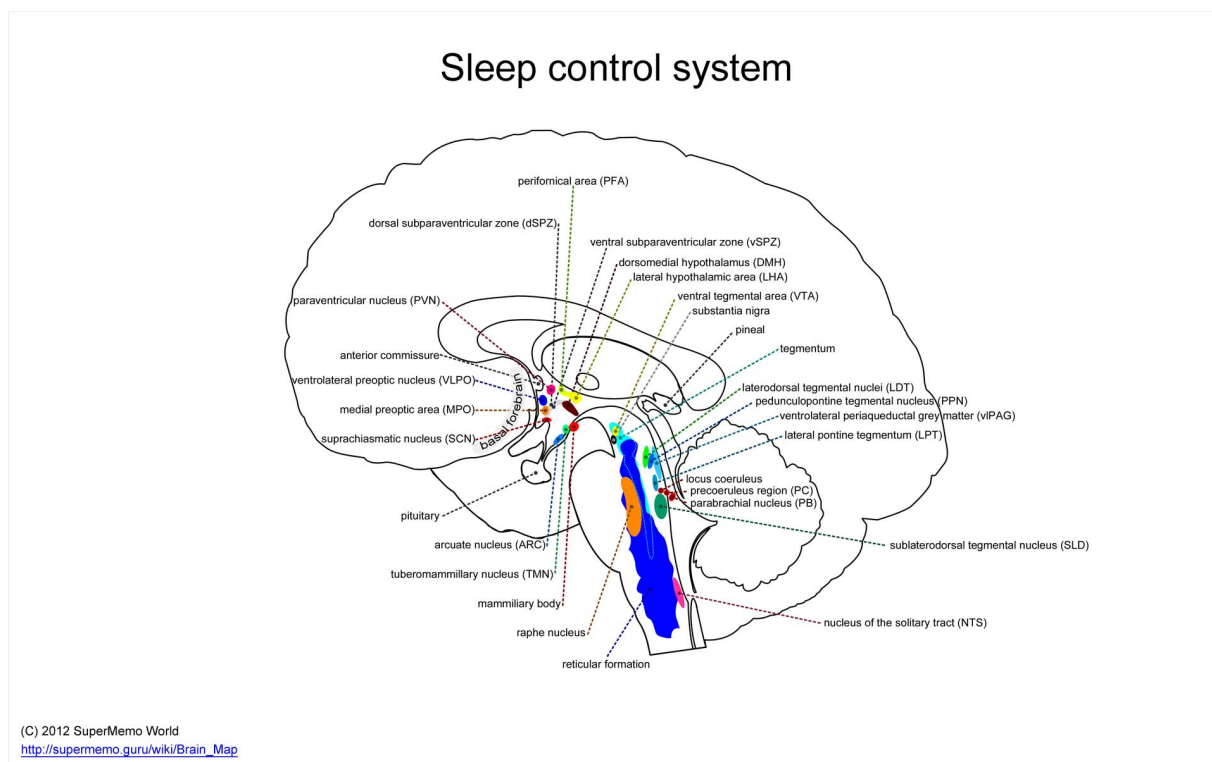
The **homeostatic** signal is generated in the neural networks of the brain. It is associated with slow-wave activity in the EEG. One of its known expressions is an increase in **adenosine** levels. The effects of adenosine are blocked by **caffeine**. This is why coffee can temporarily help overcome the **homeostatic** component of sleepiness. At the same time, **caffeine** is entirely ineffective against the **circadian** component. This is why drinking coffee during the **subjective night** is imprudent and unhealthy. As the waking hours tick on, brain glycogen and **ATP** reserves are depleted. ATP is degraded to **ADP**, then **AMP**, and finally to adenosine. Adenosine then builds up in the brain. This includes a buildup in the basal forebrain (Porkka-Heiskanen 1999^[91]), which is the hypothetical source of the neural **homeostatic** signal. Depletion of the glycogen reserve is also hypothesized to have its own contribution to the **homeostatic** sleep propensity (Kong et al. 2002^[92]). The **basal forebrain**, which is a cholinergic structure, when active, contributes to the wakefulness and **REM** sleep. Deactivation of the basal forebrain helps initiate **NREM** sleep and sleep in general.

Circadian signal

The main source of the circadian signal is the **suprachiasmatic nucleus (SCN)**. A set of genes is expressed in a **regulatory loop that keeps a 24 hour rhythm of activity**. The SCN rhythm can be reset by light, or activity, or other signals (see: **Phase response curve (PRC)**). The SCN sends most of its fibers to the subparaventricular zone (SPZ) and the **dorsomedial hypothalamic nucleus (DMH)**. One of the hormonal signals produced by the effects of the SCN oscillation is the release of the **melatonin** from the **pineal gland** during the **subjective night**. This led researchers to the idea that **melatonin** might be a natural help in initiating sleep (given sufficient homeostatic sleepiness).

Integrating homeostatic and circadian signals

The **homeostatic** signal needs to be integrated with the circadian input. The precise mechanism of the integration is not known, but there are a couple of solid hypotheses on how this might work. The **anterior hypothalamus** is the presumed site of the integration. The hypothesized integrating nuclei are: the medial preoptic area (MPA), the anterior paraventricular thalamic nucleus (aPVN), and the **dorsomedial hypothalamic nucleus (DMH)**. **DMH** and MPA send a big bunch of fibers in the direction of the ventrolateral preoptic nucleus (VLPO), which is **one of the main brain nuclei responsible for the initiation of sleep**.



Sleep control system. See the text for details. See the legend [here](#)

Adenosine agonists are also able to activate the **VLPO** (Scammell et al. 2001^[93]). It has been hypothesized that adenosine inhibits anterior hypothalamic and basal forebrain GABAergic neurons that suppress the activity in the **VLPO**.

The **VLPO** is thus able to initiate sleep by receiving both the **circadian** signal from the anterior hypothalamus and the **homeostatic** signal from endogenous substances (e.g. adenosine) that accumulate in the course of a waking day. The **VLPO** and its adjacent nuclei are then able to inhibit the histaminergic wake-promoting **TMN** and other pontine/brainstem arousal systems (e.g. LC, DR, LDT, PPT, PeF, vPAG, etc.). Sleep is a direct consequence of the inhibition of the ascending **reticular activating system (RAS)** which groups those neural structures that keep the cerebral cortex in the waking state. With the depression in the activity of the RAS, we quickly lose interest in demanding intellectual activities. Soon the only thing we can think of is sleep. Once we rest in an undisturbed place, we drift into the dreamland. People who cannot follow their natural body rhythms will often be unable to follow the above scenario.

Neural inhibition of the arousal is also accompanied by a significant drop in **ACTH** and **cortisol**, which are chief alertness hormones. Similarly, the levels of **serotonin** and **catecholamines** drop, and so does the body temperature. All those processes proceed on parallel tracks and we sleep best when they are all perfectly synchronized. It is awfully easy to put that symphony out of sync by all forms of intervention: excitement before sleep (**dopamine**), coffee before sleep (homeostat), **exercise (adrenaline)**, etc. Synergistic manipulation also has side effects: **sleeping pills**, **alcohol** or **marijuana** destroy the sleep structure. Even **melatonin has its side effects**. Sleep is healthiest when all physiological variables change in pre-designed synchrony. This can best be accomplished by following the commandments of one's own **body clock**.

Not all scientists agree

Dr James M Krueger has championed, for many years, an idea that all advanced neural networks have an inherent ability to enter a sleep state (in particular, cortical columns have this property). A biochemist by education and spirit, Krueger started his investigations from looking for substances that induce sleep. He was inspired by a century old finding that cerebrospinal fluid of sleepy animals contains substances that are able to induce sleep when transferred to otherwise alert animals. Over the last four decades, Krueger has amassed a great body of evidence for the existence of a huge number of sleep regulating substances (SRS) such as **adenosine**, **nitric oxide**, **TNF**, **IL-1**, **GHRH**, **prostaglandin D₂**, etc. (Krueger et al. 1999^[94]; Krueger et al. 2001^[95]). Some of SRSs, like **adenosine**, build up with mental activity (e.g. as a result of the release of glutamate (Simasko et al. 2005^[96])) and may play a role in sleep homeostasis, while others (e.g. **melatonin**) are circadian. In his recent publications, Krueger asserts that sleep is a network-emergent phenomenon, and that sleep control nuclei in the brain play only an accessory synchronizing role. Even though the overarching principle may seem to quarrel with the mainstream science of neural sleep control, the body of

undisputed facts is overwhelmingly larger than the areas of disagreement. Even though Krueger theories do not seem to explain the computational aspects of sleep, where a [neural control of sleep centers seems indispensable](#), they all align pretty well with the [homeostatic](#) aspect of sleep control. In the place where biochemists meet neural network experts and neurophysiologists, we can find the most fruitful field for further exploration of the mysteries of sleep.

Circadian cycle

The human body clock runs in a cycle of circa 24 hours. That cycle was therefore named a circadian cycle. Understanding the circadian cycle is vital for healthy sleep. My wild guess is that 95% of sleep problems in industrialized nations are caused by the lack of understanding of the circadian cycle, or lack of respect to its power and importance. The cycle is [encoded deep in the human genome](#) and cannot be easily changed or overridden. Playing with the circadian cycle may result in [long-term health consequences](#). All cells in the body express various clock genes, however, there is a master clock in the brain that helps synchronize other clocks in the body to run in harmonious synchrony that is vital for health, well-being, longevity, learning, creativity, etc. The master clock is located in the brain and is called the [suprachiasmatic nucleus \(SCN\)](#). Circadian cycles of the SCN result in periodic release of [melatonin](#) from the [pineal gland](#). This led to the use of [melatonin](#) as a sleep remedy. The popularity of [melatonin](#) comes from its natural origins and the possibility of oral administration. However, as [melatonin](#) is located downstream of the SCN in the circadian cascade, it does not have the full magic powers of generating complete nighttime [circadian](#) states. Even the natural release cycle of [melatonin](#) may get misaligned with the sleep-wake cycle in irregular schedules. This limits [melatonin](#) applications. It can be used to produce [phase shift](#) (e.g. phase advance if taken 1-2 hours before natural bedtime), but it is not the universal sleeping pill as it is often advertised.

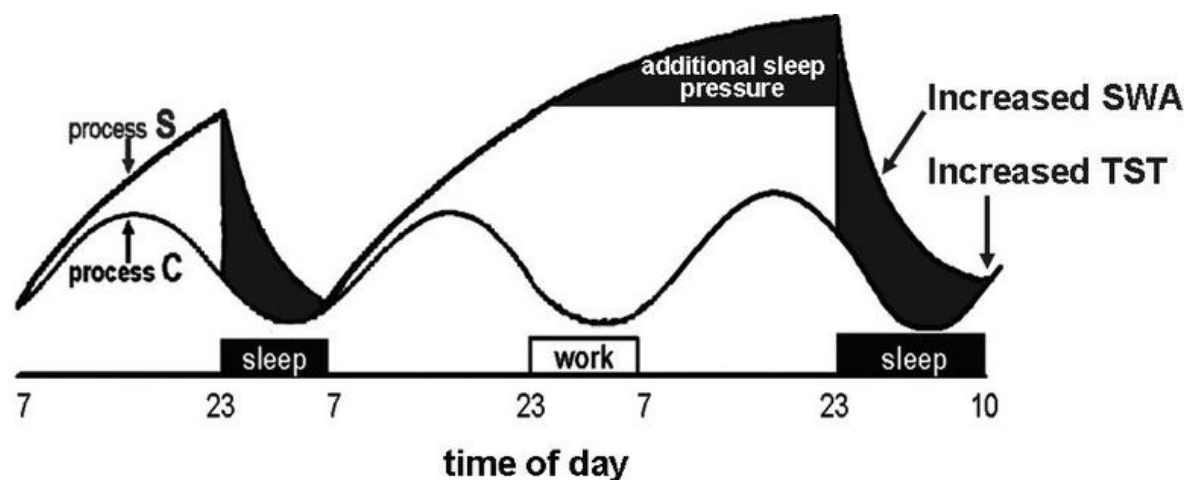
An important alertness hormone, [cortisol](#), can be used to map a well-timed circadian cycle. Its levels drop during the first half of sleep, and raise dramatically on waking giving us a sharp waking mind. On the other hand, [growth hormone](#) is less dependent on the clock and is released primarily during deep sleep having its hand in the anabolic power of sleep making it important for both the brain and the brawn.

Circadian alertness is partly hormonal and partly neural. The brainstem contains a collection of nuclei known as the [reticular activating system](#). These nuclei, when activated, keep us awake and alert. Those "vigilance nuclei" include the serotonergic [raphe nuclei](#), adrenergic [locus ceruleus](#), [parabrachial nuclei](#), and more. Various lesions to those areas and their connections may result in insomnia or coma.

Borbély model

In 1982, a Hungarian sleep researcher, [Alexander A. Borbély](#) published a seminal paper titled "A two process model of sleep regulation"^[6]. This model has later been described in pretty precise mathematical terms, and is now the mainstay of our understanding how sleep is initiated and how the sleep-wake flip-flop works in healthy sleep in abstraction from the actual neurophysiological interpretation.

In short, [Borbely](#) noticed the distinction between the two components of sleepiness: [homeostatic](#) sleepiness and circadian sleepiness. [Homeostatic](#) sleepiness increases during the day as a result of mental effort. [Circadian](#) sleepiness increases at nighttime. Borbély's model argues that for a good night's sleep, you need to go to bed with both components of sleepiness in a high gear. This means that going to sleep early, before your circadian sleepiness kicks in, is a bad idea. You won't be sleepy enough to fall asleep, or your sleep will be shallow and easily interrupted. On the other hand, the model also implies that a premature awakening may clear the [homeostatic](#) sleepiness, and we may find it hard to fall back asleep even though the circadian sleepiness ensures we are pretty tired.



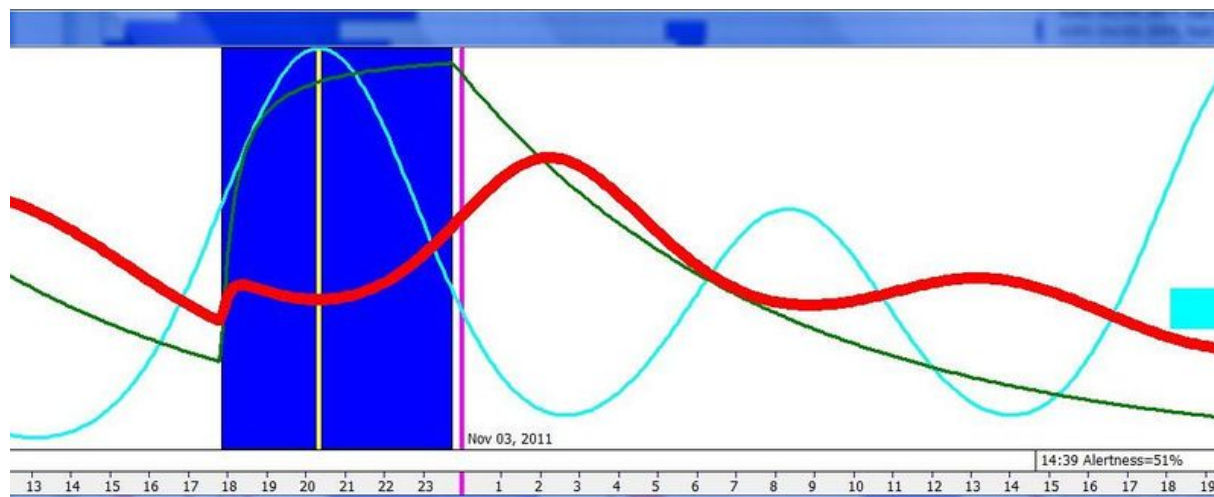
An exemplary interpretation of the two process model of sleep for normal sleep and sleep following a sleepless night. **Homeostatic** sleepiness is denoted as Process S (throughout this article, I use H for mnemonic reasons).

Circadian sleepiness is an inverse of Process C. Sleep occurs when C is low and S is high. Additional sleep pressure accumulates after a night without sleep, and the sleep can occur earlier and last longer (it starts at higher **homeostatic** sleepiness despite slightly lower **circadian** sleepiness). SWA - slow-wave activity - is a brain wave activity that represents the deepest sleep. TST - total sleep time - is higher after a sleepless night.

During sleep, cortical slow-wave activity (EEG power density range of 0.7 to 4.5 Hz) depends on the duration of prior waking. This is why it is considered a hallmark of **homeostatic** sleep propensity (Daan et al. 1984^[97]). It decreases exponentially after the sleep onset. One of the limitations of the model is that it does not account for NREM-REM exchange, while the **homeostatic** sleepiness (Process S) might actually increase in the **REM** phase. Circadian sleepiness correlates with the release of melatonin, but can also be mapped onto core body temperature, or release of other sleep inducing or alertness hormones.

Borbély model in practice

A two-component model of sleep propensity, inspired by **Borbély** model is available in **SuperMemo**. It makes it possible to predict changes in alertness depending on the timing and duration of sleep.



An exemplary interpretation of the two-process model taken from an actual sleep log in **SuperMemo**. Aqua line represents circadian sleepiness. Green line represents **homeostatic** alertness (an inverse of the homeostatic sleep propensity). Red line represents overall alertness that is an inverse of overall sleep propensity. Best alertness is achieved when both components of sleepiness are at their lowest.

[find a better graph! esp. one that aligns well with the Wikipedia picture].

In **Borbély** model, sleep timing is determined by the points in which the curves representing the two processes cross. **SuperMemo** uses a more intuitive approach, in which both components of sleepiness are integrated heuristically to match the expected course of overall alertness (red line in the graph). Sleep is initiated when the overall alertness drops below a certain level. Sleep may thus be initiated by both components of sleepiness independently, as it may

happen in early life, but the timing and duration of sleep will differ for various values of both variables (and the status of the **circadian** system).

You can "feel" both components of sleep. **Homeostatic** sleepiness is more likely to be described as feeling "unrefreshed", while circadian sleepiness is more likely to be named "grogginess". In a healthy cycle, you should never see the difference between the two: you wake up fresh, and you get sleepy in the evening when both components of sleepiness kick in making you just "very sleepy". However, if you are jetlagged and groggy, you can feel the unpleasant circadian sleepiness that does not go away and cannot be helped with a nap if your **homeostatic** sleepiness is too little to fall asleep. On the other hand, after a sleepless night, you may be dead tired and unrefreshed, however, with the morning sunlight you get a new energy to survive yet a couple of hours. As your circadian sleepiness passes by, you may feel **homeostatic** sleepiness that seems survivable (until the next circadian low hits)(see more: [Sleeping against your natural rhythm](#)).

Borbély model and evolution

The **homeostatic** component of sleep may simply be an unavoidable cost of the evolving neural networks. To prevent catastrophic forgetting, neural networks need to implement an [overload protection](#). That protection is the homeostatic drive to sleep. We do not know how much of that protection is a natural consequence of the network overload, and how much of it is an added effort by the brain to prevent further overload. For example, we can improve cognitive function with the help of **caffeine** by blocking the adenosine-based component of the homeostatic sleep drive. This proves that the brain provides a degree of network overload protection. The overload will result in progressive decline in [recall](#) and [memory consolidation](#) in the waking day.

The circadian component evolved long before the neural function of sleep was established. However, it was convenient for the organism to do its neural housekeeping at opportune times. For example, for human hunters and gatherers, night is a time of inaction. This is why hooking up sleep to the night time period made an evolutionary sense. Other animals may have made different choices, however, the **circadian** cycle is always a good hint on the optimum timing for neural optimization.

In short: **Neural optimization is unavoidable: (1) network overload signal has a homeostatic nature, while (2) the opportune optimization time signal has a circadian nature.**

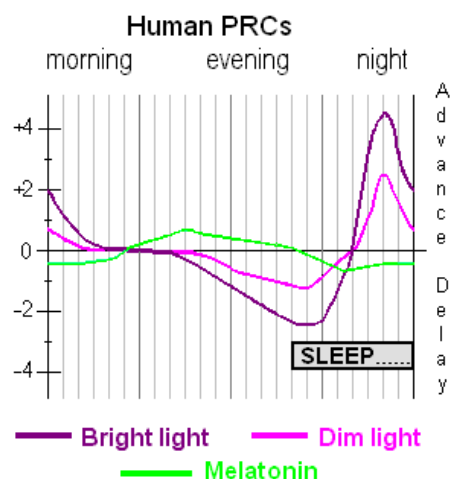
Three-process model

Borbély's two-process model has been extended by an additional process W that represents [sleep inertia](#). The basis for that model was self-rated reports of sleepiness (Akerstedt and Folkard 1990^[98]). The [model used in SuperMemo](#) does not include the sleep inertia factor as it is primarily targetted at studying [free running sleep](#).

Phase response curve (PRC)

Phase response curve (PRC) represents a function that tells us how much a phase of an oscillator shifts in response to selected stimuli depending on the timing of these stimuli. PRCs can be used to study circadian rhythms as well as other biological, physical or electronic system (e.g. the heartbeat).

For example, **PRC** for light may tell us that applying a green light pulse of a given intensity 1 hour before sleep pushes the circadian cycle forward by 10 minutes (phase delay), while a blue light of a higher density might push the same cycle by 25 minutes. During the subjective night, there is a dead zone when light does not produce shifts in the circadian cycle.



Exemplary human PRCs for bright light, dim light, and [melatonin](#).

There are many PRCs for different stimuli such as exercise, stress hormones (e.g. cortisol), [melatonin](#), and other stimuli. The crossover time between the delay side and the advance side of the PRC for light is near the core body temperature minimum. The sleep control system seems most sensitive to shorter wavelengths of visible light in suppressing the release of [melatonin](#) (Brainard et al. 2001).

Stimuli that cannot shift the cycle or have a negligible impact (e.g. cup of warm milk), can also have a PRC plotted. However, that PRC will be a straight horizontal line running along the phase shift of zero. SleepChart uses an algorithm for plotting the so-called [recursive PRC](#), in which the degree of phase shift is measured in reference to the actual position of sleep episodes in [free running sleep](#) without differentiating between the actual causes of the shift. rPRCs differ between people. They also change in response to lifestyle changes.

Changing the length of the circadian period

The existence of the PRC implies that the length of the clock period is under our control. If we apply zeitgebers early or late enough we can affect larger phase shifts that can lengthen or shorten the period of the cycle. Everyone can prove it all to himself or herself with relatively simple measures (e.g. bright lights in the late evening to shift the phase forward, or early morning exercise to shift the phase back). This is why PRCs are very important when treating phase-shift disorders. This is also why lifestyle determines phase shifts and possible sleep problems. This is why the modern lifestyle based on the use of electricity causes an epidemic of [DSPS](#) in the young learning generation. Recently, the fact of the adaptability of the body clock period was demonstrated with investigations into a possibility of astronauts adapting to a Martian day (Scheer et al. 2007^[99]). This was also demonstrated earlier in rats by various "lifestyle" changes (e.g. wheel restriction increases the circadian clock period).

Phase-shifting neural inputs

Our master clock, the [SCN](#), is affected by 3 major zeitgeber inputs that allow of a phase shifts:

- [retinohypothalamic tract](#) (RHT) carries light resetting stimuli and acts via the NMDA receptors. This input bypasses cognitive vision
- intergeniculate leaflet (IGL) projects to the SCN via the geniculo-hypothalamic tract (GHT) and carries motor resetting stimuli
- the raphe nuclei provide serotonergic input that is hypothesized to modulate some aspects of the [circadian](#) cycle and might be involved in changes to the circadian cycle in affective disorders. Lesions in this pathway or decrease in serotonin lengthen the active phase in constant darkness without affecting the circadian period

Recursive phase response curve (rPRC)

To study the phase response, scientists need expensive laboratory setups and time-consuming research procedures. However, a simple computational trick makes it also possible to see the effects of phase shifting stimuli in SleepChart without the use of a sleep lab.

SleepChart implements a concept of the **Recursive Phase Response Curve (rPRC)**. The curve is recursive because it is first obtained by computing the impact of phase shifts in sleep episodes in relation to the circadian [acrophase](#)

computed using statistical methods. Once the first approximation of rPRC is obtained, it can be used to produce a better approximation of the middle of the **subjective night** line that is then used to generate a better approximation of the rPRC. A few iterations of such a process are sufficient to produce the best fit of the rPRC that corresponds well with the actual sleep data. **SuperMemo** uses **acrophase** estimates by using a fixed rPRC that roughly corresponds with rPRCs obtained with **SleepChart**. Whereas a typical **PRC** employed in chronobiology maps the response of the sleep system to a single stimulus (e.g. light, exercise, melatonin, or various chemical agents), rPRC is the resultant of all natural sleep delaying factors (incl. light, activity, stress, etc.). It can also be interpreted as a PRC, in which the waking activity forms the input to the **free running sleep** system. Unlike a **PRC** which responds to a shifting factor, rPRC responds to the evening **phase shift** caused by the same factor. As such, rPRC is not a de facto PRC, and all departures from the free running condition invalidate the computation. The main advantage of rPRC is that it can be derived from sleep data without collecting blood samples, saliva samples, or taking core body temperature measurements. This way, **SuperMemo** can correlate learning with sleep models that use only plain sleep log data as input.

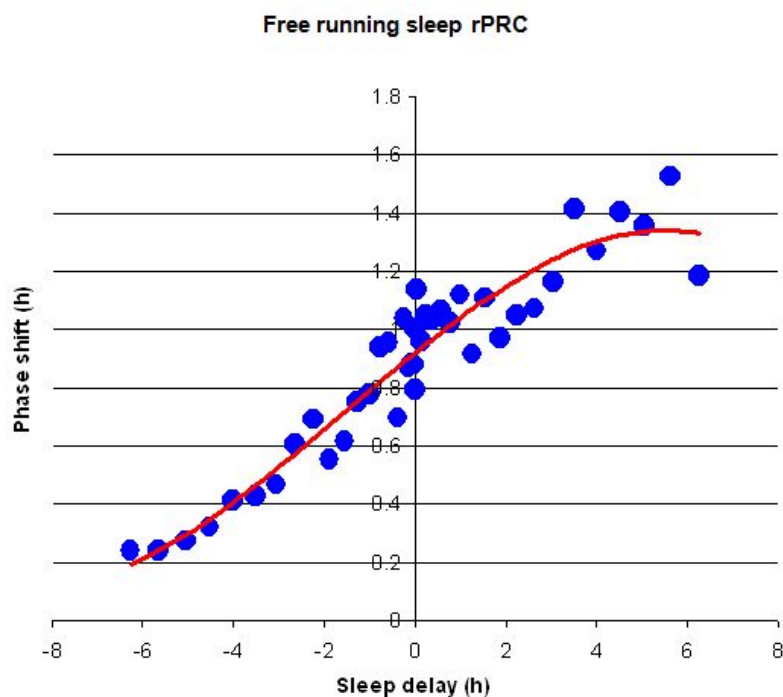
In the presented graphs, *Sleep delay (h)* stands for the bedtime delay and equals the difference between the actual bedtime and the bedtime as computed by **SleepChart** from the prior history of sleep. As the measurements refer to free running sleep, little phase advance data is available due to the natural way of waking. The causes of sleep delay may include light, social interaction, stress, a conscious decision to delay sleep, exercise, ingestion of caffeine, medication, etc.

Phase shift (h) stands for a **phase shift** and equals the difference between two exponentially weighted waking hour averages on two successive days: the day on which the bedtime delay occurred and the following day. Instead of the bedtime hours, waking hours were compared as these are less affected by the **homeostatic** shift caused by the actual delay thus representing a truer reflection of the actual **phase shift**.

The flattening of the curve (as compared with a typical PRC) is caused by the recursive reference to actual sleep data, which results from the fact that plotting the circadian **acrophase** by **SleepChart** is an approximation based on the same sleep measurements. As a result, polynomial approximation shows a slight increase in phase shifts with increasing delay, which is not the case in typical **PRC** plots. The deviation of the bedtime hour from the optimum bedtime may result from either environmental delay factors or from the approximation error resulting from heuristic procedures used to plot the **circadian** function, while sleep onset usually occurs naturally at optimum physiological time. The inherent asymmetry of the graph comes from the fact that earlier bedtime is nearly always natural, while delayed bedtime may be natural or forced. It is the forced bedtime delay that is the main source of phase shifts in **free running sleep**.

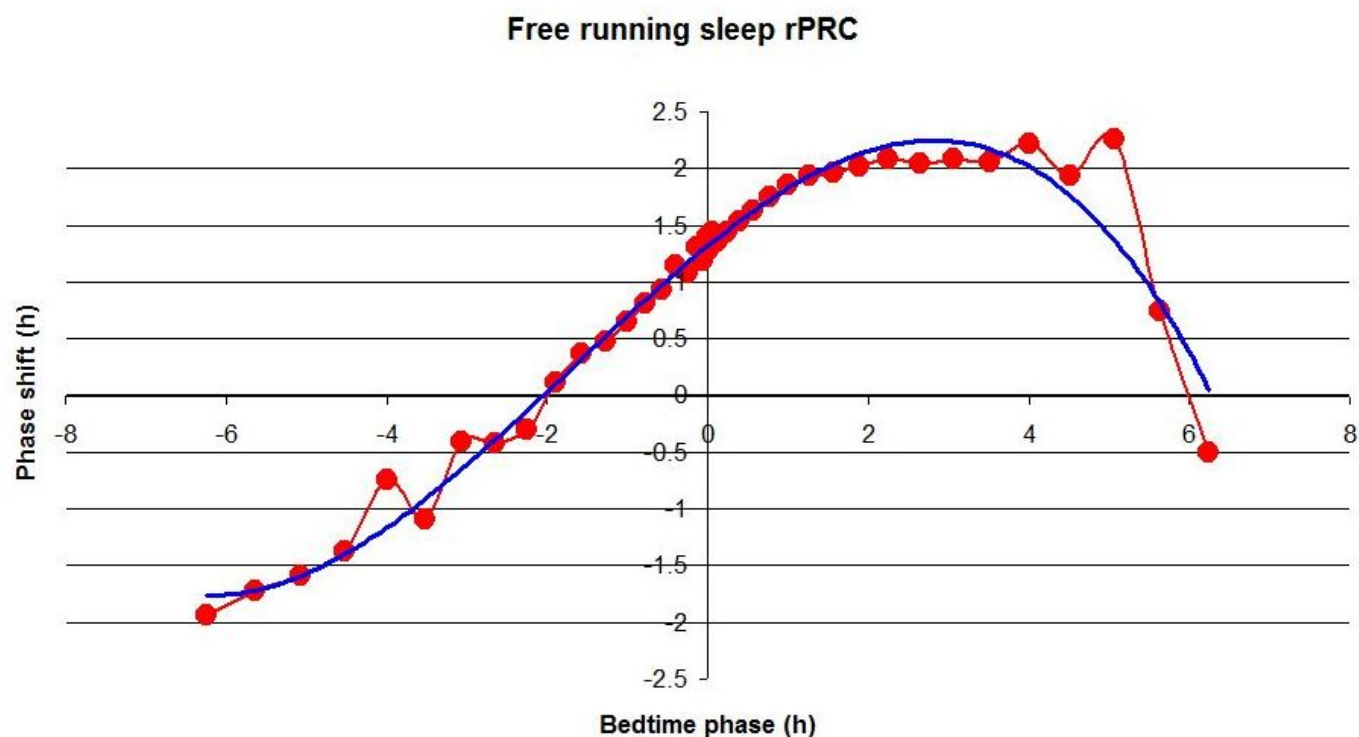
Recursive PRC in DSPS

The graph presented below implies that, in the case considered, delaying sleep by four hours results in a shift of sleep phase equal to 1.4 hours (which seems to be close the maximum shift possible). Phase advance would require a natural onset of sleep that preceded the optimum retirement time by as much as 6 hours. Going to sleep at the optimum hour results in the natural daily delay, in this particular case 1.0 hour, typical of DSPS disorders or conditions of isolation from zeitgebers (e.g. constant lighting).



Recursive PRC and phase advance

Delaying sleep should always be avoided (except for cases where it is used as a form of chronotherapy). The next graph shows how sleep delays can actually advance the sleep phase. This is a reverse situation to the described earlier phase delay caused by an evening [melatonin](#) overdose. Where the wakefulness intrudes past the circadian [acrophase](#), which follows the stationary point of the rPRC, phase delays decrease rapidly up to a point where further delay in sleep will push the phase backwards. Naturally, this "method" of phase manipulation is particularly unhealthy as it implies arousal in the middle of the [subjective night](#) (see: [Health effects of shift-work and jetlag](#)).



Recursive [PRC](#) showing phase advanced that can be caused by either (1) bedtime delays of above 5 hours, or (2) bedtime advances of more than 2 hours.

In the presented exemplary graph we can read the following:

- going to sleep at one's natural bedtime causes a 1.3 hour [phase shift](#) resulting in a circadian cycle period of 25.3

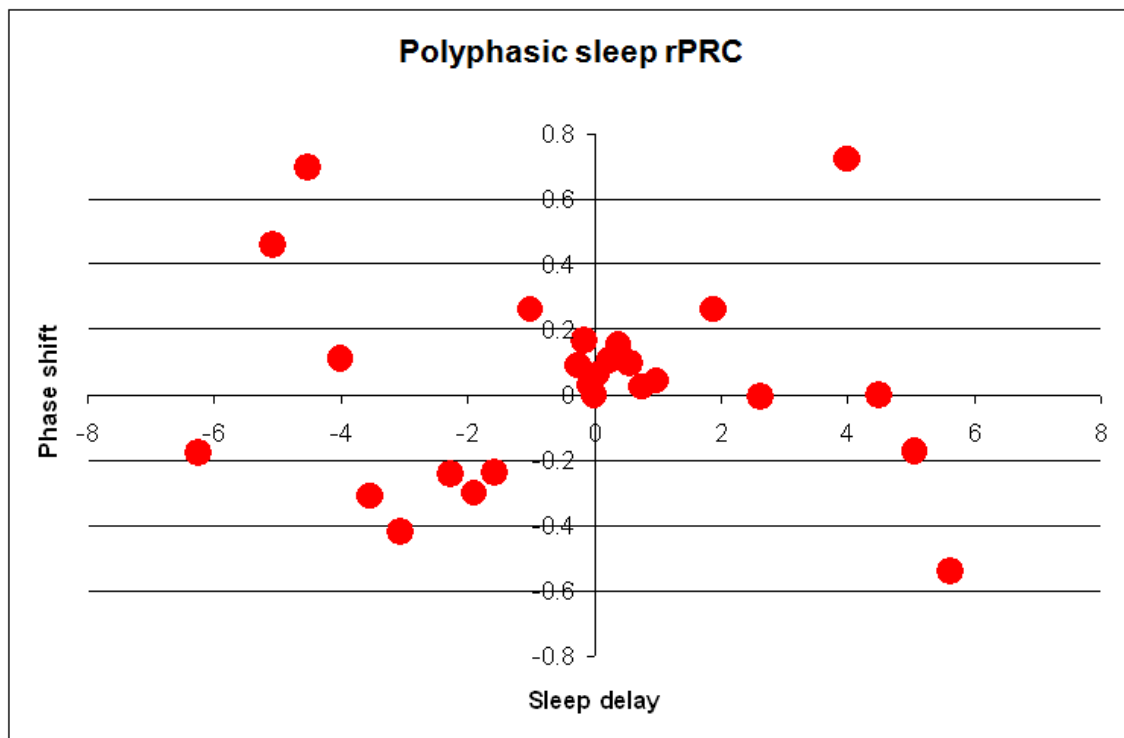
hours

- phase shifts are eliminated only when going to sleep 2 hours ahead of the natural bedtime
- phase advances of 2 hours are possible, but require an unnatural early bedtime (e.g. as induced with intense exercise such as running a marathon)
- phase delays of more than 2 hours are unlikely
- a delay in bedtime larger than 5 hours can result in an actual phase advance due to the impact of arousal on the morning end of the **subjective night**. Obviously, this should not be considered a "cure" to phase delays because such serious deviation will seriously affect the quality of sleep and produce major ripples in the control of the circadian cycle

If you run your sleep free and have a sufficiently large set of data (e.g. several months of a sleep log), you can generate your own rPRC data with **File : Export : Recursive PRC** in **SleepChart** (you need **SuperMemo 15** or later).

Recursive PRC in polyphasic sleep

It is possible to feed **SleepChart** with data obtained from "Uberman experiments". Obviously, the mere departure from free-running condition makes the outcome hard to interpret. Even the recursive nature of the procedure used to obtain rPRC cannot effectively cope with the lack of the leading **circadian** crest. With all that in mind, it is still interesting to peek at "Uberman rPRC" as it nicely reflects the chaotic nature of the sleep system subjected to a polyphasic experiment.



A polyphasic sleeper pushes his sleep phase back and forth largely at random. That can only result in a chaos and complete asynchrony of all neural, endocrinal and biochemical processes depending on the circadian component of the sleep cycle. One might expect serious health consequences of such a chaotic input to the system; however, natural defense mechanisms make life quite miserable for those who attempt a struggle against the natural sleep cycle. As a result, those who attempt **polyphasic sleep** are doomed to drop out sooner or later.

Chaotic phase-shifting input

Chaotic signals sent to the phase-shifting inputs as seen, for example, in polyphasic sleep, may have hard to predict negative consequences for the sleep control system. The risk is not fully known and hard to estimate. It could include in the order of decreasing likelihood:

- desensitization to signals sent by the sleep control system
- long-term instability in the sleep control system
- damage to nerve cells involved in the control of the circadian cycle

The first possibility can actually be observed in shift-workers and people running a constant battle with **sleep**

deprivation. In those individuals, the concept of "refreshed mind" and "refreshing sleep" becomes hazy, and one can observe an increased tolerance to permanent degree of tiredness coming from insufficient sleep or sleep in a wrong circadian phase. In other words, a degree of fatigue becomes a norm.

Instability of the sleep control system is also observed in shift-workers. I am not sure if shift-induced instabilities can become chronic or are fully reversible in a relatively short time. Even in a perfectly tuned sleep control system, minor rhythm perturbations, such as a switch to the DST, can produce regulatory ripples lasting for days. Larger perturbations might, in theory, result in uncoupling of master and slave oscillators with a particularly slow return to a fully stabilized control. Perhaps this kind of uncoupling is the primary factor that underlies a myriad of disorders that plague shift-workers in the long-term.

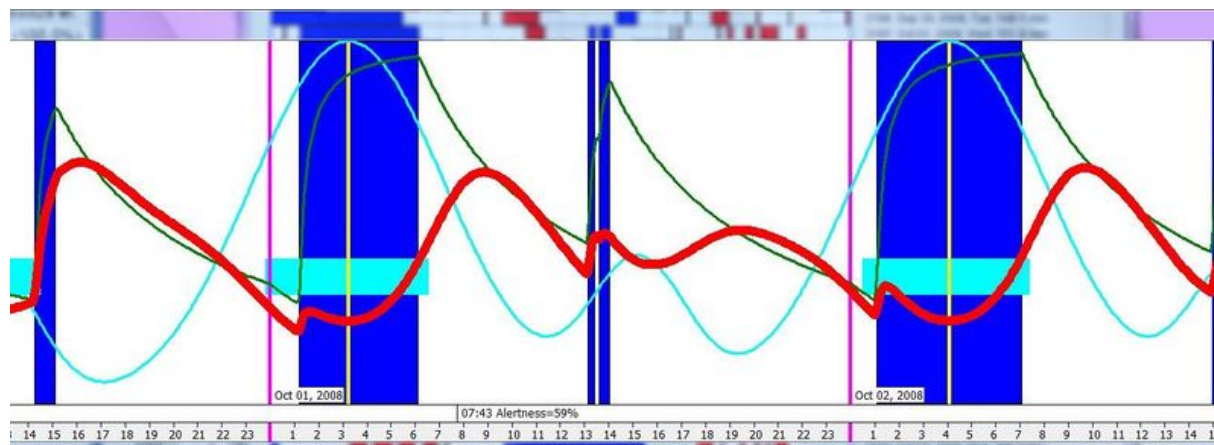
Two-component model of sleep in SleepChart

SuperMemo uses a two-component sleep model inspired by the [publications of Alexander A. Borbély and Peter Achermann](#). Unlike other models, **SuperMemo** uses user's sleep data to predict the **homeostatic** and **circadian** status of overall sleep propensity. This model is helpful in choosing the optimum time for learning on a given day (given a particular history of sleep). It can also help planning the optimum bedtime in cases where the sleep pattern is highly irregular. The model does not predicate on the timing and duration of **NREM** and **REM** sleep episodes.

The model is tuned to fit typical **SleepChart** data logs. However, there are individual genetic differences that affect the length of the circadian cycle, steepness of the **homeostatic** decline in alertness, sleep length preferences, sleep architecture, spectral properties of sleep, fragmentation of sleep, etc. This model is limited in accounting for these variables. If you are sleepy against the simulations based on the model, you can probably trust your own instincts better. If you feel alert against the simulations based on the model, you can certainly get down to learning and ignore predictions of the model. Moreover, sleep patterns are a good measure of your sleep control systems only if they are not artificially disturbed (e.g. by forcefully delaying sleep, using alarm clock, using medication, etc.). In other words, if you are not free running your sleep, the presented model may fail to map your circadian rhythms correctly. You can mark blocks as artificially shortened or delayed (**Forced awakening** and **Delayed retirement** on the context menu available with a right-click). However, marked blocks will have a limited effect as there is no way of knowing the degree of the cut into the sleeping patterns, and, consequently, knowing the resulting perturbation in the sleep control system produced by artificially modified sleep.

In [Borbély model](#), the timing of sleep is determined by the points in which the curves representing the **homeostatic** and circadian processes cross. **SuperMemo** uses a simpler, but more intuitive approach, in which both components of sleepiness are integrated into an overall alertness level (red line in the graph). **The advantage of that approach is the possibility of instant feedback from an actual learning process**, where the level of memory **recall** is supposed to correlate directly with the level of alertness determined by the model. The formula for integrating the two components of sleep into overall alertness was chosen heuristically with the help of alertness data gathered in **SuperMemo**. The purpose of the integration was to achieve the best possible match of the predicted alertness in the model with the average **recall** level in **SuperMemo**. As it has been shown earlier, both **homeostatic** sleepiness and **circadian** sleepiness affect the grades in SuperMemo, however, only a combined effect of both components provides a good match with the changes of **recall** for different combinations of homeostatic and circadian sleepiness. In the model used in SuperMemo, sleep is initiated when the overall alertness drops below a certain level. Sleep may thus be initiated by both components of sleepiness independently, but the timing and duration of sleep will differ for various combinations of changes in the homeostatic and circadian sleep propensity. Despite using a different approach to determining the sleep onset, predictions of the model fit the actual sleep log data pretty well in free running condition in cases studied.

To see the predictions of the model for your own sleep data for any given day, make sure you have your sleep log filled out for recent days in SleepChart, and shift-click the day in question in the sleep log.



*Two-component sleep model in SuperMemo: The horizontal axis represents time. Blue blocks show the actual sleep episodes. Aqua line shows the 24h circadian sleep drive with a mid-day **siesta** hump. Green line is an inverse of the homeostatic sleep drive and can be interpreted as **homeostatic** alertness, which declines exponentially during wakefulness and is quickly restored by slow-wave sleep (for simplicity, as in [Borbely model](#), the entire sleep block is assumed to have a contribution proportional to its length, as the [SleepChart](#) model does not account for sleep stages). Yellow vertical lines show the prediction of the circadian **acrophase** (circadian middle-of-the-night peak). **Acrophase** computations are done with the help of a [phase response curve](#) model (as opposed to a statistical model used in earlier versions of SleepChart). Red line shows the resultant alertness (peaks are best for learning, valleys are best for sleep). For example, Alertness on Oct 1, 2008 at 7:43 was predicted to be at 59% of the maximum but would keep increasing fast in the first 2 hours of wakefulness (a typical symptom of a night sleep that is terminated too early). The picture shows two peaks in alertness on Oct 1, 2008, at 9 am and at 7 pm. Those periods would likely be best suited for learning on that day.*

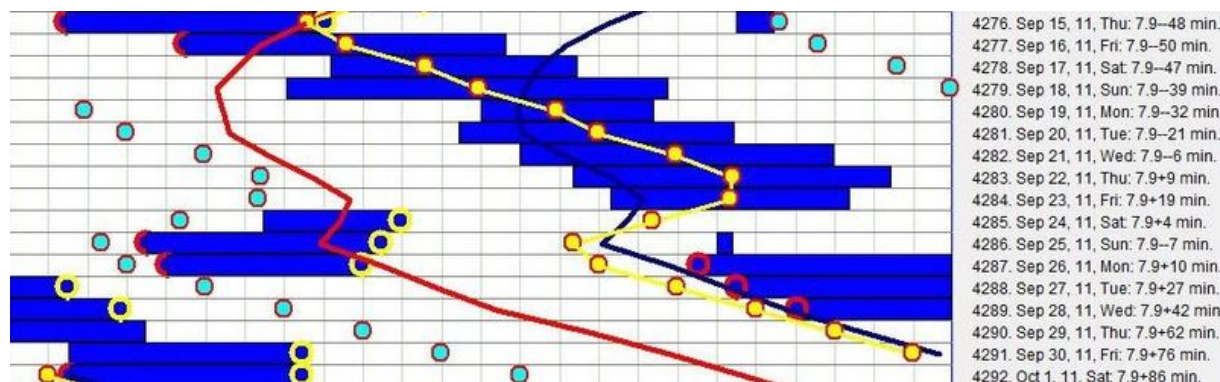
To see a more accurate presentation of your own homeostatic and circadian alertness in SuperMemo, see the **Alertness** tab in [SleepChart](#).

REM rebound hypothesis

Researchers know that [Borbely's two-process model](#) is not complete and does not explain all known properties of sleep, nor even all possible sleep patterns (e.g. various napping habits, newborn sleep, irregular sleep patterns, sleep in psychiatric disorders, etc.). There have been numerous attempts to expand the model by new variables that may show up in specific circumstances (e.g. adding noise to simulate a sleep-wake pattern in autistic children, ultradian dynamics to model NREM-REM occurrence, adding the impact of light intensity, etc.). [Borbely](#) and [Achermann](#) keep investigating various aspects of sleep that would help make the model more complete. One of their investigative targets is a **REM** sleep rebound following a **REM** sleep deprivation. It has already been discovered long ago that **REM** sleep deprivation reduces alpha activity, waking, and **NREM** sleep. These are clear signs of **REM** homeostatic compensation (Borbely et al. 1990^[100], Brunner et al. 1993^[101]). It has been proposed that increases in muscle atonia episodes in **NREM** (MAN) be considered as markers of an increase in **REM** sleep pressure (Achermann et al. 2002^[102]).

Kinky napping

For many years now, I have observed an unusual phenomenon in [SleepChart](#) logs that I could not explain with the two-process model. In people with irregular sleep, late naps are often exceedingly long and unrefreshing. Those long naps clear up the homeostatic component of sleep propensity, and often result in later bedtimes. In some extreme cases, this can lead to confusion about the optimum timing of sleep. The affected person will nap long enough to lose the sense of the timing of his or her own **subjective night**. A graph below demonstrates such a classic occurrence.



"Kinky" napping may result in confusion as to the timing of the subjective night in DSPS.

In the exemplary sleep log above, a middle-aged woman working from home and suffering from a [delayed sleep phase syndrome](#) shows a clear and pretty regular progression of the sleep phase from a bedtime at 2 am to sleeping past midday. The lady claims to suffer from irregular sleep, daytime tiredness, and never knowing when to go to sleep to get a "good night's rest". On Sep 24, due to feeling tired, she went for a nap at 6:30 am. This nap unexpectedly lasted 3.5 hours and produced the impression that no more sleep was required on that day. Despite some tiredness, the lady did not go to bed that evening even though the chart clearly says that it was the period of her [subjective night](#) and she should retire. After a particularly tiring evening and night, the lady went to sleep 3:30 am on the assumption this was her "night sleep". That sleep was 6 hours long and refreshing enough to "impersonate" the night sleep. This completed the role reversal between the night and [siesta](#) periods. The two circadian lows have been swapped in the sleeper's mind. This swap is then reflected in retirement rituals, expectations, and other habits that can perpetuate the reversal for a few days despite a potentially highly unrefreshing sleep. A night-vs-siesta reversal is not stable though. On Sep 25, in the period of the subjective night, a short nap was taken which seemed particularly refreshing. Still the refreshing impression dissipated fast and the third "night at [siesta](#) time" followed. On Sep 26, sufficient sleep debt accumulated leading to a "nap" that suddenly turned into 8 hours of deep and refreshing sleep. The sleep pattern flipped back to the norm after 3 prolonged napping episodes. This role reversal cannot be explained with the two-process sleep model. Nor can it be explained with the model employed in [SleepChart](#). Those three outlier naps taken past the [siesta](#) time should rather be shorter due to the fact they were not enhanced by the [circadian siesta](#) dip. Those naps were also occurring too early to capitalize on the nighttime circadian low. In other words, those "kinky" naps, despite missing the circadian component of sleep, lasted unusually long.

REM deficit

Having seen those kinks in sleep patterns dozens of times, I came to believe that the 2-process model of sleep propensity needs to be extended by a third component. However, it was hard to come up with a sensible hypothesis that would plausibly fit with what we know about the function of sleep and its evolution. A big clue came from interviews with people affected by kinky naps. It appears that those long naps are very often triggered by consumption of alcohol or, in some cases, smoking marijuana. If the timing of alcohol or cannabis administration aligned with the late waking hours, shortly before the subjective night, the kinky nap could follow on the next day. In addition, those naps are preceded by a particularly strong feeling of being unrefreshed in the morning, which is a frequent case in alcohol or cannabis abuse (as much as in the application of [sleeping pills](#) or even [melatonin](#)). As both substances are known to reduce the proportion of sleep spent in REM, I hypothesized that it is the REM-sleep deficit that might be causing the said sleep perturbations.

I have also documented cases where kinky naps followed a healthy and refreshing night sleep that did not involve alcohol, cannabis nor other substances affecting sleep. Those remaining cases also had another common factor: a substantial one-time delay in optimum bedtime and the resulting sleep [phase shift](#). This would agree with the REM-deficit hypothesis. If sleep is delayed past the circadian [REM](#) peak, it is also known to be less REM-rich.

Finally, those kinky naps, unlike the healthy well-timed naps were reported to be dream rich. This could also indicate that they might be involved in [REM](#) compensatory function.

If the REM-deficit hypothesis was to be right, we would need to always consider separate homeostatic [REM](#) and [NREM](#) sleep propensity. In healthy sleep, the [REM](#) component might be hard to notice. Some researchers hypothesize that [homeostatic REM](#) drive depends on the preceding [NREM](#) sleep. If so, homeostatically, healthy night would produce no [REM](#) deficit, while waking activity would only produce homeostatic [NREM](#) sleepiness.

How could [REM](#) deficit produce those prolonged naps? There are some indications that [REM](#) sleep can also produce an

increase in demand for **NREM** sleep. Thus those two, functionally vital phases of sleep, could produce a mutually amplifying cycle that would run its course until the demand for both sleep components was fulfilled. Why would **REM** sleep increase towards the end of normal night sleep? Some of that increase is circadian, some of it might come from the fact that homeostatic **NREM** sleep demand is satisfied faster. The biological explanation of sleep terminated with **REM** is difficult, esp. in the light of **Buzsaki** model of hippocampal "training" in **REM**. Waking up with a clean slate seems biologically more advantageous. Perhaps that last **REM** period is responsible for creative breakthroughs of the early morning? Only a detailed mathematical modelling and comparisons with actual sleep cycle measurements could answer the questions about the homeostatic interplay between **NREM** and **REM** sleep.

Three components of sleep propensity

SleepChart cannot easily verify the nature of the REM-deficit hypothesis. Not only are sleep stages missing from its logs, detecting **REM** sleep is not practicable in home conditions amongst users of **SuperMemo** or **SleepChart**. However, the third variable needed to explain kinky naps in sleep logs, which I will call the RD variable (for **REM** deficit), could possibly be included in the two-process model in hope of mathematically explaining the impact of kinks on the estimated sleep phase. As mentioned earlier, those kinky naps do not need alcohol or other REM-suppressing factors, sleep blocks marked as **Delayed retirement** often cause similar effects due to a wrong phase alignment vs. the **circadian REM** peak. Once sleep misalignments are explained successfully with the RD variable, it would be up to sleep labs to verify the model using EEG measurements. The interaction between the RD variable and the other two sleep variables (H and C) is not straightforward. For example, high RD would not suffice to initiate sleep, as it is not possible to initiate sleep without an appropriate combination of H and C. High RD and high C might also be insufficient (as it is indicated by sleep logs where sleep is pretty short in the nights that follow kinky naps due to the low H). However, high RD and high H could initiate fully blown sleep and result in kinky naps with possible negative consequences for the subsequent night sleep (low H), and sleep phase. At the moment of writing, I am still now sure how the sleep phase is affected, however, I am pretty sure it is. For example, in the [example presented earlier](#), the sleep phase seems to have been shifted back by a few hours, however, it could as well be caused by the deficiency of the model employed in **SleepChart** (precisely due to the missing RD variable). The need for both high H and high RD to initiate sleep for low C seems consistent with current research on the mutual interaction between **NREM** and **REM** sleep stages where one increases the demand for the other.

Sleep-wake flip-flop

The sleep-wake flip-flop is a system of two sets of brain nuclei that produce a rapid switch from sleep to waking, and vice versa. One set of nuclei is responsible for inducing sleep and inhibiting the arousal centers, while the other set acts in the opposite way. Both sets inhibit one another. This means that when there is time to sleep, the sleep centers take an upper hand and turn off the wake centers. Later on, in the morning, the wake centers take control and turn off the sleep centers. This sleep-wake flip-flop is constructed in such a way that the transitions from sleep to wake and back are pretty fast and thorough. In a healthy sleep cycle, we should be half-awake only for a very short time before sleep, and perhaps a little while longer in the morning. Unfortunately this does not mean that we can switch the flip-flop wherever we wish. It also does not imply that we won't feel tired before sleep. **Homeostatic** increase in sleepiness is a natural process and it proceeds throughout the waking period. It is only the transition from wake to sleep that is fast and the time when homeostatic sleepiness meets a sufficient degree of circadian sleepiness. The sleep-wake flip-flop is stabilized by orexin neurons. As demonstrated by Siegel, the level of [orexins](#) (also called hypocretins) is not related to the circadian cycle but to a particular behavior. During a waking activity, e.g. during exercise, the level of orexins may remain high thus preventing the switch in the sleep-wake flip-flop. When the orexin stabilizer is off, narcolepsy enters the picture and the flip-flop becomes unstable causing multiple sleep episodes in a single day in hard to predict circumstances.

The most important components of the sleep-wake flip-flop are:

1. the [ventrolateral preoptic nucleus \(VLPO\)](#) on the sleep side, and
2. the [tuberomammillary nucleus \(TMN\)](#), [locus coeruleus \(LC\)](#) and [dorsal raphe nucleus DR](#) on the arousal side.

Once sleep is initiated, another flip-flop starts operating: the [one that is responsible for transitions between NREM and REM sleep](#).

Suprachiasmatic nucleus (SCN)

Human brain harbors a clock that runs in a cycle that is slightly longer than 24 hours. That clock is called the suprachiasmatic nucleus (SCN) and is located in the anteroventral [hypothalamus](#). The SCN is made of two groups of

neurons (10,000 each, 0.25 mm^3) situated bilaterally just above the [optic chiasm](#). The SCN is slightly more elongated in women, and there is a marked difference in VIP expressing neurons between sexes (up to twice as many in males) (Swaab et al. 1990^[59]). Homosexual men have larger SCNs and twice the number of VP expressing neurons than heterosexual men (Swaab and Hofman 1990^[103]). Incidentally, I am pretty sure that this difference is not by choice and it cannot be remedied with self-discipline or by prayer.

In 1972, the SCN has been identified as the body's master clock that can run without environmental cues and receives resetting inputs from the retina. [Clock genes](#) in the SCN are responsible for a circadian cycle of gene expression that determines the output from the SCN. The neurons in the SCN express the cycle that finds its reflection in signals that travel from the SCN to other brain nuclei and the rest of the body in various neural and hormonal forms. If we surgically damage the SCN, the [circadian](#) cycle wanes or disappears. It can be restored with a transplant of SCN cells.

The SCN signal is most active during the subjective day, esp. in the evening hours. It is the weakest during the subjective night, esp. in the early morning when the body temperature reaches its minimum. If you ever tried to [sleep polyphasically](#), it is the SCN that will bother you and make you crave the core sleep and make you oversleep during the [subjective night](#) time. The SCN controls alertness, attention, release of hormones, body temperature, [melatonin](#) secretion, feeding, and more. Most of the output from the SCN flows to the subparaventricular zone (SPZ) and the dorsomedial nucleus of the hypothalamus (DMH). Neurons in the dorsal SPZ (dSPZ) affect the circadian rhythm of the body temperature, while those in ventral SPZ (vSPZ) are running the wake and sleep cycle. vSPZ in turn commands the inputs to [DMH](#) which is the chief command center for waking behavior, motor activities, cortisol cycles, feeding, etc. [DMH](#) affects sleep promoting [VLPO](#) and the wake promoting LHA (lateral hypothalamus). Lesions to [VLPO](#) and LHA can produce loss of sleep or insurmountable sleepiness respectively.

This central positioning of the SCN and the [DMH](#) at the crossroads of the most essential and influential neural pathways controlling behavior is a powerful demonstration of how a tiny group of a few thousand neurons exerts a powerful influence on what we do as active feeding and surviving organisms. This should remind everyone that sleep hygiene is essential for the proper function of this tiny structure in the human brain. Disrupting circadian cycles with alarm clocks, shiftwork and the like can [lead to a whole volley of physical and mental disorders](#). For a thorough review of the interaction between the SCN, the [DMH](#) and the rest of the body see Dr Clifford B. Saper "Hypothalamic regulation of sleep and circadian rhythms" (Saper et al. 2005^[104]). Interestingly, Dr Saper hypothesizes that it is the [DMH](#) that integrates the circadian resetting stimuli such as exercise or social interaction. In rodents, [DMH](#) can also be reset by the availability of foods or even the temperature. It is unlikely though that you will be able to combat jetlag or adapt to any shift-work pattern with the help of zeitgebers such as food or temperature.

SCN oscillates with a period slightly longer than 24 hours. To adapt to the 24h world, the oscillation needs to be reset daily to match the daylight cycle of the Earth. The resetting is done with the help of zeitgebers ("time givers") such as light, exercise, feeding, etc. The most important zeitgeber is light. Light signals are received by glutamatergic melanopsin-expressing retinal ganglion cells in the retina (pRGCs). From there, they are transmitted to the SCN via the retinohypothalamic tract (RHT). The impact of light signals and other zeitgebers on the [circadian](#) phase is described by the so-called [phase response curve \(PRC\)](#). Most importantly, morning light signal helps reset the cycle. The circadian period gets shortened to match the 24h daylight cycle. With the help of zeitgebers, the oscillator with a slightly longer period is brought back to synchrony with the daylight by a minor SCN-mediated reset. This provides for a stable oscillation. People who cannot effectively cue their oscillators suffer from phase-shift disorders. People suffering from [DSPS](#) could experiment with light dimmers, toning down their schedules in the evening, properly timed [exercise](#) and bright light in the morning. People with [ASPS](#) should use opposite measures (e.g. 3000 lux light in the evening). In addition to light, the SCN is affected by activity. Locomotor activity affects the SCN by activating NPY-containing neurons in the intergeniculate leaflet (IFL) and serotonergic neurons in the median raphe nucleus (MRN). This is why exercise and social interaction act as powerful zeitgebers.

The neural symphony commanded by the SCN goes awry when we use artificial lighting or do exciting evening activities such as watching TV, surfing the net, playing computer games, reading, etc. It has been hypothesized that light (as well as other stimuli) may affect the SCN in two different ways during the [subjective night](#). Short light pulses simply change the expression of [clock genes](#) and result in phase shifts along the [PRC](#). However, constant lighting may result in uncoupling between the SCN neurons and the downstream nuclei affected by the SCN resulting in dangerous arrhythmicity (Ohta et al. 2005^[105]). Continuous disruptions to circadian cycles as seen in shiftwork or jetlag may lead to a gradual mental decline as indicated by research in rodents (Ree et al. 1985^[106]). Circadian changes associated with aging and Alzheimer's can be correlated with loss of cells in the SCN or changes in its inputs. Vasopressin-expressing cells are particularly prominent in their decline in Alzheimer's. All forms of artificial control of sleep cycles, including the use of alarm clocks, can affect the health of those few precious neurons.

The SCN sends projections to the dorsal PVH (parvocellular paraventricular nucleus) whose neurons project to sympathetic preganglionic neurons in the spinal cord that in turn affect the [pineal gland](#) and the release of [melatonin](#). This tells us that melatonin, which is often advertised as a "natural sleeping pill" is produced by the [pineal gland](#) downstream from the SCN control. This is why it cannot be considered a central factor controlling circadian sleepiness. [Melatonin](#) does produce phase shifts along its unique [melatonin PRC](#) (see [picture](#) in the [PRC](#) section). It is possible that this effect is caused by a direct impact of the [melatonin](#) on the SCN. However, early sleep will also result in earlier waking and this will also have a phase shifting effect.

Dorsomedial Hypothalamic Nucleus (DMH)

Dr Saper and colleagues demonstrated that excitotoxic lesions to the [dorsomedial nucleus of the hypothalamus](#) (DMH) in rats cause a major impairment to circadian rhythms (Saper et al. 2003^[107]). As lesioned animals sleep more, it was suggested that the impact of [DMH](#) is predominantly activating even though other explanations of the available findings are also imaginable. It appears that a great deal of output from the [SCN](#) travels via the subparaventricular zone (SPZ) to the [DMH](#) and only then, via inhibitory tracts, to the [VLPO](#) that is responsible for the initiation of sleep. The [DMH](#) also projects to the [lateral hypothalamic area](#) (LHA) that contains wake-promoting [orexin](#) neurons. It has been hypothesized that the [DMH](#) might be in the center of control of various variables that change along the [circadian](#) cycle such as arousal, feeding, locomotor activity, cortisol levels, body temperature, [melatonin](#), etc. Restricted feeding synchronizes circadian rhythms of the [DMH](#) so that the highest [c-Fos](#) expression and locomotor activity coincide with mealtimes (Saper et al. 2006^[108]). As most of the input arrives to the [DMH](#) via SPZ, it is important to note that dorsal and ventral portions of the SPZ seem to play different functions. Lesions to the dSPZ reduce circadian rhythms of body temperature, while it is the vSPZ that seems to control sleep-wake cycles and locomotor activity (Saper et al. 2001^[109]). The dSPZ controls body temperature via the [medial preoptic area](#) (MPO) that includes the median preoptic and ventromedial preoptic nuclei. The [DMH](#) is affected by the hormones controlling the appetite, [ghrelin](#) and [leptin](#), via the [ventromedial nucleus](#) (VMH) and the [arcuate nucleus](#) (ARC). VMH enhances [lipolysis](#) in [adipose tissue](#) and decreases feeding. Dr Saper hypothesized that the [DMH](#) may serve as a secondary [circadian](#) control center that would enable [entrainment](#) of the rhythms to the availability of food. However, from the standpoint of control systems, it would seem biologically more sensible to phase-shift the [SCN](#) rather than to employ a second asynchronous or phase-locked oscillator. In humans, it is very hard to influence the circadian cycle in any way other than via a minor phase-shift with the use of various zeitgebers, of which, food is a very weak one. It therefore seems highly unlikely that shiftworkers or jetlagged travellers could tangibly benefit from changes to the timing of their diet. Differences between rats and humans cannot, naturally, be excluded. Nevertheless, the [DMH](#) is definitely a very interesting further research target.

Ventrolateral Preoptic Nucleus (VLPO)

The ventral lateral preoptic nucleus (VLPO) is one of the chief brain centers needed to initiate sleep and to maintain slow-wave sleep. Lesions in this area halve the amount of sleep, and result in insomnia combined with persistent tiredness. Both [NREM](#) and [REM](#) can be affected depending on the type of the lesion. For its role, the [VLPO](#) is often called a "sleep switch". In both nocturnal and diurnal animals, the SCN is active during the period of daylight, while the [VLPO](#) is primarily active during sleep. Once the [VLPO](#) is on, it is believed to maintain inhibition of the monoaminergic and cholinergic excitatory systems that keep the brain cortex "awake". Those [VLPO](#) projections go to the [tuberomammillary nucleus](#) (TMN) ([histamine](#)), [lateral hypothalamus-perifornical region](#) (LHA/PF) ([orexin](#)), ventral [periaqueductal grey](#) (vPAG) ([dopamine](#)), [locus ceruleus](#) (LC) ([noradrenaline](#)), [parabrachial nucleus](#) (PBN) and [dorsal raphe](#) (DR) ([serotonin](#)), lateral [tegmentum](#) (LDT) ([acetylcholine](#)) and the [pedunculopontine tegmental nucleus](#) (PPT) ([acetylcholine](#)). The inhibitions enacted by the [VLPO](#) are mediated by GABAergic neurons as well as by galaninergic inputs to the histaminergic [tuberomammillary nucleus](#) (TMN). Inhibition of the TMN and other alertness nuclei results in a drop in alertness hormones and a drop in cortical activation causing drowsiness. A hypothesis says that separate populations of the [VLPO](#) might be responsible for expressing circadian aspects of [NREM](#) and [REM](#) sleep. A subset of [VLPO](#) cells is able to stimulate cholinergic neurons in the LDT and PPT. This contributes to inducing [REM](#) bursts that activate the cortex without wakefulness during [REM](#) sleep.

The [VLPO](#) receives its circadian signal input from the SCN (the main body clock) via the [dorsomedial nucleus of the hypothalamus](#) (DMH), which is the other brain clock that is usually synchronized with the SCN. The [VLPO](#) neurons do not build up a homeostatic need for sleep, however, some [homeostatic](#) mechanisms, such as the intracellular build-up of adenosine, may inhibit aminergic or cholinergic wake centers and thus activate the [VLPO](#). For example, infusion of adenosine agonists into the basal forebrain increases both [NREM](#) and [REM](#) sleep (Satoh et al. 1999^[110]) and increases [c-Fos](#) in the [VLPO](#) (Scammell et al. 2001^[93]). In sleep deprivation, the activity in the [VLPO](#) is not much higher than in ordinary waking. This low level of activity persists until the bedtime. Once the sleep begins, [VLPO](#) neuron firing rate

may double in conditions of [sleep deprivation](#) (Saper et al. 2005^[104]). This indicates that even though the [VLPO](#) does not build up homeostatic sleep propensity, it is impacted by the homeostatic mechanisms in the end. This also indicates that the [VLPO is located downstream the circadian and homeostatic signal integrator](#). Aminergic arousal nuclei such as the TMN, [LC](#) and the raphe form a part of the sleep wake switch. That switch is stabilized by orexin/hypocretin cells from the [lateral hypothalamus-perifornical region \(LHA/PF\)](#), esp. during motor activities or feeding. The arousal can thus be maintained uninterrupted despite competing inhibitory influences. The arousal nuclei inhibit the [VLPO](#) in waking as much as the [VLPO](#) inhibits them back in sleep. Scientists believe that this mutual inhibition forms a classic unbalanced flip-flop with sharp state transitions. This is what helps us fall asleep fast, and wake up fast, spending minimum time in transition, and maximum time in the desired states: alertness or deep sleep.

For more on the place of the [VLPO](#) in the sleep control system see [Figure 39](#) in [Functional Anatomy of the Hypothalamus and Pituitary](#).

For a thorough review of the role of various sleep and wake centers, see Saper's "Hypothalamic regulation of sleep and circadian rhythms" (Saper et al. 2005^[104]).

Nucleus of the Solitary Tract (NTS)

This section speaks more of fads and fashions in science than of the actual involvement of the [nucleus of the solitary tract](#) (NTS) in sleep. I heard of the importance of the NTS for sleep in the early 1980s during my college years when studying biology. Some time later, I added a couple of items on the NTS to [SuperMemo](#) to consolidate that knowledge for years to come. When writing my [Good sleep, good learning, good life](#) article in 2000, I still mentioned the NTS and how rocking babies to sleep might work even though I knew that destruction of NTS does not lead to insomnia, which should be a big clue. The NTS seems to be more involved in processing signals received from the gut. These signals play only a minor part in sleep control. In the end, I fell victim to the same old affliction that pesters science since its inception. Sometimes it takes the old generation of scientists to die out for a new idea to take hold. Old knowledge makes us more conservative, because not knowing makes us seek answers while knowing makes us passive even if our answers are wrong. Once you believe you know all the answers, there is less pressure to investigate. In the end, many other brain centers play a role comparable to that of the NTS. After all, the brain is a highly connected structure and few things happening in one corner of the central nervous system have no bearing on events in other corners. Consequently, activation of nearly all major nuclei will have an arousing or inhibiting effect within the [reticular activating system](#), which has also been for years a mainstay of our thinking about arousal. At the same time, back in 2000, I hardly mentioned the [VLPO](#), as it was perhaps not fashionable enough. A similar situation, we may or may not face with the [SLD](#), which has emerged as an alternative to the well-established PPN/LDT [REM](#) on system. Even the [DMH](#) might not be immune to fashions. Like the NTS, it is also involved in feeding behaviors. Perhaps, in a decade, this article will warrant a complete rewrite with a great deal of old fads gone. Equally well, in the era where all new findings in science are available at our fingertips, and we can easily communicate via e-mail and other means, we will all show a lesser tendency to swim with the crowd. More importantly, new investigative technologies are likely to open new areas that might still be subject to fads, while the subject matter discussed in this article will gel out and solidify.

Incidentally, the pain of fashions was once the main factor that pushed me away from peer-review writing to blogging. Writing the presented article was the acme of fun. The article was written using [incremental writing](#), and polished collaboratively as a wiki. Being part of a commercial company, I am not subject to publish-or-perish pressures. This is a precious freedom. Back in 1992, with Dr Gorzelanczyk we studied the literature of the spacing effect and came to conclusion that the mountain of data we collected with SuperMemo, as well as a clear computational formulation of the concept of spaced repetition will sweep the world of education and memory science off its feet. A vast majority of the spacing effect literature of that time was focused on short-term studies (e.g. checking the memory effect after just a week from the trial). Bahrick's study of the retention of Spanish vocabulary was a major and stellar exception. However, Bahrick could only study the retention of vocabulary many years after the original training with no specific data on the timing of exposure to individual words during the period of learning, or during the long period preceding the measurement. In that light, we thought we have all we needed to start a new revolution in learning and in the science of memory. To our monumental disappointment, we could not push our paper through to be published in [Memory and Cognition](#). Our failure came partly due to our inexperience, and the lack of credentials. We both have just come out of the university with MSc degrees. However hard we tried to phrase our paper around the fashionable spacing effect, we were not able to mold it to match the mainstream science of memory. From some old obscure journal, we picked the best-sounding scientific name for our repetition scheduling methodology. We called it repetition spacing. This term mutated later into [spaced repetition](#) and remains the only tangible legacy of the original paper, even though it has not yet penetrated the scholarly namespace. Perhaps it never will. More general "distributed spacing" or "distributed presentation" still predominate, while users of computerized flashcard now consistently speak of "spaced repetition". The editors of Memory & Cognition congratulated us on our results and mentioned that the

computational aspect of the paper made it suitable to journals devoted to computer algorithms. The world of fashion in memory science was so different from our proposition that no top model took our stance. In the end, we published in a lesser known [Acta Neurobiologiae Experimentalis](#). Sadly, the paper has got only 18 citations in the course of 20 years since publishing, and when it is mentioned, it is quoted with caution. After all, the "optimization algorithm" feels like a black box. It was offered free for anyone, and yet it is hard to study it in action. It is not a neat formula. It is an algorithm, and it can best be run on a computer and studied with computer means. Our line of clothing appeared to be highly unfashionable. It is now commonly used by millions, and new designers hop on board monthly. Scientific community remains largely impervious for now though. It awaits a wave of new talent grown on the feed of spaced repetition.

Fashions in science are part of our collective cognitive prejudices. They slow down progress. They are unavoidable. And still, in the long-run, they regress to the mean of the approximate truth. It is important that for each step back, we can make a dozen steps forward.

Adenosine

Adenosine is one of the endogenous markers of the [homeostatic](#) sleep drive. During the waking period, as the [cortex](#) and other parts of the brain keeps burning their [glycogen](#) reserves, [ATP](#) is converted to adenosine which accumulates extracellularly. The role of adenosine was first discovered upon the finding that its systemic administration promotes sleep (Radulovacki et al. 1984^[111]).

The increased activity of the cholinergic neurons in the basal forebrain neurons causes a buildup of adenosine that in turn inhibits the activity in that region via its [A1 receptor](#) (Strecker et al. 2000^[112]). This is one of the hypothetical homeostatic triggers of sleep. The accumulation of adenosine in the basal forebrain is particularly important as it is here that its effect is most pronounced (Strecker et al. 2000^[112]). The accumulation in the basal forebrain causes the inhibition of some aminergic waking centers and the disinhibition of the [VLPO](#), which promotes sleep. Infusion of [A_{2A} receptor](#) agonists into the rostral basal forebrain increases both [NREM](#) and [REM](#) (Sato et al. 1999^[110]). Moreover, adenosine [A_{2A}](#) receptor agonists stimulate the [VLPO](#). The resulting activation of the [VLPO](#) may be measured by the increase of c-Fos activity (Scammell et al. 2001^[93]). Some of the presented scenario has recently been questioned upon finding that rats with a 95% loss to cholinergic neurons in the basal forebrain show intact sleep homeostasis despite the lack of the hallmark increase in adenosine.

Adenosine is particularly interesting as its well-known antagonist is [caffeine](#). [Caffeine](#) binds to adenosine receptors thus blocking the homeostatic sleep propensity. This proves that network overload is not the cause or at least not the sole cause of the homeostatic sleep drive. The brain has evolved sleep protection mechanisms, in this case involving adenosine, to ensure that before a network overload leads to any significant consequences, homeostatic sleep drive pushes an animal to take a sleep break and do the [necessary neural housekeeping](#).

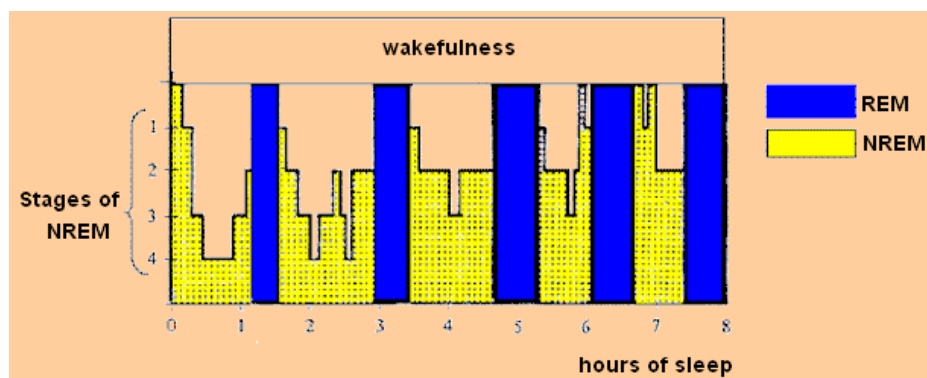
NREM and REM sleep

NREM and REM alternations

In the course of the night, we alternately enter two phases of sleep:

- [NREM](#) sleep (named for non-Rapid Eye Movement)
- [REM](#) sleep (named for Rapid Eye Movement)

Using EEG measurements, scientists are able to distinguish 4 phases of [NREM](#) sleep which correspond to progressively deeper sleep. In newer literature you may read of three stages as Stages 3 and 4 of [NREM](#) have been bundled together as a single stage of slow-wave sleep.



NREM-REM cycling through a typical night.

As we close our eyes, it takes 3-15 minutes to enter Stage 1 **NREM** sleep (in a healthy and well-regulated individual). In this stage we will often experience little jerks associated with the impression of falling. Minor disturbances will wake us up and often we will even deny being asleep! Once State 1 **NREM** solidifies, we move towards Stage 2 **NREM** sleep which is still relatively light. After that we move to Stage 3 (and Stage 4) **NREM**, which is also called deep sleep or slow-wave sleep (SWS).

Historically, the importance of **REM** sleep for memory and learning was documented before we became truly aware of the role of slow-wave sleep. Consequently, articles and books on sleep are peppered with an overemphasis on the role of **REM** sleep in learning as compared with **SWS**. Over time, **REM** deprivation studies received lots of criticism. Today, we know that the natural harmonious interplay of uninterrupted **NREM** and **REM** sleep is essential for memory, learning and creativity (Salzarulo et al. 2000^[113]).

Cruel **sleep deprivation** studies actually show that sleep deprived rats can live longer if **REM** deprived than if **NREM** deprived. [Rats deprived of sleep survive for 2-3 weeks](#). Rats deprived of **REM** sleep only survive for some five months.

Napping human subjects reported that it is Stage 4 **NREM** that feels most restorative. The release of [norepinephrine](#), [serotonin](#) and [histamine](#) is inhibited during **REM**. During dreaming, the primary visual cortex is not active, while its secondary areas are active. This is similar to the situation in which people are asked to imagine a visual scene as opposed to a situation in which they actually see the scene. Blind people have dreams that are more auditory and more tactile. This seems to confirm the role of **REM** sleep in the replay of experiences and in optimization of memories. They do not show the typical eye movement pattern in **REM** sleep either. Those observations led to an idea that **REM** sleep is vital for creativity (more than **NREM** sleep). During **REM**, cholinergic modulation suppresses the flow of information from the **hippocampus** to the neocortex. This is supposed to [help build new associations within the neocortical areas](#).

Evolution of NREM and REM

REM sleep is phylogenetically younger than **NREM** sleep. Fish, amphibians or reptiles do not show typical **REM** sleep. Yet, interestingly, **REM** sleep is present in both mammals and birds. This made some scientists hypothesize that **REM** sleep has been invented twice by evolution! Clearly, **REM** sleep plays a role critical for survival of creatures with bird-mammal IQ levels (see: [How much do animals sleep?](#)). However, [Dr Siegel](#) who studied **REM** sleep in [echidna](#) concluded that this animal's sleep combines aspects of both **REM** and **NREM** sleep. As a result, he suggested that **REM** and **NREM** might have evolved from a phylogenetically older unified form of sleep (Siegel et al. 1996^[114]). If **REM** sleep is as disparate from **NREM** in its function and as complex as implied by the theories on the [neural optimization in sleep](#), the re-invention factor might be used by evolutionists as an argument against neural optimization. However, like aerial flight, re-invention combined with complexity could equally well add weight to emphasizing the vital neural function of sleep.

NREM and REM deficits

Cruel **sleep deprivation** studies actually show that sleep deprived rats can live longer if **REM** deprived than if **NREM** deprived. [Rats deprived of sleep survive for 2-3 weeks](#). Rats deprived of only **REM** sleep survive for some five months. After sleep deprivation, it is the **SWS** deficit that is repaid first. **SWS** deficit is a result of **NREM sleep deprivation**. **REM** deficits are paid off later. A frequent scenario is that the **SWS** deficit is paid fully on the first night of recovery, while **REM** sleep deficit may persist through to the second recovery night.

Forced desynchrony protocols are sleep protocols in which subject sleep is dissociated from its natural circadian cycle.

In condition of forced synchrony, we can observe that slow-wave activity that characterizes **NREM** sleep is associated with homeostatic sleep propensity, while the proportion of **REM** sleep in sleep episodes depends on both homeostatic pressure and the circadian cycle.

NREM control

NREM sleep is primarily controlled via a [homeostatic mechanism](#). During the waking day we build a pressure to initiate sleep and its deeper **NREM** stages. If sleep is initiated without a contribution of the circadian component, it is likely to be short and NREM-only. One of the signals correlating with homeostatic sleepiness is the buildup of [adenosine](#). It is the adenosine receptors that are affected by [caffeine](#) resulting in its short-lived impact on reducing the [homeostatic](#) sleep pressure. One of the consequences of the buildup of adenosine is the inhibition of the aminergic wake centers, inhibition of the basal forebrain, and the disinhibition of the [VLPO](#): the chief brain center responsible for the initiation of sleep. **REM** sleep also has a [homeostatic component](#), however, in times of deficit, it is **NREM** sleep deficit that is compensated for first. There is also more evidence indicating that **REM** sleep increases **NREM** sleep pressure (Beersma et al. 1990^[115]). In addition to adenosine, other signals such as [interleukin-1](#), [tumor necrosis factor](#), [interferon](#), [prostaglandin D₂](#), [NO](#), [GHRH](#), and others have also been associated with the increase in homeostatic sleep propensity (Krueger et al. 2008^[116]).

Sleep deprivation increases both **NREM** and **REM** sleep propensity. Short sleepers have less **NREM** 2, but there is little data on the actual quality and effectiveness of their sleep. Thomas Edison or Nicola Tesla, on one hand, are well-known for sleeping relatively little, while Einstein is a well-known long sleeper, who, supposedly, slept over nine hours per night. Interestingly, all these geniuses also belonged to notable nappers. It is true that by getting less sleep you compress the less critical **NREM** 2 sleep, but there is no evidence that this can become your regular habit without hurting the quality of your NREM-REM interplay. With the currently available sleep data the conclusion is: [do not try to compress NREM 2 by sleeping less](#). You are likely to hurt the [memory optimization](#) process occurring in sleep.

Some scientists believe that during sleep, an ultradian oscillator in the [mesopontine](#) junction controls the regular alternation of **NREM** and **REM** sleep. However, the term oscillator is rather misleading as the mechanism of NREM-REM mutual interaction is more of a [flip-flop nature](#), and the timing of alternation is pretty irregular indicating significant internal and external homeostatic influences that ultimately culminate in the extinction of the sleep cycle.

Neuromodulation in sleep

The AIM model of sleep ((Hobson et al. 2000^[89]) emphasizes the importance of cholinergic modulation that dominates **REM** in the absence of aminergic activity.

In **NREM** sleep, cholinergic systems in the [brainstem](#) and the [forebrain](#) are less active than in waking. Serotonergic [raphe](#) and noradrenergic [LC](#) are also less active. On the other hand, in **REM** sleep, these aminergic structures are strongly suppressed, while the cholinergic systems flare up. Release of [histamine](#) is also down in **REM**. It has been hypothesized that cholinergic modulation suppresses the flow of information from the [hippocampus](#) to the [neocortex](#). This is supposed to play an important role in the [dual network](#) model of learning in which the [hippocampus](#) plays a role in building up new associations on the basis of old information (see: [Neural optimization in sleep](#)).

Dr Siegel, who does not believe in the role for sleep in memory and learning, believes that **REM** sleep serves recovery as serotonergic, noradrenergic, and histaminergic neurons stop firing. It is as if they were overused and attempted to replenish their resources. This interpretation might pass the shutdown test (see: [Sleep theories](#)) as many of these neurons are vital for maintaining arousal. However, it is hard to imagine that evolution would not find a way to re-design the brain in which neurotransmitter replenishment would be possible without the shutdown. Some areas of the brain keep firing in waking and as well as in all stages of sleep. The neurons involved are able to replenish their resources without going offline.

Growth hormone and cortisol

In addition to changes in firing patterns of neurons releasing different types of neurotransmitters, circulation of systemic hormones also changes during sleep. Of these, [growth hormone](#) and [cortisol](#) are of particular importance as they impact glucose metabolism. Growth hormone increases at sleep onset and peaks in deeper stages of **NREM**. On the other hand, cortisol levels increase in the later stages of the night dominated by **REM** sleep. Unlike the release of cortisol, which is largely circadian, the increase in GH is associated with a sleep onset (Van Cauter et al. 1997^[117]). **Sleep deprivation** or sleeping in a wrong phase are both involved in major disruption of glucose metabolism for different reasons. This is why **healthy sleep is vital for preventing obesity**.

REM Homeostasis

In the same way as sleep in general, REM is controlled via homeostatic and circadian processes. **Acrophase** of the circadian REM cycle comes late in the **subjective night**. Benington and Heller proposed that it is the presence of NREM sleep rather than the absence of REM sleep that leads to an increase of REM sleep propensity. Slow-wave sleep builds homeostatic REM propensity, and the best REM comes from the combination of slow-wave "exhaustion" and the circadian REM peak which comes in the last hours of sleep. There is also a strong **homeostatic** link between learning and the demand for REM sleep. The more you learn, the stronger the drive towards REM. There is an increase in both the number of minutes of REM sleep and the density of REM sleep following intensive learning (De Koninck et al. 1989^[118]). It is not clear if learning affects REM demand directly or via NREM demand. However, it is more than clear that heavy learners should be heavy sleepers!

Stimulating the **basal forebrain** causes a release of **acetylcholine**, which induces wakefulness and is also conducive to REM sleep. This means that the basal forebrain that takes part in the **initiation of sleep** is also involved in NREM/REM transitions. Similarly, a subset of **VLPO** cells contribute to generating REM sleep.

The impact of adenosine antagonists, such as **caffeine**, is also important. Adenosine agonists infused into the basal forebrain increase **c-Fos** in the **VLPO** as well as increase the release of acetylcholine by the basal forebrain. Acetylcholine is known to induce the states of wakefulness and REM sleep. As a result of the agonist infusion, both the total amount of NREM and the total amount of REM sleep increase (Satoh et al. 1999^[110], Scammell et al. 2001^[93]).

Of other homeostatic hormonal influences, increased levels of **VIP** and **prolactin** in sleep promote REM. It is possible that substance abuse, delaying sleep, as well as the use of alarm clocks can all read to REM sleep deficits (see: **REM rebound hypothesis**).

One of the **sleep theories** says that REM sleep helps the brain recover from NREM sleep to speed up the responses in waking. This theory fails the shutdown test as the same recovering might simply be taking place in a waking state unless the hard work of the networks in dreaming is a faster recovery method for some unknown reason. However, why would a brain experience a REM rebound in conditions of full "recovery" to waking? The claim that **histamine**, **serotonin** and **noradrenaline** neurons need recovery time sound more plausible, however, it does not explain why we would need different populations of neurons with different neurotransmitters with different restoration and recovery strategies.

Transition to REM

After an hour or so of healthy NREM sleep during the **subjective night** sleep, there is a gradual increase in the activity of cells in the **pontine tegmentum** which is responsible for triggering REM sleep. Structures responsible for triggering REM sleep might include **pedunculopontine tegmental nucleus (PPN)** and **sublaterodorsal tegmental nucleus (SLD)**. GABAergic SLD and cholinergic PPN send their signals in multiple directions. One of the outcomes is muscle atonia. Another is the activation of the **thalamus**, **hippocampus**, and the **cortex** with an appearance of the typical REM EEG. As a result the brain behaves as if it woke up internally! Injections of **acetylcholine** into the **pons** during an ongoing NREM episode may trigger REM sleep, which illustrates the importance of this neurotransmitter in sleep cycle regulation. During REM sleep, the cortex behaves as in the state of wakefulness. Dreams experienced at that stage seem to be generated by random impulsation sent from the **brainstem** to the cortex. The cortex produces best possible and most coherent imagery of that chaotic input. During dreams we experience connected events, real people, realistic scenery, etc. However, all these are put together in most improbable configurations as if the brain was testing "*what if*" scenarios. Yet we cannot act upon our dreams (except for people who suffer from violent sleeping). Pontine structures responsible for REM control make sure that the cerebral output gets cut off from motor nuclei that move the muscles. It happens often that we want to act in sleep (e.g. to escape a ferocious dog), and yet we remain motionless as if mired in molasses. At that time, only the eyes move rapidly, while the muscles in the middle ear also twitch.

The movements of eyeballs that gave REM its name is controlled by impulsation generated in the **pontine nucleus** that projects to the **superior colliculi**. That impulsation is associated with generating of the **ponto-geniculo-occipital waves (PGO)** that are also used to detect REM sleep.

During dreaming, the primary visual cortex is not active, while its secondary areas are active. This is similar to the situation in which people are asked to imagine a visual scene as opposed to a situation in which they actually see the scene. Blind people have dreams that are more auditory and more tactile. This seems to confirm the role of REM sleep in the replay of experiences and in optimization of memories. They do not show the typical eye movement pattern in REM sleep either. Those observations lead to an idea that REM sleep is vital for creativity (more than NREM sleep).

REM flip-flop

The interplay between **NREM** and **REM** sleep is most likely controlled by a **REM** flip-flop. Some scientists believe that during sleep, an ultradian oscillator in the **mesopontine** junction controls the regular alternation of **NREM** and **REM** sleep. However, a flip-flop model is a better analogy considering the timing of the alternations.

As it is the case with the **sleep-wake flip-flop**, the **REM** flip-flop causes a continuous switches between a relatively stable **NREM** and **REM** states, however, the flip-flop is under far greater influence of various homeostatic inputs resulting in a somewhat chaotic succession of NREM/REM states that gradually become dominated by **REM** circadian peak towards the end of the **subjective night**.

For many years, an oscillation between cholinergic and monoaminergic states seemed like a final answer to the control of **REM** sleep. However, some inconsistencies and new research lead to a newer similar model involving GABAergic structures (see the next section).

Models of REM flip-flop

In 1962, Jouvet showed that stimulation of the caudal mesencephalic region or **pontine tegmentum** in cats produced a state similar to **REM** sleep. This led to a hypothesis that **mesopontine** cholinergic structures are responsible for the activation of the **thalamus** and the **cortex** in **REM** sleep. The hypothesis would also be supported by the fact that injections of cholinergic agonists into the **pontine reticular formation** would enhance **REM** sleep.

The original reciprocal interaction model in which pontine aminergic and cholinergic neurons have formed a classical REM-on/REM-off flip-flop has been accepted as a fact for a quarter of a century. New research has identified GABAergic populations that might be part of the **REM** flip-flop on both on and off sides of the switch.

The old **REM** flip-flop included cholinergic **PPT** and **LDT**, which are particularly active in **REM** (and wakefulness), as well as the BRF (brainstem reticular formation). The REM-off component was composed of **DR** (**serotonin**) as well as the **LC** (**NA**) (Saper et al. 2001^[119]).

Newer research questioned some inconsistencies in the model. For example, selective lesions to cholinergic or monoaminergic nuclei of the brainstem have only limited effect on **REM** sleep. Low **c-Fos** expression in REM-on structures during **REM** was also troubling. Instead, it was suggested that the key REM-on area is the GABA-ergic SLD (**sublaterodorsal tegmental nucleus**) (Lu et al. 2007^[120]). As the SLD does not directly inhibit DR-LC, their direct participation in the flip-flop was questioned as well. GABA-ergic neurons of SLD project to the vlPAG (ventrolateral periaqueductal grey matter) and LPT (lateral pontine tegmentum), which thus became REM-off suspects. Lesions of the SLD cause a loss of **REM** sleep.

The precise nature of the **REM** flip-flop must yet be determined. Components of the old and new models show some interaction as well. For example, PPT/LDT do excite SLD neurons, while DR/LC may inhibit the SLD or activate the REM-off components. However, that interaction is not directly mutual. Hence the exclusion of the old components from the core of the new model.

Termination of sleep

The sleep control system would act as an infinite seesaw were it not for the circadian component of the sleep drive. Towards the end of sleep, the **circadian** sleepiness determined by the suprachiasmatic nucleus (**SCN**) will produce decline in sleep propensity, and the sleep will be terminated after one of the **REM** sleep episodes. It is the SCN which provides the link between the strongest zeitgeber, the light, and the circadian cycle. SCN generates the rhythm endogenously, but is able to get reset by light. Light impulses from the **retina** travel to the **hypothalamus** and the SCN to produce a stop&reset signal. End of sleep will see the end of **melatonin** release. Instead, another neurohormone starts building up: **serotonin**. A hypothesis says that it is the high level of serotonin that we feel as the morning sunshine happiness. High serotonin combines with the alertness hormone **cortisol** to give us a good alert start into a new day. Unless you suffer from sleep phase advancement, always make sure the sunshine streams into your sleeping room in the morning to wake you up.

Why do we need sleep?

Biological origins of sleep

Human brain is the highest achievement of the biological evolution. It all started from a simple ability to conduct

impulses. Then the amazing concept of a neural network was developed. The brain of primitive vertebrates started adding new structures as well as new mechanisms for optimizing the jungle of neural connections. Sleep is a relatively old invention used to re-organize memories via molecular and neural mechanisms. Circadian rhythms are known in plants and in animals independent of the need for sleep. The process of evolution has, however, conveniently hooked up sleep to circadian rhythms to efficiently alternate between the explorative state (i.e. the use of the brain for learning new things) and the **consolidation** state (i.e. sleep). The circadian cycle has been associated with around a hundred known physiological functions and parameters that change in concert during the day (this number now increases rapidly, e.g. with circadian analysis of gene activation). Closely related to sleep are cycles in the levels of hormones such as **serotonin** and **melatonin**, **ACTH** and **cortisol**, **acetylcholine**, **adenosine**, and **growth hormone**. There is a circadian function that we can observe on our own without complex measurements: changes in the body temperature (see the figure [Temperature changes in the course of the day](#) in [Biphasic nature of human sleep](#)).

As we spend a third of our lives sleeping, there is little wonder that sleep has attracted lots of attention from neurophysiologists. Given the enormous complexity of the brain and its functions, there have been literally hundreds of theories that attempted to explain the role of sleep. Only recently, with the arrival of new research technologies, have we been able to see the big picture in the sea of detail.

Sleep theories

Over the last two centuries, dozens of theories of sleep have been proposed. Some scientists believe that we sleep to remember. Others believe that we sleep to forget. Yet others believe that sleep has nothing to do with memory. There are also theories that come from philosophers, religious figures, ideological movements, etc. For example, "sleep maximizes positivity" is a very vague "theory" that is actually largely correct.

For a biologist, the best ground for determining a validity of a theory is its evolutionary perspective. The main question to ask is: **what vital function is subserved by sleep that demands turning off cognitive functions for a third of our lives!** Each sleep theory must pass this primary litmus test. Let's call it a **shutdown test**. [Allan Rechtschaffen](#) put it best saying "*If sleep does not serve an absolutely vital function, then it is the biggest mistake the evolutionary process has ever made*". The shutdown test is the best sieve for eliminating implausible theories of sleep, however, as an exercise, you can also check which theories explain the fact that if we do not get sleep on one day, we need more on another. For example, if sleep was to help avoid predation, we would not incur the predation avoidance debt that needs to be repaid. If we survive predation despite roaming around, our chances of survival on the following night are exactly the same.

We cannot forget, naturally, that some variables related to sleep do not need to be an expression of its primary function. In evolutionary terms, sleep is a very old phenomenon, and all species learned to attach dozens of neural and non-neural functions to this state. For example, sleep is the main **anabolic** state for the body. For this multifunction reason, it is hard to determine the primary function of sleep by just studying variables such as the sizes of animals, sizes of their brains, their habits, types of food, longevity, levels of activity, proportion of sleep spent in REM, etc. These all studies are very interesting but seem to explain little because of the huge number of overlapping variables which effectively obscure the main function of sleep.

Below I will quickly list theories that attempt to explain the role of sleep. I will divide them into those which answer and those which fail to answer that main question: why the conscious mind needs to be turned off. Let me start with a subset of countless theories that fail to pass the **shutdown test** (as suggested above).

Theories that fail the shutdown test

Here are just a few of innumerable theories that may be based on true facts, true models, or partially explain the function of sleep. However, they **do not** explain the essential need to "lose consciousness" for many hours each day:

- **energy conservation** - If sleep was just a form of rest, why would we not just lie down in a dark place, while staying vigilant to predation. The brain is actually buzzing through the night as much as in waking, so turning it off would not offer any extra advantage. Sleep is no hibernation.
- **repair and restoration** - If sleep was just to rebuild the body used up during the day, why does it not employ a simple metabolic reversal without a loss of consciousness? Many tissues can restore and repair in waking. Dedicated anabolic state is useful, but it could easily be enacted with the brain still on.
- **reactivation of infrequently used circuits** - If activation of infrequently used memories was necessary to prevent forgetting, evolution might have simply employed molecular mechanisms in which once synapses were potentiated, they would spontaneously build up synaptic strength in time without secondary activation. Naturally, this would abolish the valuable evolutionary mechanism of forgetting. Similarly, random **REM**

activation for the purpose of memory fixation would simply be wasteful. Forgetting plays a specific evolutionary function and the increase in synaptic strength should only result from a repeated exposure to a specific experience (for example, a repetition in [SuperMemo](#) serves the exactly this purpose)

- **recovery from slow-wave sleep** - REM sleep was postulated as a recovery stage from NREM sleep. If REM was just a recovery stage, why should it happen several times during the night? Would it not just better come at the arrival of zeitgebers indicating the end of the sleep period? Why would we enter NREM sleep in the first place? NREM and REM clearly play a complementary function, but the theory says little about the need to enter the unconscious state of sleep.
- **avoidance of predation** - Inactivity during sleep is supposed to minimize exposure to predators? However, why would we need turn off all the senses and extend reaction times to a near-useless degree? Moreover, carnivores tend to sleep far more than omnivores. This would hint that vigilance might be better than slumber in eluding the predator.
- **reversing oxidative stress damage** - How does a loss of consciousness help the process of cleaning up free radicals? Carnivores sleep more than omnivores? Slow and big elephants need 3 hours of sleep while fast-living tiny rats may sleep for 18. Not all sleep variables need to be an expression of its neural function.
- **Siegel theory** - Dr Jerome Siegel, a famous opponent of the link between sleep and memory, proposed his own theory of sleep: *"sleep is merely a good way to increase an animal's efficiency, by hunting only when the hunting is good, for example, and minimize its risk"* (Siegel 2009^[121]). A tiny subset of the complex sleep control machinery would be sufficient to meet Dr Siegel's proposed function of sleep. For example, it would be enough to keep the animal awake and paralyzed as in REM sleep. All the rest of sleep control would be a simple waste of time and resources. For more on this theory see: [Robert Vertes and Jerome Siegel](#)
- **corneal anoxia** - a theory says that REM sleep nourishes the corneas. Again, would not just waking up do the job if eyeball movement is all that is needed? If that function needs the anabolic state of sleep then it is only secondary to the main purpose of sleep. That eyes move in REM might simply be an expression of the fact that this is a movement that can do animal no harm. Possibly, eyes move just because their muscles do not need to be turned off.
- **promoting longevity** - sleep is vital for survival, as such it contributes to longevity indeed. However, so does the liver, and no one claims that the main function of liver is to promote longevity. Moreover, the evolutionary process does not optimize for longevity, but for the perpetuation of a gene pool.
- **thermoregulation** - some scientists believe that sleep serves thermoregulation while others attribute a large role for the body core temperature in generating sleep propensity. Dr Kurt Kräuchi summarizes his reasoning as follows: *"all thermoregulatory effects which lead to an increase in the core/shell ratio (e.g. a reduced shell by increased distal skin temperature) lead to increased sleepiness and, as a consequence, to increased sleep propensity. However, the sleepiness/sleep regulatory system feeds back onto the thermoregulatory system only indirectly via sleep-related behaviors (e.g. relaxation, lying down)"* (Kräuchi 2007^[122]). That theory speaks a lot about causality, but very little about the purpose. It flunks the shutdown test.
- **detoxification** - One of the fathers of sleep science, Romanian psychiatrist [Constantin von Economo](#) asserted that sleep was a detoxification process, in which the hypnotoxins were removed from the blood. However, some New Age authors who attempt to revive this view seem to commit a simple logical fallacy in which the brain shuts down for the purpose of preventing a hypnotoxic shutdown. The hypothesized function could well be done by the kidneys, the liver and other mechanisms that do not even come close to passing the shutdown test.
- **other theories**: other theories of sleep such as **psychoanalytical theories**, **Cayce theory**, etc. border on paranormal and pseudoscience. They all may carry a grain of truth (e.g. neural network optimization will indeed serve self-edification), however, listing them all goes well beyond the scope of this article.

Theories that pass the shutdown test

If we consider the current status of knowledge about the function of sleep, many of the older theories start making sense. They all seem to converge into a central theme and all carry lots of inspiration. Here are some of these:

- **Krueger and Obal theory**: the theory speaks of a natural propensity of neural networks to enter sleep states. However, the theory probably goes too far when calling sleep a network-emergent phenomenon that requires little or no central control (compare: [Why we fall asleep?](#)).
- **dreams create wisdom**: yes! Dreams are an expression of a process that serves reorganization of memories. As a result of dreaming, knowledge becomes more coherent, more abstract, more applicable, etc. In sleep, skills get honed and fine-tuned. This means that we are wiser and more skillful in the morning than before going to sleep!
- **garbage collection**: an early theory by Evans (1965), derived from computer [garbage collection](#) metaphor, says that sleep is needed to clean up the brain from useless memories. Indeed, there is a lot of evidence on synaptic weakening in sleep. Lots of garbage and chaos evaporates from the brain overnight.

- **reverse learning:** inspired by the ideas of Evans, reverse learning was proposed in 1983 in *Nature* by Crick and Mitchison. Reverse learning theory, a neural equivalent of garbage collection, says that dreams sift away memories that are not needed, irrelevant or incongruent. Born in 1916, Francis H.C. Crick together with James Watson unraveled the mystery of the DNA double-helix for which they were awarded a Nobel Prize in 1963. In 1983, Crick and his colleague from Salk Institute, Graeme Mitchison argued in *Nature* (Crick and Mitchison 1983^[123]) that human memory can get overloaded and REM sleep is used to run a **garbage collection** process on memories. They called this process *reverse learning*, and originally attributed it only one purpose: forgetting the unnecessary memory ballast. Crick named those ballast memories "*parasitic memories*", saying that "*REM sleep allows us to have a smaller brain for a greater purpose*". Crick's seminal 1983 article was taken further by many researchers who have ultimately concluded that REM sleep must serve optimization of memories expressed by synaptic weights of the neural network of the brain! If REM sleep was only to be used for forgetting the excess information, Crick's theories would run into the same evolutionary trouble as other theories listed above. After all, spontaneous loss of synaptic information with passing time would be a cheap solution that could be easily implemented metabolically. The value of the network optimization goes far beyond just forgetting.
- **consolidation of memory** - some researchers posited that memories get consolidated in REM sleep. What is the purpose of NREM then? How can this be that antidepressants do not damage learning even if they are strong REM suppressants? Why does the REM brain behave like a waking brain? The term **consolidation** is a bit ambiguous. It may refer to processes occurring at the molecular as well as at the neural levels. Only neural **consolidation** might require turning off the brain. In reference to procedural learning a distinction has been made between acquisition, **consolidation** (post acquisition) and enhancement (sleep dependent). Of these, only the enhancement would depend on sleep. For a number of procedural tasks, sleep-dependent enhancement has been demonstrated (Stickgold and Walker 2007^[124]). For more see: [Neural optimization in sleep](#)
- **psychotherapeutic theory** - The theory says that in sleep we dream up situations that would be emotionally difficult to confront in real life. This is supposed to help us learn how to react in emergencies without actually living through those emergencies. This interpretation is plausible due to the fact that it involves an actual need to turn off the consciousness. Moreover, when dream contents are analyzed it is indeed found to be dominated by threatening situations. The psychotherapeutic theory, however, should rather be considered a narrow interpretation of a larger and more encompassing function of sleep: optimization of the neural circuitry. In this case, known information is played back in various constellations to compile new behavioral strategies that might be useful for survival. As I try to argue throughout this article, creative and optimizing function of sleep is more general and needed also for other neural functions, not only those related to the threats encountered in waking life.
- **activation and synthesis theory** - Proposed by Hobson and McCarley in 1977 (Hobson and McCarley 1977^[125]), [Activation-Synthesis theory](#) says that during sleep there is a sensory inhibition (input attenuation), and, during REM, there is a motor inhibition (output inhibition). Pontine PGO waves characteristic of the REM sleep travel up to the cortex that tries to interpret that stimulation resulting in dreaming. Visual, auditory and motor areas of the cortex are active and responsible for whatever we experience in dreams. Activation-Synthesis theory inspired further research into the neural function of REM sleep.
- **AIM model** - the AIM model is a Hobson's improvement upon the activation-synthesis model that has dominated this field of research for two decades (Hobson et al. 2000^[89])([picture](#)). In the AIM model, brain states are described by 3 variables: (1) Activation, (2) Input source, and (3) Modulation. A healthy brain moves in selected trajectories in the AIM space. Various psychiatric and sleep disorders can be characterized as the departures from those trajectories. The model does not explain the function of sleep, but helps describe sleep in simple neurohormonal terms. For example, REM sleep is characterized by high activation, minimal sensory input, and cholinergic modulation.
- **brain development** - In brain development theories, dreaming is supposed to provide internal stimulation of brain circuitry to ensure growth and development. As babies dream far more than adults, this theory finds inspiration in the correlation between the degree of immaturity in infancy and the proportion of REM sleep in animals. Human babies are particularly limited in their ability to interact with their environment and dreaming is said to act as a substitute for the waking experience. REM-induced muscle atonia combined with the brain activation would enable brain growth by activating the synapses without the negative consequences of acting out. The role of REM sleep in developing the visual system has been demonstrated by Stryker (Stryker et al. 2001^[10]). REM deprivation results in developmental abnormalities later in life. Recently, the role of NREM sleep has also been confirmed.

Sleep as a neural optimizer

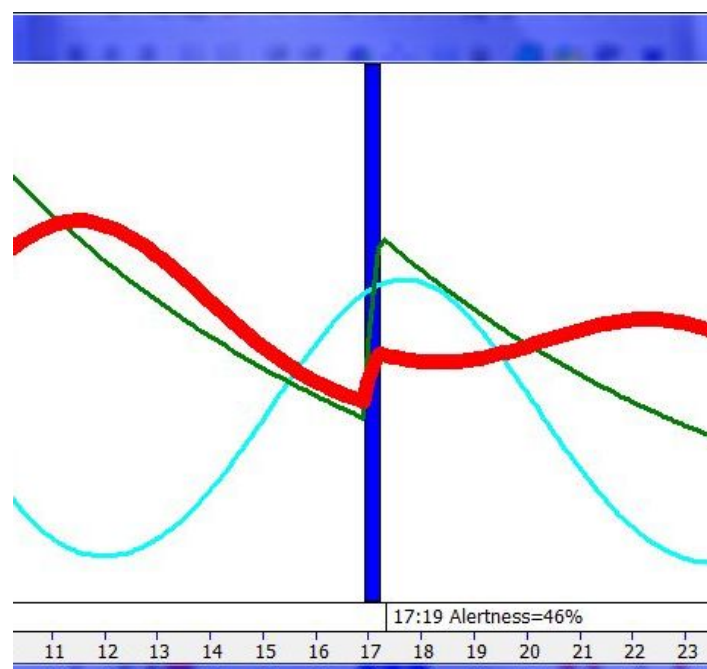
All the above theories that pass the shutdown test are compatible with what seems to be the chief function of sleep:

- **neural optimization** - A whole series of theories seems to indicate that sleep is a neural optimizer. Neural networks get rewired overnight. Memories move from a temporary low-capacity fast-encoding fast-association low-interference storage to areas where they can safely be used for months and years without much interference from newly encoded memories. Abstract patterns are extracted, while details obscuring the big picture are discarded. For more see: [Neural optimization in sleep](#).

Sleep and memory

NREM and memory

NREM sleep has magic powers! If you fall asleep for just a couple of minutes and manage to enter the deeper stages of sleep, you are likely to wake up with a brain that feels like brand new. Obviously, a short nap of that sort is only possible when it is properly timed and when awakening is natural. However, the impact of a short bout of **NREM** on learning is staggering. It takes many hours of heavy learning to make a brain homeostatically sleepy. It takes minutes of **NREM** sleep to take that sleepiness away.



Two-component model in SuperMemo shows how a 19 min. nap can nearly double the homeostatic component of alertness (green line). (for more details see: [Two-component model of sleep in SleepChart](#)). This theoretical model is backed by years of sleep and learning data.

This effect is so powerful that the whole myth of Uberman sleep was grounded on that foundation. Even a few minutes of sleep can provide sufficient refreshment for the brain to continue working for at least a few hours. Obviously, the power of **NREM** is only a fraction of the big picture. However, in this short section I would like to peek at what we know about the effects of **NREM** on memory.

NREM and hippocampal cleanup

The most convincing hypotheses on the function of **NREM** sleep picture it as a process in which the short-term novel memory stored in temporary storage (primarily the [hippocampus](#), [the entorhinal cortex](#), and the adjoining structures) is written down optimally into the vast networks of the cortical storage (Born and Marshall 2007^[126]). The **hippocampus** connects various areas of the brain to form quick memory associations. For example, when we learn a new French word, it might provide a link between the concept or its expression in English with the new French sound, text, or a set of syllables. That hippocampal memory switchboard is, naturally, limited in size. This is why it needs to be emptied periodically, so that the new connection between the English and French words could be laid down at slower and more complex cortical storage. The hypothesis says that this happens in **NREM** sleep, and it happens pretty fast. Scientists noticed long ago that during slow-wave sleep, hippocampal and neocortical networks tend to replay the firing patterns associated with novel experience (Wilson and McNaughton 1994^[127]). This led to the suspicion that the **hippocampus** might be rehearsing the cortex with the newly learned information, incl. the new French vocabulary. To understand how such training might be done, one needs to know more about the properties of neural networks and how they fire in synchrony with theta/gamma oscillations during explorative activity (e.g. learning) and SWP/200 Hz

ripple bursts during consummatory activity (deep sleep)(Buzsaki 1996^[128]). For more see: [Neural optimization in sleep](#).

NREM and declarative memory

Research into NREM sleep and memory is contradictory and does not fully align with the neat picture painted above. Everyone can see the power of sleep in SuperMemo, where even a short nap can bring [recall](#) and [consolidation](#) in learning back to the baseline. [Sleep spindles](#) associated with NREM sleep correlate well with the degree of feeling refreshed (Goetz et al. 1983^[129]). This says little about the function of the hippocampus, and inner working of the brain in sleep, let alone NREM sleep. However, Takashima noticed that the duration of naps correlates positively with later memory performance, and negatively with the activity in the [hippocampus](#) registered at retrieval (Takashima 2006^[130]). This might indicate that even a short nap can reduce the hippocampal memory load. Other researchers noted that after spatial learning, the amount of activity in the [hippocampus](#) in slow-wave sleep was proportional to overnight improvement in performance (Peigneux 2004^[131]). It has been observed in many experiments that slow-wave [sleep deprivation](#) affects declarative memories more than procedural memories (Plihal and Born 1997^[132]). Riding a bicycle is an example of a skill that requires procedural memory, while textbook knowledge is declarative in nature. In other words, cutting down on sleep before an exam effectively makes it harder to retain knowledge learned for the exam. This effect is particularly pronounced in the long term. This means that it is less pronounced on the exam day. This is why so many students keep making the same mistake over and over again. They get some more study time on the last night, at the cost of long-term retention of the learned knowledge. Obviously, extra study time has its benefits for the exam itself. Otherwise it is harmful for both health and wisdom.

Sharp wave bursts and long-term memory

In deep sleep, [SPW](#) bursts (sharp wave bursts) can be recorded in the [hippocampus](#). Some researchers believe that this may be the critical moment of memory [consolidation](#) in which the [hippocampus](#) works as the neural trainer for the neocortex in which long-term memories are stored in cross-cortical connections. During [SPW](#) bursts, the experience of the day will optimally be transferred to neocortical networks via neural training. This will be followed by the initiation of gene expression and protein synthesis. Both these processes are needed for modifying long-term synaptic weights. Protein synthesis makes up the beginning of memories that will last for months and years (if sustained by a repetition/review, e.g. with SuperMemo). For more details see: [Molecular correlates of the two-component model of long-term memory](#) (Wozniak et al. 1998^[133]). Those long-term memories cannot be formed without entering appropriate stages of the sleep cycle! You cannot build long-term memories without sleep. In addition, learning will be less efficient if it is cut short in the morning with an alarm clock.

Detecting memory optimization with interference tests

All research into declarative memories may be confounded by the neural optimization occurring in sleep. Sleep will often have a form of refactoring in which the same memories are stored differently. This way, it may not be possible to see the effect of memory change, but its internal representation will change. Such refactoring may not be detectable with behavioral tests or may be very difficult to test for. The same French word stored in working memory feels the same way as when stored in long-term storage. It does not seem to mutate overnight, and if it does, the changes are very hard to notice. Lack of sleep, however, will affect imperfectly stored memories more than those whose storage was optimized. Researchers found it hard to confirm the importance of sleep for declarative memories until they employed interference techniques to show how sleep prevents memories from being overwritten with new information (Ellenbogen et al. 2006^[134]). Using SuperMemo, it is possible to collect sleep data that would make similar long-term determinations possible. Due to the scarcity of data with unambiguous sleep restrictions, at the moment, we only know that memory [consolidation](#) gets progressively worse as the waking day goes on (see: [Memory consolidation](#)).

REM and memory

There are many theories on the functions of [REM](#) sleep. It has long been known that most dreams occur in [REM](#) sleep, yet some scientists see dreams and [REM](#) sleep as separate though temporally overlapping phenomena. It has been found in a number of experiments that [REM](#) sleep is important for learning, yet some scientists question those findings pointing to experimental errors or to the fact that antidepressants do not damage memory even though they are potent [REM](#) suppressants. Some scientists believe [REM](#) is needed to reinforce little used synaptic connections, others that it weakens or deletes little used memories, others that [REM](#) helps the brain recover from slow wave sleep, or simply prepare the networks for the state of waking (Klemm 2011^[135]). Still others believe that [REM](#) evolved just to

fine-tune bifocal vision, to prevent corneal anoxia (eye movement stirs aqueous humor), or even restore the hydraulic properties of intervertebral disks (Fryer 2009^[136]). Even a few advocates of the old psychoanalytical interpretation of dreams originated by Sigmund Freud can be sparsely found among scientific community. Some researchers believe that memory **consolidation** is possible during REM, others contest it, and yet others insist that REM has nothing to do with memory. On one hand, the percentage of REM sleep decreases with age which might indicate a correlation with the demand for learning. On the other, the percentage of REM during the night increases. Some researchers believe that if REM was to be involved in memory, it should rather begin quickly as we fall asleep. Others point to the fact that REM is phylogenetically younger and it is NREM that should play the most essential functions related to memory and learning. Historically, the importance of REM sleep for memory and learning was documented before we became truly aware of the role of slow-wave sleep. Consequently, articles and books on sleep are peppered with an overemphasis on the role of REM sleep in learning as compared with SWS. Over time, REM deprivation studies received lots of criticism. Today, we know that the natural harmonious interplay of uninterrupted NREM and REM sleep is essential for memory, learning and creativity (Salzarulo et al. 2000^[113]). For more on the theories of sleep, incl. the function of REM, see [Sleep theories](#).

REM and learning

It was 1953 when Eugene Aserinsky and Nathaniel Kleitman published their famous article that demonstrated that sleep is composed of periods in which rapid eye movements occur and which might be associated with dreaming (Aserinsky and Kleitman 1953^[137]). Little did they know how monumentally important that finding was. 60 years later, we know that REM and NREM sleep are two totally different brain states that are as different from each other as they are from the obviously different state of wakefulness. REM sleep shows a very different pattern of activity in various brain nuclei. It is characterized by a different direction of information flow. It is dominated by the release of a different set of neurotransmitters.

Carlyle Smith in 1991 showed how the administration of protein synthesis inhibitors during REM sleep windows in rats would prevent behavioral improvements that normally occur after sleep. This was a strong indication that REM sleep is important for memory ([not all scientists agree](#)). Moreover, an increase in procedural learning was accompanied by an increase in the density of REM, and the degree of that increase was proportional to the learning capacity of an individual (Smith et al. 2004^[86]). The function of REM sleep is different than that of NREM sleep. Some researchers believe that REM may be more important for procedural memory (with declarative memories impaired more with loss of NREM sleep). However, the separation between declarative and procedural learning is more likely to be anatomical (e.g. the cerebellum vs. the hippocampus). It is important to note that fish, as an example, do not show any hallmarks of REM sleep and they definitely do lots of procedural learning after hatching (and probably also even before hatching).

REM deprivation diminishes the effects of learning in proportion to the complexity of the task. Some simple tasks do not seem to be affected (e.g. passive avoidance, simple maze, etc.). However, REM sleep deprivation affects more complex tasks (e.g. operant conditioning, probabilistic learning, complex maze, etc.) (see "[Sleeping brain, learning brain. The role of sleep for memory systems](#)" (Peigneux et al. 2001^[138]) for review).

In the animal world, the rule of the thumb is that the more immature the newborn at birth, the greater the proportion of REM sleep in the first months. Human newborns are particularly immature in terms of the development of their central nervous system. This is why REM is very important for brain development in babies. REM deprivation in the neonatal period can result in a decreased brain mass, and various developmental and behavioral problems. As all forms of stress affect sleep structure, babies are particularly vulnerable to all forms of sleep disruption and the resulting negative effect on brain development (Peirano and Algarín 2007^[139]). Leaving a baby alone in a cot to **cry it out** is a form of stress that will have long-term detrimental effects on the brain. Instead of a REM-first pattern that characterizes newborns, baby naps in conditions of stress can be REM-poor. Absence of the mother is a cause of stress in babies. For that reason, I advocate [sleeping and feeding on demand, as well as co-sleeping for babies](#).

Some of my **SleepChart** data seems to tentatively suggest that REM sleep might also affect simple declarative memory (as in learning with SuperMemo). It is not possible to log REM sleep in **SleepChart** to know for sure, however, delayed sleep as well as sleep interrupted by an alarm clock are likely to be both REM poor. I do not know (yet) how a REM-poor night affects the learning that occurred before sleep. However, a REM poor night definitely reduces learning performance on the day after. In case of an alarm clock disruption, it is hard to say what is actually causing a decline in performance. However, with delayed sleep, the only conceivable alternative explanation is a lesser natural sleep total. I tend to believe that it is rather the scarcity of REM that causes the worse performance. This is because there are subsets of natural short nights that actually lead to excellent learning results.

As **NREM** and **REM** are two totally different brain states, what separates roles do they play? In the light of recent findings on the [role of NREM sleep in learning](#), what could possibly be the role of REM, which bears no resemblance to **NREM** except for the outside appearance of being in the state of rest? One big clue comes from the fact that **NREM** and **REM** states keep flipping between each other overnight. Bouts of **REM** increase the demand for **NREM** and vice versa. The two stages of sleep show all the hallmarks of the complementary processes that abound in biological control systems. They behave in a flip-flop manner like waking and sleep, they counteract like synthetic and catabolic metabolic pathways, and they compensate. They act like the atria and the ventricles in pumping the blood. This hints at complementary functions, and the plethora of research findings seems to indicate that those functions revolve around learning and memory.

REM as a form of neural training

One of the hypotheses says that **REM** sleep is a form of training for the brain. While normal waking activities train the **hippocampus** with new patterns of activity, **REM** sleep does the same, only by using imaginary randomized hypothetical patterns. It is as if the brain did not get enough in waking, it needed more special training in sleep. The extra training would be beneficial for it would cost little (no need to expend behavioral energy). It would capitalize on the information already stored in the brain. For example, in **REM** sleep, the brain might generate a hypothetical situation in which we make a simple but costly mistake in our lives. The brain would then re-enact the hypothetical situation and look for possible scenarios with possible beneficial conclusions. Perhaps we will wake up in sweat on the realization of the cost of the damage and take necessary steps. Frequently enough, the solution will be absurd, which should probably be interpreted as that we should not read too much into dreams. Scientists noticed that some networks replay their waking patterns of activity in REM, and still these are not simple re-enactments of episodic memories of the day, which only serve as a sparse inspiration for dreams.

As much as it is easier to program a computer than make it learn from real life situations, it is easier and faster to load the **hippocampus** and other structures with new memories in **REM** sleep. After each load of new associations, the brain needs to redistribute the information in its long-term cortical storage. That is the [function of NREM sleep as described earlier](#). After many hours of waking, we need over an hour of **NREM** sleep. However, only a few minutes of **REM** seem to swing the balance back to favor **NREM**. The cycle keeps repeating.

REM and creativity

As the night progresses, there is more **REM** and less **NREM**. If the "REM training" hypothesis was correct, it might mean that it is harder to generate new information as the night progresses. It might also mean that each **NREM** bout is incomplete and the remnants of unprocessed information keep blocking full swing **REM** until the very early morning hours. Perhaps the circadian **REM** propensity provides for a balance between the storage of old and the synthesis of new information with a gradual shift to favor the latter in later stages of sleep? If all the above scenario was to be true, we might wonder why the brain does not tend to wake up with a clean slate by terminating sleep with the last final **NREM** episode? Perhaps the transition to waking is all that is needed to clean up the remnants of newly "discovered" information lingering in the working memory? Or the new loads produced by the last bout of **REM** might have some special survival value? These could be the building blocks for that creative morning insight that the history of science is so rich in. It is possible that it is the very last segment of sleep that ends with **REM** sleep that provides the morning brain with that next big idea. Some evidence supporting this notion was gathered by Walker when researching performance in anagram puzzles in subject woken at different stages of sleep (Walker et al. 2002^[140]). If the reasoning about the creative contribution of the last **REM** episode is correct, we could arrive at a dramatic conclusion that **the alarm clock might be the primary killer of big ideas in the modern world!** Stress or rat race are guilty of undermining human creativity too, but it is easier to keep stress in check to get good sleep than to produce great ideas in a stressless world without sufficient sleep. Researchers and educators should be very cautious when diminishing the damage inflicted by alarm clocks (see: [Jim Horne and Daniel Kripke](#)). Parents should also show more tolerance for kids who cannot wake up for school (see: [Sleep and school](#)).

REM as a neural optimizer

If **REM** sleep was just a training or creative option in sleep, why would we run [REM deficits](#)? Circadian **REM** propensity might provide for a balance between **NREM** and **REM**. Homeostatic **NREM** pressure might result from learning (in waking or in REM). However, the **homeostatic REM** sleep propensity, and **REM** sleep rebounds after **REM** deprivation both seem to indicate that **REM** is far more than just an option. The intricate impact of **REM** deprivation on complex tasks and procedural memory may be an expression of the more important function of **REM** sleep in which [neural optimization](#) is based on the reversal of the direction of the flow of information in the brain as compared with **NREM** sleep. It is possible that **NREM** merely serves as the long-term memory storage tool without much ability to optimize

the network layout. **NREM** might simply be an anti-interference tool. However, sleep helps organize memories, increase their abstractness, and reduce the cost of storage. Perhaps that optimizing role rests solely with **REM** sleep. Perhaps a pseudopattern training makes it possible to relocate wide-network expensive memories into a smaller more generalized circuits (see: [Neural optimization in sleep](#)). A big clue comes from baby sleep. As newborn's ability to explore its world is limited, the exploratory function of **REM** sleep might play an essential role in development. However, [Dr Siegel](#) noticed that the time spent in **REM** in humans does not correlate well with their learning abilities. I believe that such inconsistencies are well explained by individual differences that not only express themselves in the learning ability, or the average amount of **REM** per night, but also in the efficiency of **REM** (i.e. learning-to-REM ratio). This is analogous to, for example, our digestive abilities. Some people can gorge themselves on food and let it all go out. Others eat very little and are still able to extract all the nutrients down to the last milligram (and bloat). If we look further at various species, we will see even a lesser link between the amount of **REM** and "animal IQ". This could be explained that smart animals will extract far more value from **REM** sleep. In other words, no amount of optimization can do wonders in a small capacity network. Even more troubling might be the claim that it is hard to detect any **REM** in [cetaceans](#), esp. infants (Castellini 2002^[141]). If **REM** was as essential for procedural learning as depicted in this chapter, it would seem indispensable in young intelligent predatory swimmers. Obviously, as a relatively new evolutionary entity, REM-based neural optimization might have its variants with different phenomenology that might not be instantly apparent to researchers. Moreover, cetacean sleep featuring the miracle of [unihemispheric slow-wave sleep](#) had over 50 million years to develop characteristics that would set it apart from **REM** sleep in humans. That's a significant proportion of **REM** sleep's existence.

Synaptic changes in sleep

Some research shows that synapses get strengthened in sleep while other research finds the opposite effect. Overall synaptic strength tends to increase in waking^[142], while the learning capacity keeps declining. Wakefulness increases cortical firing frequency in all behavioral states (Tononi et al. 2009^[143]). The simultaneous weakening and strengthening of selected synapses in sleep could best be explained by some kind of memory reshuffling taking place overnight. This does not contradict the memory **consolidation** function of sleep. This also does not stand in contradiction with the fact that our learning ability tends to decline during the waking day.

When investigating the changes in synaptic strength in sleep, we always need to differentiate between:

1. **short-term memory**: short-term increase in synaptic conductivity that is a result of a day's learning
2. **long-term memory**: the ability to **recall** older memories (e.g. as [measured with SuperMemo](#))

To put it metaphorically, the brain is like a computer that keeps loading chunks of data to its memory during the day (short-term memory). As the memory fills up, the computer slows down, and all applications crawl into a halt. However, if you test individual memory cells, you will notice that they strongly cling to their new data. In the night, the computer will gradually organize these chunks of data, remove discrepancies and duplicates, write down memories to the hard disk (long-term memory), and run a defragmentation process for easy and fast access. We need to look at neurophysiological correlates of that metaphor, and for the most likely explanation for the weakening of the **recall** during the waking period as both the increase in synaptic conductivity in wakefulness, and the decline of learning capacity during the day are well documented. The most coherent, attractive and best-supported hypothesis says that the overload of short-term low-interference networks is responsible for a declining capacity of memory during a waking day (see: [NREM and memory](#)). This decline cripples the working memory, and in consequence, it affects the entire spectrum of human cognitive capabilities. The main function of sleep would then be to redistribute, reconsolidate, and optimize those short-term memories that slow down further learning.

As for the decline in synaptic strengths during sleep, it also fits well into the present models of sleep and learning. One of the main functions of sleep should be to optimize the memory storage. This entails representing memories in the most efficient way, so that they are most abstract, consume least space, generate minimum interference, and so on. That process should indeed result in reducing the overall cost of memories, and result in weakening of redundant synaptic connections.

Dr Tononi believes that waking activity produces an overall increase in synaptic weights, and sleep may be necessary to counterbalance that increase. The hypothesized downscaling would occur in slow-wave sleep (Tononi and Cirelli 2006^[144]). Dr Tononi clusters disparate components of the memory hierarchy from short-term (phosphorylation), to long-term (AMPA trafficking) to remoulding (sprouting), while I would rather stake my bets on daily learning and short-term memories. Overall cortical downscaling could be a beautiful expression of the post-learning clean-up congruent with the [ideas of Crick and Mitchison](#). The clean-up could be combined with selective synaptic strengthening governed by short-term memory structures (e.g. the hippocampus, the amygdala, etc.).

Let us consider a famous Halle Berry neuron, i.e. a hippocampal neuron that might respond selectively to all-things Halle Berry after an exposure to Halle Berry pictures in a training session. All cortical neurons potentiated during the training would best be silenced in the course of the SWS with the exception of sparsely encoded Halle Berry representation refactored from the hippocampal association, incl. the HB neuron, to a cortical shortcut. This process would free hippocampal learning capacity, produce an overall downscaling, and still retain sparsely encoded pieces of newly learned information.

You may know that **SuperMemo** is based on the claim that memories get weakened overtime in a molecularly programmed manner. That weakening does not refer to the loss of short-term memories in sleep, but to a long-term decline in memories over months and years. Dr Tononi proposed a variant of the theory of forgetting by suggesting that synaptic downscaling in sleep is done in proportion to the existing synaptic strengths. This way the weakest synapses would lose their memory trace. Tononi's proposition may find it difficult to pass the [shutdown test](#) unless it shows how the downscaling process requires a network-wide computational operations as opposed to a simpler "molecular forgetting clock" as described in [Molecular correlates of the two-component model of long-term memory](#) (Wozniak et al. 1998^[133]). However, it is important to note that Tononi often speaks of short-term memory traces registered on the day preceding sleep, not of what, using the two-component model of memory terminology, we call **memory retrievability**, which tends to decline exponentially between reviews of the learned material (Wozniak et al. 1995^[5]). Tononi found that the activated portions of the brain show most slow wave activity in the following night. Both in declarative and procedural learning, increases in cortical SWA are locally specific and proportional to the degree of learning and overnight improvements (Tononi et al. 2004^[145]). Tononi explains those findings with an idea that downscaling affects mostly those portions of the brain that are subject to most change. However, another possible explanation is that those portions of the brain get reactivated in sleep as a result of short-term storage changes in the **hippocampus** to reflect the experience of the day. The **hippocampus** would represent a short-term memory network used in the training of cortical circuits. Instead of getting weakened though, selected synapses might actually get strengthened while reduced propagation of the stimuli in the cortex (as documented by Massimini (Tononi et al. 2005^[146])) could be explained by the need to lay out memories without the following creative and associative propagation of stimuli that might activate more synapses. Overall downscaling would affect all newly potentiated synapses that would not be subject the hippocampal reinforcement.

For an excellent take on the mechanics of sleep see [Dr Tononi's lecture at 2011 Allen Institute for Brain Science Symposium](#).

Ribeiro and Nicolelis believe that experience-dependent plasticity-related gene expression in **REM** is compatible with Tononi's synaptic downscaling. However, downscaling should affect only the circuits that have not been activated by the waking experience. In other words, upscaling would affect activated circuits, while downscaling would affect inactive circuits. This would increase the signal-to-noise ratio (SNR) in memory **consolidation** in sleep (Ribeiro and Nicolelis 2004^[147]). Dr Walker believes that both the upscaling and downscaling processes might take place in sleep in a complementary manner: *"homeostatic synaptic downscaling could result in the removal of superfluous neural connections, resulting in improved SNR. However, neural reactivation and strengthening of experience-dependent circuits, done without removing redundant synaptic connects, may equally improve SNR. Therefore, both mechanisms, while different, could produce a similar outcome: enhanced fidelity of the memory representation"* (Walker 2009^[148]).

This author believes that this process might be even more general in nature and involve long-term memories that would serve as a structural blueprint for newly optimized fabric of memories collected in short-term memory. This means that upscaling would also involve new neurons in the neocortex that have not been activated by experience. This belief comes from the simple need to recruit new cortical synapses for long-term memories that would become consolidated in an experience-dependent manner over months and years using a simple molecular mechanism that would not be sleep dependent. In other words, recruitment of new cortical synapses would largely be sleep dependent, downscaling would be associated with the post-learning clean-up, while the build-up of memory stability would be a process dependent on reactivation in waking and/or in sleep over the lifetime of a memory trace (Wozniak et al. 1995^[5]).

Neural optimization in sleep

After a day of hard work over a problem, if frustration sets, and the problem seems unsolvable, or exceedingly complex, our working memory may feel like clogged up with pieces of information that do not fall into a coherent structure in which the solution might be found. However, after a night of refreshing sleep, we may suddenly hit upon an idea! This is a not necessarily a result of fresh mind and more morning thinking. Very often, the idea is already there upon awakening. As if the brain worked hard over night without our conscious participation. The process responsible for this magic insight is neural optimization.

Even though the list of biological functions associated with sleep is very long, **sleep has evolved for one primary purpose: optimization of memories stored in the neural networks of the brain.** This function is so essential that no complex nervous system can survive without it. This is why all complex animals sleep (which is not always easy to tell (Siegel 2008^[149]). Even ants take naps.

The size of the cortex is fixed. This means that there are anatomical and functional limitations on how much information can be stored there. Don't believe mnemonic gurus who tell you "*we can remember everything*", all we need is a "*way to access hidden memories*". To maintain the ability to form new memories, the cortex must continually rework its representations in order to ensure that only the most salient memories are stored for long-term use. The belief that sleep is helpful in that process is as old as our understanding of the fact that the brain is involved in thinking and in memory. [There are researchers though who still find it difficult to reconcile learning with unconscious states.](#)

Hippocampal lesions

In 1953, [Henry Gustav Molaison](#) (aka H.M.) had portions of his medial temporal lobe removed bilaterally. After the surgery, H.M. lost his ability to form new long-term memories while retaining his pre-1953 memories, procedural learning and cortically-based working memory capacity. This led researchers to discovering the pivotal role of the **hippocampus** in the learning circuits of the human brain. The **hippocampus** receives rich connections from nearly all areas of the cortex, and it feeds back to targets in the same cortical areas. This means that its dense network of connections can maintain a snapshot of the current activation pattern in the cortex. It can also project the same pattern back to the cortex. Once memories are formed, they depend on the **hippocampus** for a period of days. This suggested that the memories might need to be relocated back to various areas of the neocortex at later time. As **sleep deprivation** affects this process, it has been suggested early that sleep might be playing a role in the process. Other richly connected areas of the brain play a similar role for various forms of specialized memories. The purpose of "memory transfer" became clear gradually over many years with contributions coming from various researchers coming from various fields.

Hippocampal lesions provide a very strong clue to the idea that the conversion of short-term to long-term memories is computational, and not just molecular/synaptic in nature. It also hints that the nature and the layout of memories will differ upon the conversion.

Temporally graded retrograde amnesia

When there is an injury to the hippocampus, in addition to the inability to form new memories (anterograde amnesia), there is also a degree of loss to previously formed memories (retrograde amnesia). As early as in 1881, [Théodule Ribot](#) suggested that recent memories are more likely to be lost in retrograde amnesia ([Ribot's law](#)). Loss of memories proportional to their recency was termed the *temporally graded retrograde amnesia*. There have been many hypotheses for explaining this phenomenon, some of which, wrongly implicate the **hippocampus** in the process of prolonged storage of some of those memories, which are supposedly being gradually consolidated into the long-term storage. Other interpretations speak of a gradual physical transfer of memories in the network (e.g. one integrating neural cell layer after another), in the process that may last years. To anyone familiar with the two-component model of long-term memory (Wozniak 1995^[5]), it is pretty obvious that the involvement of the lesions to the **hippocampus** in the temporally graded retrograde amnesia does not need to imply the involvement of this structure in storing memories in the long term. It could equally well be explained by the hippocampal involvement in the reconsolidation process that serves the build-up of memory stability. The **hippocampus** does not need to slowly consolidate memories stored in its connections. It is enough that it is involved in re-activation of those memories through review in the same way as it is done in the original establishment of cortical connections. This way, in retrograde amnesia, memories with lower stability will be lost in the first order. A simple way to verify this fact would be to track the course of the amnesia over years (e.g. with SuperMemo). If the **hippocampus** is necessary for the buildup of memory stability, the degree of amnesia should progressively get worse as implied by the natural process of forgetting. Possibly, the forgetting would not be as fast as it is the case in a healthy brain due to the lack of interference from new memories.

If the above interpretation of temporally graded retrograde amnesia is correct, it will provide a further clue as to the role of the **hippocampus** in establishing new memories and building memory stability over time. This would strengthen the concept of the **hippocampus** serving as the primary gateway for declarative memories stored in the cortex, and re-emphasize the computational aspect of this process.

Memory processing in sleep

In 1963, Sokolev suggested that the primary power of the brain rested in its ability to build a model of the surrounding world. However, it has always been hard to figure out how a chaos of data that arrives at sensory inputs gets reshaped into the magic world of abstract shapes and models of the human mind. In 1970, Marr suggested that memory **consolidation** in sleep might be an inductive process of sorting experiences into categories. This process would be based on statistical sampling of the environment. Marr proposed that the **hippocampus** stores experiences acquired during the day, and replays them back to the neocortex overnight. That replay would be the time when the category formation would occur. In 1979, Wickelgren suggested that the **hippocampus** is needed to assign cortical representations to novel conjunctions of inputs. The neocortex can then treat these conjunctions separately (e.g. like new items in SuperMemo). In 1992, French noticed that humans rarely forget "catastrophically". To explain this, he suggested that to prevent catastrophic forgetting, it was necessary for the neural networks of the brain to separate their internal representations during learning.

Catastrophic forgetting

In 1995, inspired by Squire's work on amnesia and his hypotheses on the involvement of the medial temporal cortex in memory **consolidation** (Squire et al. 1984^[150]), McClelland, McNaughton, and O'Reilly capitalized on earlier theories and proposed that the brain copes with the problem of **catastrophic forgetting** by evolving two separate memory systems to separate novel representations from established memories: a **dual network** system. They gave their theory a computational framework. In the proposed complementary encoding mode, the **hippocampus** and the neocortex play the role of the **dual network** system. Using neural network simulations, the researchers showed their own interpretation of how temporally graded retrograde amnesia could proceed (still implicating the hippocampus as a possible long-term storage)(McClelland et al. 1995^[151]).

In 2001, French et al. suggested how pseudopatterns could serve as a way of transferring information between neural nets (French et al. 2001^[152]) (shortened): *"A neural network has learned a number of input-output patterns corresponding to some underlying function f . How can we get an approximation of the original function f ? One solution: send random input into the network and observe the output for. We thus create a series of pseudopatterns, ψ_i , where each pattern ψ_i is defined by a random input and the output of the network after that input has been sent through it. Pseudopatterns were first introduced by Robins to overcome catastrophic interference. Robins suggested that when a network had to learn a new pattern, a number of pseudopatterns be generated. Then, instead of learning just the new pattern, P , the network would be trained on the new pattern plus the set of pseudopatterns that reflected what it had previously learned. In this way, the new pattern would be interleaved with patterns that, even though they were not the originally learned patterns, nonetheless reflected the original function learned. Robins showed that his technique did, indeed, reduce catastrophic interference"*.

Two-stage memory processing in sleep

It might seem an attractive and plausible proposition to envisage the **hippocampus** as a device for taking snapshot of the cortical activation status. Those snapshots could be taken in **NREM** and played back to the neocortex in the **REM** training mode. Some neuronal firing experiments seemed to even indicate such a possible sequence. However, Dr Georgi Buzsáki concluded that the process is actually reverse in nature. Again the sequence of neuronal firing measured experimentally was important to come to his conclusion.

In 1989, Pavlides and Winson demonstrated that hippocampal neurons active during a learning episode are more active during subsequent sleep (Pavlides and Winson 1989^[153]). In the same year, Buzsáki suggested that hippocampal sharp wave bursts (abundant in deep sleep) may represent a mechanism for the **consolidation** of representations in intra and extrahippocampal circuits and for memory transfer from the **hippocampus** to the neocortex (Buzsáki 1989^[4]). Buzsáki ideas led to a belief that **SPW** result in reactivation of cell assemblies which were earlier potentiated by exploratory activity (experience or **REM** sleep).

A student of Alexander Luria, and Sokolev's disciple, Olga Vinogradova, in her last publication, which was accepted a week before her death at the age of 72, summarized her 35 years of work over the hippocampal function in "Hippocampus as Comparator: Role of the Two Input and Two Output Systems of the **Hippocampus** in Selection and Registration of Information", which paints the **hippocampus** as the primary novelty detector with far reaching implications for its role in memory optimization (Vinogradova 2001^[154]).

Buzsáki, however, proposed a model in which the **entorhinal cortex** is the comparator (Buzsáki, unpublished, 2000). He hypothesized that the entorhinal cortex would help detect novelty in the system as follows: *"The EC functions as a "comparator" and evaluates the difference between neocortical representations and the feedback information conveyed by the **hippocampus** (the reconstructed input). The resulting difference or "error" is regarded as "novelty" and it is this novel*

information which initiates plastic changes in the hippocampal networks (error compensation). Alteration of synaptic connectivity in the hippocampus, in turn, gives rise to a new hippocampal output. In this process, the **hippocampus** generates separated (independent) outputs, i.e., it minimizes mutual information between its outputs. The output of the hippocampus, in turn, trains the long-term memory traces to minimize mutual information transfer amongst them. After long-term memories are trained properly, the hippocampal output will no longer affect synaptic weights in the EC. This feature is expressed by the auto-associative nature of the model: the **hippocampus** provides the reconstructed input (the auto-association) and the difference between the input and the reconstructed input drives the training of long-term memories. Because only the reconstruction error enters the hippocampus, a relatively limited computational network is sufficient for training long-term memories in the EC/neocortex".

According to Buzsáki, the memory optimization may be executed with the mediation of the **hippocampus** that would work in

1. explorative mode during the **REM** sleep (in which neocortical information is used to train hippocampal circuitry), and
2. in consummatory/sleep mode during the **NREM** sleep (in which the hippocampus is used to train neocortical circuits).

The network optimization hypothesis would explain why it is hard to detect rote learning deterioration in **sleep deprivation**. NREM/REM interplay defined as above should have less bearing on the output generated by the same inputs in reference to low-level associations (such as stimulus pairing). To detect the damage induced by **sleep deprivation** more complex tests should be used. Indeed some research by Dr Carlyle Smith has already been able to show the difference in the impact of **REM sleep deprivation** (REMD) on paired associate learning (which suffers little damage in REMD) and complex logic tasks which are most affected by **REM sleep deprivation** (Smith 1993^[155]).

Buzsáki model is based on the changes in the direction of the flow of information in the brain during **NREM** and **REM** stages of sleep. The control of that flow is probably partly systemic/neural and partly neurohormonal. Anticholinergic drugs such as scopolamine can produce a delirious waking state with hallucinations, anxiety, and confabulations (Perry and Perry 1995^[156]). The [AIM model describes various brain states that pivot around the modulation axis and its cholinergic dimension, which is central to memory optimization in sleep](#) (Hobson et al. 2000^[89]). Cholinergic modulation in **REM** and wakefulness could help load the hippocampal circuits with new memories while aminergic dominance would reverse the flow to enhance the encoding of memories in the neocortex while inhibiting hippocampal encoding (Hasselmo 1999^[157]).

Optimizing memories

We can now conclude that, in sleep, memories move from a temporary low-capacity fast-encoding high-associativity low-interference storage to areas where, on the basis of their novelty and applicability, they can safely be used for months and years without much interference from newly arriving memory data at little cost. Abstract patterns are extracted, while details obscuring the big picture are discarded. Rewiring of the network might bring some of the following advantages:

- converting poorly associative memories into highly associative memories (the origin of the ancient phrase: *let me consult my pillow*)
- eliminating knowledge interference to help avoid confusion between similar concepts
- extracting common properties of objects and building models (pictorially: instead of holding 100 pictures of someone's face and searching on each encounter, recognize all common model characteristics and execute recognition in milliseconds)
- optimizing procedural reflexes (some researchers even proposed that **REM** is mostly targeted on consolidation of procedural skills which seem to suffer most from **REM** deprivation, while **NREM** sleep would serve only the consolidation of declarative skills)
- transferring memories from overloaded circuits (e.g. the hippocampus) to spacious areas of the neocortex

Garbage collection

Network optimization is not only a process that ensures long-term usability of memories, but also a vital cleanup mechanism that makes sure working memory storage is unaffected by the pile up of data. We can see a correlation between the activity in prefrontal cortex and the degree of sleepiness in memory tasks. In line with the **dual network** theory, once the short-term memory storage starts filling up, a compensatory mechanism is involved and the cortex may temporarily be used to assist in memory tasks. Giulio Tononi of the University of Wisconsin proposes that the network overload simply makes the brain more and more expensive to maintain (see: [Synaptic changes in sleep](#)). This

is why the sleep is needed to do synaptic downscaling. Those downscaling ideas threw some confusion into sleep research. Some findings indicate that synaptic connections get strengthened in sleep, while other researchers noticed the opposite effect. If sleep was to be a neural optimizer, we should expect some connection to get weakened while others would get stronger. Marcello Massimini (Tononi et al. 2005^[146]) used TMS to see how activation in one area of the cortex got transmitted to other areas of the brain in waking and in sleep. He noticed that in NREM sleep, the initial response was very strong, but would get quickly extinguished and did not propagate far beyond the site of stimulation. In line with [Evans or Crick theories](#), Massimini noticed a weakening of synaptic connections in sleep. This could agree with the overall downscaling process observations of Tononi, however, the picture could be confused by the effects of neuromodulation that changes the modes in which the networks operate in sleep. Videos of the signal propagation in waking and sleeping brain can be seen [here](#).

While Tononi and Massimini hypothesized on the synaptic downscaling in sleep, other scientists theorized and showed experimentally that slow-wave sleep can also enhance synaptic connections (Lee and Wilson 2002^[158]; Sejnowski and Destexhe 2000^[159]; Steriade and Timofeev 2003^[160]). Sleep deprivation leads to a higher cortical activation, and increases the number of areas active when solving complex tasks (Drummond et al. 2000^[161]). Tononi interprets those results as an effect of an overall increase in synaptic weights in the course of waking. Increased weights result in higher overall activation. However, the shifting patterns of activation (e.g. from temporal to parietal lobes) might suggest that the cause is a bit different. It seems like the brain recruits new areas of the cortex to compensate for overloaded networks that cannot keep up with the extra encoding and processing. This observation is essential in figuring out to what degree the sleep process is a network-emergent phenomenon as suggested by hypotheses by [Krueger](#) and [Tononi](#), and to what degree it requires central control to fulfill its computational role in NREM-REM sequence interplay.

Unihemispheric sleep

An interesting question arises in the case of dolphins and birds that developed unihemispheric sleep. That form of sleep should be suboptimal for storage optimization. It could be compared to disk defragmentation in which only half of the disk space is available for disk housekeeping. Such a process could be highly beneficial, and yet to approach an optimum full-storage optimization it would require an exponentially more time for each increment in quality measurement. Most importantly, we could expect more hemispheric specialization and less inter-hemispheric communication. Obviously, unihemispheric sleep would be precious as a temporary measure in conditions of danger, migration, etc.

If the evolutionary step towards unihemispheric sleep seems complex, one only needs to note that cats with severed [corpus callosum](#) were able to sleep with one hemisphere in NREM sleep and the other hemisphere in the state of waking. In other words, blocking the inter-hemispheric communication may be all that is needed to produce hemispheric asynchrony. On a lighter note, efforts of polyphasic sleepers might actually bring a similar adaptation in humans. It would probably take thousands of years and many evolutionary casualties before polyphasic sleepers would finally "adapt" and be able to sleep unihemispherically.

Problem solving in sleep

Inspired by the concept of neural optimization in sleep, years ago, I developed my own formula for problem solving, which works for me each time I need a solution to a complex task marred by excess contradictory information. Sleep makes a half of the solution! This is my formula:

1. **get good sleep:** sleeping in the right phase and without any artificial control is vital! (see [Free running sleep](#))
2. **think** about the problem: how can I solve it? what information can help solve it? This step requires 100% isolation from the outside world. It works great in nature or when just pacing a room up and down.
3. **read** about the problem until my brain sizzles. With [incremental reading](#), it can really take an hour or two to load the working memory up to its capacity, and push the brain to exhaustion. Again, this step requires minimum interruption to ensure 100% focus on the problem. Not a single brain cell should be absorbed with the conflicts of the world. All resources must go into problem solving.
4. **exercise:** to stimulate circulation, to provide time for lazy unstructured thinking, and to fill the time before the next opportune sleep episode, I exercise. I know many people who solve problems successfully without ever exercising. So this might be just my personal optional favorite. I think it is important to keep the brain pure in its focus on the problem. I "pollute" the mind with irrelevant information only in cases of a major lockup, or mental block, where the solution to the problem is particularly elusive.
5. go back to Step 1, only to discover that the previous round pushed my thinking by a country mile, and that sleep portion was essential for being able to see the big picture. Napping is great as it counts as much in the cycle as

night-time sleep does. Pity we have been designed to [nap only once per day](#). Perhaps multiple napping would provide for more creative steps forward per day ([if it was feasible](#)).

For difficult problems, time is an ally! The more think-learn-sleep cycles you can run, the closer you can get to the target. Keeping the mind pure is vital, but taking occasional breaks for unrelated information processing can unclog prejudiced pathways in the brain.

Conclusions

During the exploratory activity in waking, the associative networks of the brain (incl. the hippocampus) integrate information from various portions of the cortex with new information coming from various highly-processed sensory inputs. Cortical processing is responsible for the working memory and thinking, while the associative networks hold patterns of recent activity. During waking, cortical networks get overloaded with potentiated connections, while the **hippocampus** gets overloaded with new associative patterns. In **NREM** sleep, cortical processing is inhibited, the cortex is globally depotentiated and hippocampal patterns are used to integrate newly acquired information with previously stored cortical long-term memories. **REM** sleep is used to train the hippocampal network with new patterns garnered from the cortex in a process that can be likened to a "simulated waking". Those new patterns are then transferred back to the neocortex in the successive **NREM** episode. NREM-REM interplay is used to remould knowledge away from detail-rich patterns towards generalized patterns. This interplay, which repeats several times in the course of the night, is what makes us smart. This interplay helps us use little information for maximum effect. Frequently used patterns get reinforced in the cortex by gradually building their synaptic stability, while the synaptic retrievability spontaneously decays in a negatively exponential manner to maximize the utility of memories and minimize the cost of storage (Wozniak 1995^[5]).

Not all scientists agree

[November 2, 2001 issue of Science](#) included opposing articles on the physiology of sleep that provided more fuel to the fire of a scholastic dispute on the function of sleep. At the time when the effort to disentangle details of complex neural optimization process called sleep seemed close to bringing major breakthroughs, there were reputable researchers throwing a spanner in the works. Prominent narcolepsy expert, Dr Jerome M. Siegel from the Center for Sleep Research of the Department of Veterans Affairs analyzed the evidence for the role of sleep and figured out that... the evidence is scant! An array of well-organized evidence against the role of sleep in memory **consolidation** was rolled out in a journal that for years has stood as the bastion of highest quality science (Siegel 2001^[162]). Siegel acknowledged the vital evolutionary function of sleep but, at that time, did not present a viable alternatives to the position taken by Stickgold, Hobson and Maquet in the same issue of Science (Stickgold et al. 2001^[163], Maquet 2001^[164]).

In his later publications, Siegel proposed his own theory of sleep saying: "*sleep is merely a good way to increase an animal's efficiency, by hunting only when the hunting is good, for example, and minimize its risk*". I have mentioned earlier that [this theory fails to meet the shutdown test](#), and it would be enough to keep the animal conscious and atonic to accomplish Siegel's criteria for preserving sleep in the course of evolution. For more on Siegel's theory see: [Robert Vertes and Jerome Siegel](#).

Behind all opposing positions in science, there is a root belief or model which is only later enhanced or muddled by existing clutter of evidence. The root of the role of sleep in learning is in the evolutionary explanation of the need to turn off the conscious mind for a third of our lives. Those who oppose the role of sleep in memory **consolidation** start off with the difficulty in reconciling with the fact that unconscious brain might be involved in learning which seems to require a conscious mind. Some researchers dismiss findings showing the role of sleep in learning as a side effect of stressful methods used in **sleep deprivation**. Others claim that sleep helps learning by nothing more than "refreshing" the mind and restoring energy reserves. In the welter of data confusing the roles of **NREM** and **REM** sleep, procedural and declarative learning, memory **consolidation** vs. memory optimization, short-term vs. long-term memory, spacing effect vs. forgetting vs. interference, animal and human studies, stressful vs. stressless research methods, there will always be room for the voice of dissent. It will take strong computational and unequivocal experimental models to leave less scope for hair splitting over the role of sleep in learning. Until that happens, you will hear many confusing voices.

Robert Vertes and Jerome Siegel

Jerome Siegel is not the only dissenting voice in the role of sleep in memory. Robert Vertes is also a highly reputable sleep researcher. Siegel and Vertes come from two opposite coasts of the US (respectively: Center for Complex Systems

and Brain Sciences, Florida Atlantic University, Boca Raton and Department of Psychiatry, School of Medicine, UCLA, Los Angeles). They also come from different fields of neuroscience and sleep research, and yet have been united in their lone battle with the highly established views on the involvement of sleep in processing memories. They have been disappointed with Dr Stickgold's making an impression that "the door is closed" in the debate on the involvement of sleep in learning. As I hope to be open to new ideas, I would like to address the concerns of Drs Vertes and Siegel.

All scientists, including the brightest ones, have their prejudices and intuitions. Actually, nothing produces a stronger prejudice than rich knowledge that has been filtered or selected for a specific purpose. Prejudiced and selective knowledge characterizes every expert. This comes from the simple fact that it is pretty hard to accumulate more than a few hundred thousands of pieces of information in one's memory over a lifetime. At the same time it is often said that to qualify for the title of an expert, one needs some 50,000 pieces of information from a given field. No wonder then that all experts can truly encompass only one field that will permeate all their thinking, even when they double their expertise on general knowledge with 50,000 pieces of information in other fields. Even if the numbers don't sound convincing, judging by the definition of an expert, it is very hard to become one in one field, let alone in two or more.

Only expertly prejudice can explain why top scientists in the field disagree with the rest of the field that includes equally bright individuals. The problem of prejudice affects everyone, and this paragraph is certainly also a reflection of my own prejudice. My prejudice comes from years of involvement in memory and learning, from my background in computing sciences, as well as from numerous events in my own life that left a long-lasting imprint on my thinking about sleep (see [later in this chapter](#)).

Vertes and Siegel opposed the idea of memory **consolidation** in sleep for over a decade. As their voices are pretty solitary, they have united their efforts. After years of the battle with "the establishment", in 2005, they issued the following appeal in the journal *Sleep*: Time for the Sleep Community to Take a Critical Look at the Purported Role of Sleep in Memory Processing (Vertes and Siegel 2005^[165]). Here are some points raised by Vertes and Siegel:

1. Sleep does not serve a role in declarative memory?

Indeed, research seems to be pretty contradictory in this respect. The **recall** of vocabulary learned on one day does not seem to be much affected by lack of sleep on the following night (except on the days that follows sleep deprivation). However, all research papers should be sifted for two important observations:

1. It is hard to know what is happening inside a black box by watching the relationship between the input and the output. The transition function may remain unchanged, while the internal workings of the automaton may change. Metaphorically, the brain after sleep could be compared to a computer after a disk defragmentation. The transition function is the same, and yet the operations are different.
2. If sleep is considered a **neural optimizer**, and the **dual network** theory is right, we should look at long-term effects of missed sleep. If the purpose of sleep is the avoidance of catastrophic interference, then it is not enough to test the status of the memory after sleep or lack thereof. We also need to allow of a sufficiently long waking period that involves further learning. A simple mental experiment should illustrate that sleep is vital for declarative memories: can anyone expect any meaningful learning after a sleepless night or two? It is not just a matter of tiredness, even a few minutes of deep sleep seems to make a world of difference in our ability to soak in new knowledge. Data obtained with **SuperMemo** shows unequivocally that **sleep is a remarkable tool for unplugging human memory for new input!**

2. REM sleep deprivation does not lead to cognitive impairment?

Vertes and Siegel write (shortened): "Several lines of evidence indicate that **REM sleep is not involved in memory processing/consolidation**. Perhaps the strongest argument for this is the demonstration that the marked suppression or elimination of **REM sleep** in individuals with brainstem lesions or on antidepressant drugs has no detrimental effect on cognition. A classic case is that of an Israeli man who at the age of 19 suffered damage to the brainstem, and when examined at the age of 33 he showed no **REM sleep**. The man, now 55, is a lawyer, a painter and interestingly the editor of a puzzle column for an Israeli magazine. Recently commenting on his 'famous' patient, Peretz Lavie stated that "he is probably the most normal person I know and one of the most successful ones".

REM sleep is younger than sleep overall in terms of its evolutionary origin and might indeed be just a mental extra for smarter animals. **REM sleep deprivation** results in much later death in rats as compared with **sleep deprivation** (months rather than weeks). Suppression of **REM** with drugs does not lead to a drastic cognitive decline. However, this cannot be used to diminish the importance of **REM**. After a sleepless night, humans can also function remarkably well. After a sleepless night, world leaders often take decisions affecting billions of people. This does not undermine the

importance of sleep. Data obtained with [SuperMemo](#) shows that [sleep deprivation](#) has a dramatic effect on learning.

As for the Israeli no-REM man, we would need to know exactly what portion of the [REM](#) control system has been damaged. After all, the expression of [REM](#) is complex and multithreaded, and we do not know exactly which components of the complex process are most essential for what memory and creativity aspects, and to what degree these are expressed phenomenologically as interpreted by the EEG, or muscle atonia, or other [REM](#) constituents that can become dissociated in various [REM](#) disorders, or even in healthy people (e.g. blind people's REM). We could be dealing here with a subset of [REM](#) that is sufficient for retaining reasonable cognitive powers. Nowadays, neuroscientists tend to shift from the link between [REM](#) and dreaming to a more anatomical approach (e.g. the link between the pontine brainstem activity and dreaming). Leading a "normal life" is a very weak test for cognitive assessment, creativity, mnemonic capacity, etc. After all, millions of people destroy their REM-rich sleep with an alarm clock and still lead a "normal" life. Even people with damage to the hippocampus, which destroys their short-memory capacity, can be deceptively "normal" in a conversation. Brain's compensatory capacity is enormous. According to Buzsaki, [REM](#) sleep might be the chief optimizer that would help load the hippocampal circuitry with patterns acquired from the neocortex for a memory rewrite in the successive [NREM](#) sleep. If that interpretation was taken into consideration, [REM](#) deprivation would allow of "normal" life, however, one's creative insight would be diminished significantly. We also need to distinguish here between a reasoning creativity, and an artistic creativity of a painter. Artistic creativity may actually benefit from a degree of information chaos (TMS experiments show how diminished abstract thinking helps a creative artistic expression in a clear neural trade-off). Anecdotal evidence coming from the interpretation of [SleepChart](#) graphs seems to indicate that misalignment of sleep that would produce an expected drop in the proportion of [REM](#) sleep does indeed affect cognitive performance and perhaps, even more importantly, the creative insight that should characterize a healthy awakening. The story is not different in cases of alcohol or cannabis consumption before sleep. As much as we cannot ignore a single point of data in the case of [REM](#) non-expression, we cannot ignore multiple points of anecdotal data coming from [SleepChart](#) reports.

3. Sleep-dependent enhancement of procedural learning has not been proven?

Theoretically, due to its stochastic nature, procedural learning should benefit from sleep even more than declarative learning. It simply provides more room for [neural optimization](#). This is why pre- and post-sleep difference should be more pronounced. However, I cannot verify this with [SuperMemo](#) as it is generally not employed in procedural learning. I can only rely on reports from other sources. Dr Matthew Walker research, for example, is pretty convincing. I am a bit confused here. In contrast to his stance in the discussed paper, Siegel himself apparently told WebMD that "*Studies of procedural learning show clear evidence that you don't get improvement until you sleep*". And later: "*Studies show that when learning muscle-related tasks -- like dancing, piano playing, gymnastics -- there is significant improvement after a night's sleep*". Perhaps the answer comes from the fact that the interview was conducted in 2001.

4. Learning in waking is far more significant than overnight enhancements?

Vertes and Siegel write: "*Although we find the notion of enhancement to be counterintuitive (improvements in learning with the mere passage of time), the question arises regarding the contribution of 'enhancement', compared to practice on tasks, to overall improvements on them. [...] My guess is that sleep contributes very little*".

To me, overnight improvements to the effects of learning are not more counterintuitive than muscle growth in lazy sleep following a heavy workout. The intuition saying that learning is done best in waking is the basis of short-term learning strategies popular amongst (not-so-good) students, where an all-nighter before an exam seems like a good idea. After all, more can be done when cramming before an exam than one might expect from overnight "consolidation". However, if one tries to stretch the idea to just two days, it becomes apparent that without sleep there is no learning. And this is not just a question of rest. If we employ Walker's metaphor of an overflowing Inbox, we can see that missing one night of "enhancement" won't do much damage. Everyone can handle his or her mail ok for a day or two without keeping one's Inbox clean. Many people keep a mountain of mail in the Inbox for weeks or months. However, in the long-run, the bulging Inbox will result in some important mail never getting answered. The same applies to learning, incl. procedural learning. In the long run the additive power of chaos will render further progress hardly possible. It is true then that a single night might not matter much, but without the neural optimization taking place during sleep, our capacity for creative thinking or ability to acquire new skill will, at some point, become saturated and the learning progress will grind to a halt.

Comparing the value and contribution of the learning process in waking with the value of overnight optimizations is not much different than quantifying the contributions of the brain and the heart to our survival. It does not matter that it is the brain that provides the spectacular and the salient. Both organs are vital and indispensable. Similarly, waking and sleep are both vital for learning and memory.

5. Sleep models should be simple

As always *lex parsimoniae* is a helpful guidance in science. The concept of [sleep as a neural optimizer](#) seems to meet the criteria of convincing simplicity. Studying PGO waves, theta rhythms or sleep spindles is important, too, to provide raw data for simple models. After all, without the EEG we would not separate **NREM** from **REM** in the first place. And those two sleep modes seem to provide the basis of the essential optimization interplay. Moreover, brain waves are the expression of the behavior of cell populations that, in the synchronous mode, can be an indication of important physiological functions underway. I am here a bit confused again as Vertes once wrote: "*We propose that theta serves to gate and/or enhance the storage of information reaching the **hippocampus** simultaneous with theta. In the awake state, the 'information arriving with theta' is governed by the situation; i.e., the sum of internal and external events time-locked to theta*" (Vertes 1995^[166]). Is hypothesizing on the function of brain waves ok for waking states and not ok for sleep? Sleep will improve memory not only because of neural optimization. Non-interference or regeneration do also have their role to play. These, however, cannot explain all the effects of sleep on learning. We need to keep the evolution in mind (see the [shutdown test](#)) and the neural aspects of sleep (e.g. why 5 min. nap makes a huge difference to one's learning capacity). Siegel's own theory: "*the main function of sleep is to increase an animal's efficiency and minimize its risk by controlling how a species behaves with regards to its surroundings*" is adequately simple. Neural optimization in sleep is doing just that: increasing an animal's efficiency.

How can random impulsations in REM make a sense in dreams?

As much as the early opponents of the evolution wondered how random mutations could lead to the development of the marvel of the human species, so much some sleep researchers wonder how could random **REM** impulsation be possibly beneficial in learning or otherwise. Robert P. Vertes says: "*The problem seems to be, that unlike waking, in which the nature of the information reaching the **hippocampus** is essentially dictated by behavioral circumstances, there appears to be no mechanism for the selection and orderly transfer of information to the **hippocampus** in **REM** sleep. If this is the case, and the transfer process in **REM** is not orderly or is basically random (as one might conclude from even the most casual inspection of dreams), then the process would appear to have no functional value for the animal; there would appear to be no benefit in encoding or 'remembering' a randomly ordered, non-related series of events. Instead, a hypothesis is advanced that "the primary function of rapid eye movement (**REM**) sleep is to provide periodic endogenous stimulation to the brain which serves to maintain minimum requisite levels of CNS activity throughout sleep*" (Vertes 1986^[167]), which naturally raises the question "why sleep in the first place", which then on the basis of research and evolutionary elimination leads us back to the need for sleep for the effective function of memory, and back to **REM** as the primary network optimizer. See also Vertes, R.P. and Eastman, K.E. "[The case against memory consolidation in **REM** sleep](#)" (Vertes and Eastman 2000^[168]). The role of randomness and pseudopatterns in transferring information between neural networks has been mentioned in [Neural optimization in sleep](#). Examples of self-organization in the natural world are too numerous to list: growth of crystals, folding of proteins, flocking of birds, or the life itself. Complex systems may arise from chaos by an application of a simple set of rules. The brain can convert random shapes in the clouds into vivid images and associations. The visual system can do miracles when juxtaposing contradictory data in stereoscopic vision. Neural networks can recognize faces with just a tiny fraction of data available. Unlike computers, the brain excels in extracting models, producing remote associations and resolving contradictions. Those abilities are essential for reorganizing networks in sleep and for exercising hypothetical survival scenarios.

Dr Siegel's theory of sleep

Dr Siegel proposed his own theory of sleep. Here are a couple of statements by Dr Siegel that do not square well with that I know about sleep physiology and evolution:

- "*Sleep is merely a good way to increase an animal's efficiency, by hunting only when the hunting is good, for example, and minimize its risk*". For that particular formulation, only a tiny subset of the complex sleep control machinery would be sufficient to meet Dr Siegel's proposed function of sleep. For example, at opportune "sleep" times, it would be enough to keep the animal awake and paralyzed as in **REM** sleep. All the rest of sleep control would be a simple waste of time and resources. Why would we need a **homeostatic** control of sleep associated with slow-wave activity? Circadian control would be enough. Or even a simpler solution: a **homeostatic** reaction to the availability to light. Animals would just drop paralyzed as soon as light was unavailable for long enough (in case of diurnal species).
- "*Smaller animals have higher metabolic rates, and this results in the generation of higher levels of small, highly reactive molecules such as free radicals. Studies on rats show that when they are deprived of sleep, their oxidative stress increases*". Oxidative stress indeed increases with activity, but turning off the consciousness does not help in recovery. The brain works as hard in sleep as in waking. That work is not directed at reducing oxidative stress,

but at making sure that all networks are ready, among others, to combat the effects of oxidative stress via homeostatic mechanisms.

- "My theory doesn't mean that significant things don't happen in sleep — it just means there is no vital universal function for sleep". "A whole spectrum of things are accomplished better in sleep than awake in some animals, such as digesting food, but it doesn't mean the function of sleep is digestion". Evolution teaches us that if a function is conserved over millions of years, it is a near-guarantee for there is an underlying vital component. All aggregates of lesser adaptive functions disintegrate, get molded, mutate, modify, get erased or amplified, split and join. Digestive or respiratory functions might go in sync in one set of circumstances, and part ways in different evolutionary settings. It is the neural optimization that retains sleep as an unavoidable part of animal life for millions of years.
- "Sleep has a lot in common with inactive states observed in a wide range of species. This includes plants and simple microbes, which in many cases do not have nervous systems - a challenge to the idea that sleep is for the brain". We all know that sleep was hooked to circadian rhythms. That means that the circadian function is older than the neural function. That implies that there are primitive organisms that express circadian cycles without sleeping. However, for Siegel's logic to hold, he would have to point to organisms with a complex nervous system that do not sleep.
- "Sleep is lying on a continuum that ranges from dormant states like torpor and hibernation, on to periods of continuous activity without any sleep, such as during migration". Sleep is part of the continuum of dormant states and occupies its most advanced and extreme position. Sleep is the acme of evolutionary success that underlies the creative component of our civilization.

My personal bias

I mentioned my personal bias. One event in my life perplexed me and left a durable imprint. The year was probably 1980. My communist-made radio-tape-recorder got damaged. I could not possibly go through my days without a dose of heavy black funk, so I strained at trying to repair the recorder. However, after half a day of trying, I was at my wits end. Seriously disappointed, I went to sleep. When I woke up in the morning, I realized that I was probably dreaming about the repairs. I even had a hazy recollection of one of my repair tricks that succeeded in bringing the tape recorder back to life. Once my mind cleared, I was convinced that I discovered a repair method in sleep. First thing on getting up, I tried the method. The tape-recorder was resurrected! Some people meet God in sleep, others get abducted by the UFO. Dreams can be vivid and convincing. They can affect one's life and convictions for many years to come. On that day, I became [cognitively biased](#) towards the belief that sleep produces new quality in our mind! Over the years, I kept noticing similar overnight breakthroughs after a day of unsuccessful problem solving. I kept confirming that the brain in the morning is of an entirely different status than the brain in the evening. I kept hearing dozens or hundreds of anecdotes about inventions made in the morning after a day of failed trying. Yes. I am prejudiced. With all that anecdotal evidence, I have no doubt that brain is doing heavy-duty memory processing in sleep (see also: [Sleep inspires insight](#) (Wagner et al. 2004^[169])).

Olive branch

Mathew Walker made the following prediction in 2009: "*We will soon have a new taxonomy of sleep-dependent memory processing, and one that will supersede the polarized all-or-none views of the past (Stickgold and Walker 2005^[170]; Vertes and Siegel 2005^[165]). With such findings, we can come to a revised appreciation of how both wake and sleep unite in a symbiotic alliance to coordinate the encoding, [consolidation](#) and integration of our memories, the ultimate aim of which maybe to create a generalized catalogue of stored knowledge that does not rely on the verbose retention of all previously learned facts*" (Walker 2009^[148]).

More reading for skeptics

If you are interested in the points of view by Drs Vertes and Siegel see:

- a boatload of interesting publications by Dr Siegel: <http://www.semel.ucla.edu/sleepresearch>
- Dr Robert Vertes 2000: "[We believe that the cumulative evidence indicates that REM sleep serves no role in the processing or consolidation of memory](#)"

Clock genes

The suprachiasmatic nucleus ([SCN](#)) is the master oscillator at the root of our main circadian cycle. Individual cells in the SCN fire in synchrony on the basis of a genetic loop that takes roughly 24 hours to complete. The loop is very complex, it includes many genes, their transcripts and protein products. Individual components of this complex

system inhibit, suppress, or activate other components. All the various interactions are not yet fully understood, however, a simplified model is presented below for the sake of hinting at the general principles behind the genetic clock.

The clock system forms a negative feedback loop, in which clock proteins built up in the cytoplasm are shunted to the nucleus to repress their own transcription. This mechanism is called a transcription-translation negative-feedback loop (TTFL) that is capable of pretty regular oscillations. The key genes of the clock system are [Clock](#), [Bmal1](#), [period \(Per\)](#), and [cryptochrome \(Cry\)](#). Those components are highly conserved in all kingdoms of living organisms indicating their essential role in survival. The two transcriptional activators CLOCK and BMAL1 form a CLOCK:BMAL1 protein dimer at that start of the day. That dimer promotes the transcription of their transcriptional target genes: period (Per) and cryptochrome (Cry). The [RNA](#) of Per, Cry, Bmal1 and Clock is translated into proteins in the cytoplasm. PER and CRY proteins accumulate in the cytoplasm during the day, peak by the evening, and by sunset start building up in the nucleus as well. In the nucleus, PER and CRY function as negative regulators of CLOCK/BMAL1 activity, and repress their own transcription. As a result, PER and CRY plummet during the night and thus close the negative feedback loop. This restarts the cycle from the production of CLOCK:BMAL1, and so on. The loop formed by Clock/Bmal1 and Per/Cry oscillates in a roughly 24 hour cycle. Complexes that contain CRY inhibit the CLOCK:BMAL1 dimer production, and slow down the transcription of Per and Cry genes. The picture gets more complicated with the fact that there are at least three variants of Per (Per1, Per2, and Per3), and two of Cry (Cry1, and Cry2). Complexes that contain PER2 protein enhance the transcription of Bmal1. PER1 modestly inhibits transcription induced by the CLOCK/BMAL1 complex.

Circadian role of individual genes is well illustrated by engineering knockout mice. For example, mice lacking Cry1 or Cry2 have altered free running circadian periods. If both genes are missing, the animals become arrhythmic in constant conditions with constant elevated levels of Per1 mRNA! Similarly, Per1/Per2 double mutants lose rhythmicity. Mutations to the Per2 gene can cause familial [ASPS](#). The non-redundant role of Bmal1 can be shown by deletion, which leads to immediate arrhythmicity in constant darkness. The clock genes are affected by various hormonal, metabolic and immune inputs (e.g. [adenosine](#)).

The circadian genetic machinery is so well conserved in the evolution that the study of [Drosophila](#) provides a cheap alternative to knockout experiments in rodents. Orthologs have been identified in mammals for most of the Drosophila circadian clock genes. In insects though, unlike in mammals, CRY1 function is light-dependent. Even [cyanobacteria](#) have a circadian genetic clock that can be reconstituted in vitro for detailed quantitative analysis and comparative simulations. One of the conclusions coming from studying cyanobacteria is that the TTFL clock may actually be a slave to a master biochemical oscillator called the PTO (post-translational oscillator) (Qin et al. 2010^[171]). The initial suggestion on the role of biochemical oscillators came from the persistence of the circadian rhythm in conditions of inhibited transcription and translation (Iwasaki et al. 2005^[172]). Beyond their circadian roles, the genes are also involved in other functions. Interestingly, cryptochromes have been shown to be involved in magnetoreception in birds, and photoreception in plant growth.

It seems that many subcomponents of the oscillator system can run in 24 hour cycles, and even a simple theoretical three protein phosphorylation loop can be formed that is temperature compensated and whose stability may depend on minor regulatory adjustments to the properties of the proteins involved and/or their processing. This might mean that individual proteins must have been perfected and tuned up in the course of evolution to produce stable rhythms that can ideally match our lifestyles linked to the rotation of the Earth. No wonder then that scientists have identified numerous mutations that produce minor changes in the properties of the oscillator or its [entrainment](#) systems (see: [mutations affecting the clock period](#) (Golombek and Rosenstein 2010^[30])).

Myths and facts

Length of sleep

- Myth: We should get 8 hours of sleep per night. Fact:** Many people can do with less sleep and they do not need to strive at 8 hours. Others may need more than 8. We should all sleep exactly as many hours as our sleep system demands. Trying to get the prescribed 8 hours of sleep will drive some people to insomnia, while others will remain sleep deprived.
- Myth: People who sleep less live longer.** In 2002, Dr Kripke compared the length of sleep with longevity (1982 data from a cancer risk survey). He figured out that those who sleep 6-7 hours live longer than those who sleep 8 hours and more. No wonder that a message started spreading that those who sleep less live longer. **Fact:** The best longevity prognosis is ensured by sleeping in compliance with one's natural body rhythm. Those who stick to their own good rhythm often sleep less because their sleep is better structured (and thus more refreshing). "Naturally sleeping" people live longer. Those who sleep against their body call, often need to clock more hours

and still do not feel refreshed. Moreover, disease is often correlated with increased demand for sleep. Infectious diseases are renowned for a dramatic change in sleep patterns. When in coma, you are not likely to be adding years to your life. Correlation is not causation

3. **Myth: If you are sleepy, it means you did not get enough sleep. Fact:** There are factors that are far more important for the refreshed mind than the length of sleep. The same person, depending on circumstances, can be less sleepy after a well-executed 3 hours of sleep than after a long night of poor-quality sleep. The main factors that result in daytime sleepiness are: using an alarm clock, sleeping in a wrong phase (either too early, or too late), [sleep apnea](#), inducing sleep with sleeping pills or alcohol, and substance abuse.
4. **Myth: The body will always crave excess sleep as it craves excess food.** Some people draw a parallel between our tendency to overeat with sleep. They believe that if we let the body dictate the amount of sleep, it will always ask for more than needed. As a result, they prefer to cut sleep short with alarm clock to "optimize" the amount of sleep they get. **Fact:** Unlike storage of fat, there seems to be little evolutionary benefit to extra sleep. Probably, our typical 6-8 hours of sleep are just enough to do all "neural housekeeping". People with sleep deficit may indeed tend to sleep obscenely long. However, once they catch up and get into the rhythm, the length of their sleep is actually likely to decrease
5. **Myth: Sleeping little makes you more competitive.** Many people are so busy with their lives that they sleep only 3-4 hours per night. Moreover, they believe that sleeping little makes them more competitive. Many try to train themselves for minimum sleep. Donald Trump, in his newest book, tells you: "*If you want to be a billionaire, sleep as little as possible*". **Fact:** It is true that many geniuses slept little. Many business sharks slept even less. However, the only good formula for maximum long-term competitiveness is via maximum health and maximum creativity. If Trump sleeps 3 hours per night and enjoys his work, he is likely to run it on alertness hormones (ACTH, cortisol, adrenaline, etc.). His sleep is probably structured very well and he may extract more neural benefit per hour of sleep than an average 8-hours-per-night sleeper. Yet that should not make you try to beat yourself to action with an alarm clock. You will get shortest and maximum quality sleep only then when you [perfectly hit your circadian low-time](#), i.e. when your body tells you "now it is time to sleep". Sleep in wrong hours, or sleep interrupted with an alarm clock is bound to undermine your intellectual performance and creativity. Occasionally, you may think that a loss on intellectual side will be counterbalanced with the gain on the action side (e.g. clinching this vital deal). Remember though, you also need to factor in the long-term health consequences. Unless, of course, you think a heart attack at 45 is a good price to pay for becoming a billionaire
6. **Myth: We can sleep 3 hours per day.** Many people enviously read about Tesla's or Edison's sleeping habits and hope they could train themselves to sleep only 3 hours per day having far more time for other activities. **Fact:** This might work if you plan to party all the time. And if your health is not a consideration. And if your intellectual capacity is not at stake. You can sleep 3 hours and survive. However, if your aspirations go beyond that, you should rather sleep exactly as much as your body wants. That is an intelligent man's optimum. With your improved health and intellectual performance, your lifetime gains will be immense
7. **Myth: You can accumulate sleep benefit in advance. Fact:** If you expect a sleepless night, it is naturally best to be in a good shape. Good sleep on a preceding night will help. However, you won't get much benefit from sleeping well in the preceding week or month. Sleep is not food. You cannot accumulate it in advance for future use. This is also why your body will not attempt to sleep longer in [free running sleep](#). If you ever sleep inordinately long, this is only an expression of prior sleep debt. Sleep credit does not exist.

Napping

1. **Myth: Avoid naps. Fact:** Naps may indeed worsen insomnia in people suffering from DSPS, esp. if taken too late in the day. Otherwise, naps are highly beneficial to intellectual performance. It is possible to take naps early in the day without affecting one's sleeping rhythm. Those naps must fall before or inside the so-called *dead zone* where a nap does not produce a *phase response* (i.e. shift in the circadian rhythm)
2. **Myth: A nap is a sign of weakness. Fact:** Nap is not a sign of weakness, ill-health, laziness or lack of vigor. It is a phylogenetic remnant of a biphasic sleeping rhythm. Not all people experience a significant mid-day slump in mental performance. It may be well masked by activity, stress, contact with people, sport, etc. However, if you experience a slump around the 5th to 8th hour of your day, taking a nap can dramatically boost your performance in the second half of the day
3. **Myth: Naps reduce life expectancy. Fact:** Habitual napping increases longevity. Napping may still be unhealthy in some circumstances (e.g. see [Phase 11 Evening naps](#)), however, well-timed naps are a blessing for cognition and cardiovascular health.
4. **Myth: Napping may cause diabetes. Fact:** While a Chinese study found that napping was correlated with diabetes (Chen et al. 2010^[173]), it did not differentiate between the types of napping, or did not imply causality. Napping is often associated with sleep deprivation, which could be the primary cause of the link. Napping at wrong hours could also cause circadian disturbances, which could also be a contributing factor. Finally, pre-

diabetic people nap more for health. This implies reverse causality. Well-timed naps in **free running sleep** should reduce the risk of diabetes, cardiovascular disorders, cognitive decline, and many other health problems.

5. **Myth: Coffee before a nap is helpful. Fact:** Coffee may help you wake up from the nap fast and feel pretty refreshed. However, the freshness is likely to dissipate faster if the nap is prevented from running its natural course due to the impact of **caffeine**. Drink coffee before a nap only if you are in a hurry (e.g. while taking a pit stop on a long driving trip).
6. **Myth: Naps are always good. Fact:** Improperly timed naps may worsen insomnia, shift the sleep phase, or result in **sleep inertia**. See: [Best nap timing](#)
7. **Myth: Long naps send you into deep sleep and result in sleep inertia. Fact:** Indeed, naps taken too late can be very long and result in sleep inertia. However, there is nothing wrong with long naps as long as they are taken at the optimum phase (usu. around the 7th hour from natural waking). For a well-timed nap without sleep deprivation, the opposite may be true: the longer the nap, the greater the gain in alertness and learning capacity.
8. **Myth: Larks should nap at 1 pm, while owls should nap at 2:30 pm. Fact:** Both larks and owls differ little in their preferred nap timing, which comes roughly 7 hours from natural waking. This means that a lark that wakes up at 4 am would feel least alert at 11-12 am, while an owl that wakes up at midday would gladly nap at 7-8 pm. Note also that natural early riser are less likely to be nappers.
9. **Myth: Everyone has his or her own optimum nap length. Fact:** Optimum nap length does not exist! Naps are subject to many **homeostatic** regulatory inputs, and will vary in length from day to day depending on circumstances. Some people nap very predictably (e.g. always within the 15-20 min. range). Others show huge variations (e.g. from no nap to 3 hours).
10. **Myth: Power nap of 20 min. is most effective. Fact:** Well-timed naps are most effective when they terminate naturally. They may last 3 min. or 3 hours. Their effect will largely be determined by the timing, napping conditions, and, importantly, lack of artificial interference in the course of the nap sleep.
11. **Myth: Don't take naps, you will only be more tired. Fact:** Well-timed naps can double your productivity. Churchill noticed that a nap makes the second part of his day as valuable as the first part. If you consider that a creative mind makes more errors in a tired state when working in the evening, and errors can often wipe out effects of one's work, there is not exaggeration in the statement that naps double productivity. Naturally they must be taken correctly. Otherwise they can reduce one's performance through sleep inertia, worsen insomnia or sleep phase problems. See: [Best nap timing](#)
12. **Myth: Keep your naps at 15 min. with an alarm clock to wake up from Stage 2 NREM and avoid grogginess. Fact:** Well-timed naps in a healthy circadian cycle should never leave you groggy. Just the opposite. They will offer a gift of a crisp mind for the second half of your day. See: [Best nap timing](#). Moreover, the duration of sleep stages depends on many homeostatic control factors as well as on the circadian phase. In a sleep deprived state at a wrong circadian phase, you may hit Stage 4 in a wink. The alarm will find you stunned and disorientated.
13. **Myth: Naps should be avoided in insomniacs. Fact:** Early naps, and naps in habitual nappers, [have a negligible impact on the onset of night sleep](#). Slight delay in sleep onset comes from slightly lesser homeostatic pressure, but shorter night sleep is as refreshing as sleep in non-nappers. In most cases, insomniacs would not suffer from insomnia if they were just allowed to go to sleep later and wake up later. It is true, however, that late naps can have a disastrous impact on the sleep phase and night sleep. All naps beyond the 9 hours from natural waking should be considered late. See: [Best nap timing](#)

Sleep inertia

1. **Myth: Most people experience sleep inertia in the morning. Fact:** Sleep inertia in the morning is entirely avoidable. If you throw away the alarm clock, you are not likely to experience sleep inertia (unless jetlagged for some reasons). If you need to get up at a specific hour, with some help from chronotherapy, you can either eliminate the alarm clock or make it less harmful. Morning sleep inertia hits mostly those who seriously cut down on the length of their sleep. Has mankind degraded to a degree that these people form a majority?
2. **Myth: Waking up is a slow process that needs to take its course. Fact:** Waking up at the right time without the help of the alarm clock should be pretty fast. On a good day, it should take as much time to wake up as it takes to fall asleep, i.e. 3-5 minutes. There is still some improvement in the learning capacity in the first hour. However, the sleep switch has been designed so that to accomplish pretty fast awakening assuming the sleep is natural, healthy and unregulated.
3. **Myth: Excess sleep causes headaches and grogginess. Shorter sleep is better for health. Fact:** This myth is yet another example of confused causation. When people catch a cold virus their thermostats shift to favor pyrogenesis (fever helps fight viruses). This means that infected people often shiver in conditions that they would otherwise find comfortable. This led to the myth that "*cold contributes to catching a cold*". Even the name of the virus wrongly associates it with the cold. The myth is reinforced by the fact that flus and colds rule in cold weather when people close windows and crowd in poorly ventilated spaces. Being cold is a sign of catching a

cold, not a prelude to the infection. Similarly, sleep deprived people often sleep very long to repay the sleep debt. Long recovery sleep indeed often leads to headaches and other unpleasant symptoms. However, it is short sleep that caused the problem in the first place. When people are allowed to sleep as much as they want, they quickly reduce their total sleep time, and experience no "sleep excess" symptoms.

4. **Myth: Sleep inertia shows no circadian cycle. Fact:** It depends on the type of sleep inertia (see: [Sleep inertia](#)). The sick groggy feeling that shows up when we are awake at the time when we should be asleep (e.g. during a poorly planned night shift) should also be classified as a type of sleep inertia as it may show up in a very similar form independent of whether it follows interrupted sleep or a prolonged waking period. That type of inertia is purely circadian. It goes away on its own once the circadian low passes away.
5. **Myth: Naps cause sleep inertia. Fact:** [Only naps taken too late cause sleep inertia](#). Properly timed naps taken in the absence of [sleep deprivation](#) should be relatively short (30-90 min.), and very refreshing. Sleep itself should not be blamed for sleep inertia! Sleep inertia is a result of violations in the art of good sleeping!
6. **Myth: Sleep inertia is correlated with the duration of prior sleep. Fact:** You can suffer sleep inertia when being woken up from deep sleep shortly after falling asleep. You may suffer from sleep inertia when waking up from a long bout of sleep at the times of your [REM](#) peak (e.g. due to falling asleep too early). You may also feel groggy at your circadian low many hours after your last sleep episode. Sleep inertia is caused by disrupting natural sleep, [NREM](#) or [REM](#) sleep processes, and isn't much related to the length of the preceding sleep.
7. **Myth: Increasing the blood flow to the brain is a great remedy for sleep inertia. Fact:** Only healthy sleep is a true remedy for sleep inertia. Caffeine, exercise, noise, bright lights, stress, etc. can only mask it. Very often, masking the inertia will do more damage than the inertia itself. For example, exercising during the [subjective night](#) is a formula for cardiac stress, injuries, and many other unhealthy effects of contradictory hormonal and metabolic signals.

Insomnia

1. **Myth: Silence and darkness are vital for sleep.** This may be the number one advice for insomniacs: use your sleeping room for sleep only, keep it dark and quiet. **Fact:** Silence and darkness indeed make it easier to fall asleep. They may also help maintain sleep when it is superficial. However, they are not vital. Moreover, for millions of insomniacs, focusing on peaceful sleeping place obscures the big picture: the most important factor that makes us sleep well, assuming good health, is the adherence to one's natural circadian rhythm! People who go to sleep along their natural rhythm can often sleep well in bright sunshine. They can also show remarkable tolerance to a variety of noises (e.g. loud TV, family chatter, the outside window noise, etc.). This is all possible thanks to the sensory gating that occurs during sleep executed "in phase". Absence of sensory gating in "wrong phase" sleep can easily be demonstrated by lesser changes to [AEPs](#) (auditory evoked potentials) registered at various parts of the auditory pathway in the brain. Noises will wake you up if you fail to enter deeper stages of sleep, and this failure nearly always comes from sleeping at the wrong circadian phase (e.g. going to sleep too early). If you suffer from insomnia, focus on understanding your natural sleep rhythm. Peaceful sleeping place is secondary (except in cases of impaired sensory gating as in some elderly). Insomniacs running their daily ritual of perfect darkness, quiet, stresslessness and sheep-counting are like a stranded driver hoping for fair winds instead of looking for the nearest gas station. Even worse, if you keep your place peaceful, you run the risk of falling asleep early enough to be reawakened by the quick elimination of the homeostatic component of sleep. Learn the principles of healthy sleep that will make you sleep in all conditions. Only then focus on making your sleeping place as peaceful as possible
2. **Myth: Caffeine can cause insomnia. Fact:** [Caffeine](#) can make insomnia worse but it is never a primary cause.
3. **Myth: Insomnia is caused by magnesium deficiency. Fact:** There are multiple causes of insomnia. Mineral deficits do not even come close to the top of the list of causes. The most frequent causes of insomnia are stress, ill health, and sleeping in a wrong phase (too early). People on a normal healthy diet should get plenty of magnesium to meet their needs. Moreover, in cases of deficiency, insomnia would not be the main reason for worry. Various forms of diet supplementation are in vogue these days, and few people realize that supplementation may often do more harm than good.
4. **Myth: Segmented sleep is natural. This is how people slept for centuries. Fact:** [Segmented sleep](#) is probably an expression of "excess nighttime". It can be observed in modern conditions when people go to sleep too early. Early bedtime is a frequent cause of nocturnal awakenings. Despite the myth, waking up in the night for longer than a few fleeting moments is not a sign of normal healthy sleep. 1-2 hour breaks in nighttime sleep are most often an indication of early bedtime or other factors that contribute to insomnia.
5. **Myth: Magnesium, folates, and other supplements can help you sleep better. Fact:** Nutrients needed for good health are also good for sleep. However, supplementation is not likely to play a significant role in resolving your sleep problems. Vitamins may help if you are in deficit, but a vast majority of sleep disorders in the society come from the lack of respect or understanding of the circadian rhythm. If you are having problems with sleep, stick to

the rules presented in this article. As for food, stick to a standard healthy diet. That should suffice

Bedtime

1. **Myth: Going to bed at the same time is good for you. Fact:** Many sleep experts recommend going to sleep at the same time every day. Regular rhythm is indeed a form of chronotherapy recommended in many circadian rhythm problems. However, people with severe DSPS may simply find it impossible to go to sleep at the same time everyday. Such forced attempts will only result in a self-feeding cycle of stress and insomnia. In such cases, the struggle with one's own rhythm is simply unhealthy. Unfortunately, people suffering from DSPS are often forced into a "natural" rhythm by their professional and family obligations
2. **Myth: Sleep before midnight is more valuable. Fact:** Sleep is most valuable if it comes at the time planned by your own body clock mechanisms. If you are not sleepy before midnight, forcing yourself can actually ruin your night if you wake up early
3. **Myth: It is best to wake up with the sun. Fact:** You should wake up at the time when your body decides it got enough of sleep. If this happens to be midday, a curtain over the window will prevent you from being woken up by the sun. At the same time sun may help you reset your body clock and help you wake up earlier. People who wake up naturally with the sun are indeed among the healthiest creatures on the planet. However, if you do not wake up naturally before 4 am, trying to do so with the help of alarm clock will only add misery to your life
4. **Myth: Early to bed, early to rise, make a man wealthy, healthy and wise (Benjamin Franklin). Fact:** Many centenarians are early risers. This adds to the impression that early risers live longer. However, early risers live long only if their early rising habit is natural. You cannot add to your longevity if you try to force yourself to an early schedule against your natural sleep habits. Everyone can be synchronized with the sun, at least for a while, and everyone can experience the beauty of getting up with the sun. Everyone should taste it at least once to know it is possible. However, for a large proportion of people this cannot last. Either due to stress, electricity, or a natural predisposition, getting up early in a natural way is not possible in the long run. When you ask a child to complete this phrase: *Early to bed, early to rise, make a man wealthy, healthy and...* You are more likely to hear "tired". Unfortunately, for a large portion of the population, "tired" is the correct answer. Personal development gurus will often put early rising close to the top of their productivity list. If your primary tool at work is your brain, do not follow this advice! Wake up only naturally, even if your natural wake hour is late! Natural waking is healthier, and is more likely to help you gain wisdom. Material wealth can often be gained faster if you sacrifice your health and other values, but only with good sleep will you accomplish a true wealth and well-being in life.
5. **Myth: Going to sleep early makes us more energized. Fact:** Maximum morning freshness and energy comes from sleeping in the right phase. Going to sleep too early may cause insomnia or premature awakening. Both will affect the quality of sleep. For evening-type people, going to sleep relatively late will improve morning energy.

Body clock

1. **Myth: Human body clock runs a 24 hour cycle. Fact:** The cycle is actually longer than 24 hours. The trick is that the brain employs a reset button that synchronizes the cycle with one's activity pattern.
2. **Myth: People are of morning or evening type. Fact:** This is more of a misnomer than a myth. Evening type people, with chronotherapy, can easily be made to wake up with the sun. What people really differ in is the period of their body clock, as well as the sensitivity to and availability of stimuli that reset that rhythm (e.g. light, activity, stress, etc.). People with an unusually long natural day and low sensitivity to resetting stimuli will tend to work late and wake up late. Hence the tendency to call them "evening type". Those people do not actually prefer evenings, they simply prefer longer working days. The lifestyle affects the body clock as well. A transition from a [farmer's lifestyle](#) to a student's lifestyle will result in a slight change to the sleeping rhythm. This is why so many students feel as if they were of the evening type
3. **Myth: You cannot change the inherent period length of your body clock. Fact:** With various chronotherapeutic tricks it is possible to change the period of the clock slightly. It can be reset or advanced harmlessly by means of melatonin, bright light, exercise, meal timing, etc. It can also be reset in a less healthy way: with an alarm clock. However, significant lifestyle changes may be needed to resolve severe cases of DSPS or [ASPS](#). The therapy may be stressful, and the slightest deviation from the therapeutic regimen may result in the relapse to an undesirable rhythm. Those who employ [free running sleep](#) may take the easiest way out of the period length problem: stick to the period that is the natural outcome of your current lifestyle
4. **Myth: Human body clock can easily adapt to various types of schedule. Fact:** The length of the clock period can only be changed slightly (perhaps as much as an hour). The phase of the clock can also be pushed only slightly each day (perhaps as much as 2 hours). Otherwise, all attempts to re-arrange the clock are harmful for health. Millions of people suffer due to this myth daily through badly designed shift-work, rapid time-zone changes or experiments such as [Uberman sleep schedule](#).
5. **Myth: Night shifts are unhealthy. Fact:** People working in night shifts are often forced out of work by various

ailments such as a heart condition. However, it is not night shifts that are harmful. It is the constant switching of the sleep rhythm from day to night and vice versa. It would be far healthier to let night shift people develop their own regular rhythm in which they would stay awake throughout the night. It is not night wakefulness that is harmful. It is the way we force our body do things it does not want to do

Sleep in children

1. **Myth: Newborns sleep nearly all day. Fact:** Newborns are more likely to spend half of their days asleep. Half of their sleep is **REM** (as opposed to the usual adult 20%)
2. **Myth: Babies should not play before sleep. Fact:** Unless the play is exceedingly exciting or in any way stressful (even a happy play may be a form of stress), play increases the **homeostatic** pressure for sleep and should make it easier for a baby to fall asleep
3. **Myth: Being late for school is bad. Fact:** Kids who persistently cannot wake up for school should be left alone. Their fresh mind and health are far more important. 60% of kids under 18 complain of daytime tiredness and 15% fall asleep at school (US, 1998). Parents who regularly punish their kids for being late for school should immediately consult a sleep expert as well as seek help in attenuating the psychological effects of the trauma resulting from the never ending cycle of stress, sleepiness and punishment
4. **Myth: Being late for school is a sign of laziness. Fact:** If a young person suffers from DSPS, it may have perpetual problems with getting up for school in time. Those kids are often actually brighter than average and are by no means lazy. However, their optimum circadian time for intellectual work comes after the school or even late into the evening. At school they are drowsy and slow and simply waste their time. If chronotherapy does not help, parents should consider later school hours or even home-schooling

Learning and creativity

1. **Myth: Geniuses sleep little! Fact:** When looking at Edison and Tesla it is easy to believe that cutting down on sleep does not seem to pose a problem in creative achievement. Those who try to work creatively in conditions of **sleep deprivation** will quickly discover though that fresh mind is by far more important than those 2-3 hours one can save by sleeping less. A less visible side effect of **sleep deprivation** is the effect on memory **consolidation** and creativity in the long term. Lack of sleep hampers remembering. It also prevents creative associations built during sleep. It is not true that geniuses sleep less. For example, Einstein admitted that he would work best if he got a solid nine-hour block of sleep. The difference between Edison and Einstein could be a combination of physiology and working mode. Edison would spend hours on manual experiments, which may involve less demand for sleep as compared with highly abstract reasoning. Edison also used to run his own business affairs that could add some adrenaline to affect the sleep physiology. Apart from the difference in the working mode, the sleep physiology can differ between individuals. In an extreme case, it is possible that Einstein's brain was "slower" in sleep and required more time to do the same job. His sleep could also include a larger proportion of non-optimizing stages (i.e. stages that are likely to act as transition between physiologically most important Stage 3/4 **NREM** and **REM** sleep). Whatever the underlying cause, you should follow your natural sleep demand and never cut down on sleep
2. **Myth: Sleep before learning can diminish the effects of learning. Fact:** This myth comes from the fact that poorly timed sleep may result in **sleep inertia**, and learning in conditions of sleep inertia is particularly inefficient. However, sleep is actually the best ally of learning. Best learning occurs in the morning as long as sleep is taken in the right phase, is not disrupted, is not diminished by substances or sleep medication, etc.
3. **Myth: Since we feel rested after sleep, sleep must be for resting. Ask anyone, even a student of medicine: What is the role of sleep? Nearly everyone will tell you: Sleep is for rest. Fact:** Sleep is for optimizing memories. Despite seeming inaction, the metabolic rate drops only by 15% in sleep. In an average night, that amounts to savings comparable to the energy contained in a single apple. To effectively encode memories, mammals, birds and even reptiles need to turn off the thinking and do some housekeeping in their brains. This is vital for survival. This is why the evolution produced a defense mechanism against skipping sleep. If we do not get sleep, we feel miserable. We are not actually as wasted as we feel, the damage can be quickly repaired by getting a good night sleep. It is our brain dishing punishment for not sticking to the rules of intelligent life-form: let the memory do the restructuring in its programmed time

Alertness

1. **Myth: We are the least alert at 8 am in the morning. Alertness increases during the day. Fact:** [Alertness has two peaks during the day](#). For most people on a healthy sleep regimen, the alertness is highest 30-80 min. after awakening. If your alertness is low in the morning, you know you do not sleep right. Lowest alertness at 8 am might be true for people who go to sleep too late and wake up with an alarm clock. However, it is definitely not

true in **free running sleep**. The person who got lowest alertness at 8 am would most likely keep sleeping till 10-11 am and only then wake up naturally. If you use SuperMemo and collect your sleep data, you can see clearly on your alertness graph, that alertness is highest at the beginning of the day (perhaps starting with the first hour after awakening due to the transition from sleep to wake that sometimes may take some time). Low morning alertness can only be explained by the misaligned circadian rhythm. If circadian lows occurred earlier, morning would be brisk and alert.

2. **Myth: Teenagers show stronger alerting in the evening. Fact:** Teenagers have a natural difficulty in reconciling their evening activities with morning school schedules. Their lifestyle predisposes them to drift to later sleep phases and show owlish behaviors. Their evening alertness does not come from a natural difference in their circadian cycle control (as compared with adults). It comes from delayed **phase shift** problem that is primarily induced by their lifestyles, which are a reflection for their passion for their evening hobbies, and their high demand for sleep. When a teen cuts his or her sleep in the morning with an alarm clock, he or she is likely to take a delayed nap after school and be unusually alert in the evening. This results in late bedtime or insomnia that compounds the vicious cycle. Teens on vacation often adopt different sleep habits. See: [Sleep and school](#)

Alarm clock

1. **Myth: Alarm clock can help regulate sleep rhythm. Fact:** Alarm clock can help you push your sleeping rhythm into your desired framework, but it will rarely help you accomplish a healthy sleeping rhythm. The only tried-and-true way to accomplish a healthy sleep and a healthy sleep rhythm is to go to sleep only then when you are really sleepy, and wake up naturally without external intervention

Sleeping pills

1. **Myth: Sleeping pills can help you sleep better. Fact:** Sleeping pills can help you sleep, but this sleep is of far less quality than naturally induced sleep. Sleeping pills can be useful in circumstances where sleep is medically vital and cannot be achieved by other means. Otherwise, avoid sleeping pills whenever possible
2. **Myth: Melatonin can be used to boost a nap. Fact:** The opposite is true. **Melatonin** is likely to make the nap feel very unrefreshing. **Melatonin** is the hormone of the night (or at least the subjective night). It can be used to advance the sleep phase or increase evening sleep propensity. It cannot be used as a sleeping pill, esp. that its effects are likely to last past the duration of a nap.

Polyphasic sleep

1. **Myth: We can adapt to polyphasic sleep.** Looking at the life of sailors, many people believe they can adopt polyphasic sleep and save many hours per day. In polyphasic sleep, you take only 4-5 short naps during the day totaling less than 4 hours. There are many "systems" differing in the arrangement of naps. There are also many young people ready to suffer the pains to see it work. Although a vast majority will drop out, a small circle of the most stubborn ones who survive a few months will perpetuate the myth with a detriment to public health. **Fact:** We are basically biphasic and all attempts to change the inbuilt rhythm will result in loss of health, time, and mental capacity. A simple rule is: when sleepy, go to sleep; while asleep, continue uninterrupted. See: [The myth of polyphasic sleep](#)

Incremental writing

This article was written using a creative writing technique called **incremental writing**.

[SuperMemo](#) can be used in the process of creative writing, which combines writing texts with the learning and review of the [incremental reading](#) process. By analogy to incremental reading, this process is called **incremental writing**. The main difference between incremental reading and incremental writing is that the "big picture" of the article is built within the collection, not in the writer's mind. This is suitable for large fact-packed material that is difficult to organize sequentially. In addition, one's own writing may be the source of most input, as opposed to external electronic sources. Incremental writing is also suitable for a compilation of a large body of prior writing, esp. of materials that are repetitive, fact-rich and often loosely connected. Incremental writing is less useful for texts with a linear line of thought. The presented article is a compilation of multiple texts related to sleep and learning from supermemo.com. All the relevant materials have been imported to [SuperMemo 15](#) and processed incrementally. The structure of the article was determined with the help of the contents tree. The explanatory notes were processed incrementally. Figures, annotations, links, and literature citations were also processed incrementally in order of priority. Incremental article writing is an open-ended process that can be interrupted at any stage for the article to be exported to as a single document for text-flow rewrites. Articles written using incremental writing may be particularly suitable for

incremental reading. They can be compared to Wikipedia. Wikipedia is an excellent source for incremental reading due to its incremental growth and solid local context. For the exactly same reasons, materials compiled with incremental writing are highly suitable for incremental reading. They may be bloated and repetitive, however, with incremental reading, they can be prioritized in a rational way. Incremental writing leaves the texts highly granular and the flow of thought is jagged, however, in incremental reading, this is an advantage as all individual articles and subarticles carry sufficient local context to be read independently. For more see: [Incremental writing](#).

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Glossary

This glossary uses definitions that have intentionally been simplified or oversimplified to carry important messages. For more precise definitions follow the provided links or do your own googlinvestigations:

acrophase

peak of a sine wave. In this article mostly used to mean "middle of the night" or "circadian nadir"

adenosine

a substance that accumulates in the brain during waking activities inducing sleepiness (see: [Adenosine](#)). Its antagonist is [caffeine](#).

Ambien

popular sleeping pill

apnea

absence of breathing

[ASPS](#)

advanced sleep phase syndrome, a condition in which a patient tends to go to sleep very early and wake up well before sunrise

[BDNF](#)

brain-derived neurotrophic factor, protein that stimulates brain growth (increased with sleep, learning, and exercise)

BF

[basal forebrain](#)

Borbely

Hungarian sleep scientist known for his [two-process model of sleep propensity](#)

Buzsaki

Hungarian sleep scientist known for his [theory of reverse information flow in REM and NREM](#)

benzodiazepines

class of popular sleeping pills

biphasic sleep

sleep that is made of two daily episodes. In this article, **biphasic sleep** is understood as composed of a long night sleep and a short daytime nap. Other variants of **biphasic sleep** are also possible, but other meanings are not used in this article (e.g. segmented sleep can also be biphasic)

[caffeine](#)

active compound of coffee, tea and coke that makes one more alert

catastrophic forgetting

massive forgetting that can occur in artificial neural networks due to interference. One of the theories says that

humans use a dual network system in sleep to prevent catastrophic forgetting. See: [Neural optimization in sleep](#)

chronotype

character of a person's sleep control system that makes him into a lark, owl, long-sleeper, irregular sleeper, etc.

circadian sleep component

one of the two main components of sleep propensity that drives people to sleep. Circadian component is usually expressed in the night and determines the timing of the night sleep

circadian cycle - ~24 hour cycle of changes in the body

circadian rhythm - the rhythm of changes in the circadian cycle

circadian phase - time of day in reference to the circadian cycle

circadian shift - shift in the phase of the circadian cycle

circadian low - the time in circadian cycle when we feel most sleepy

circadian curve - the sine wave that represents a circadian cycle (with highs and lows representing the degree of sleepiness). It may be a superposition of two or more sine waves, esp. at younger ages

circadian preferences - preferences as to the timing of sleep (e.g. larks like to sleep early)

complementary encoding theory

theory of memory that says that two complementary memory systems are needed for safe encoding of memories. Fast, low-interference, and small temporary system, as well as slow, overlapping, vast long-term system. New memories arrive to the fast system and are redistributed efficiently in the vast system. That redistribution is likely to occur in sleep. The hippocampus and the neocortex are chief examples of complementary systems

consolidation

1. MEMORY In SuperMemo, the process in which memories get reinforced by repetition. In SleepChart, sleep can be shown to have an impact on [memory consolidation](#)
2. SLEEP EPISODES Merging of adjacent sleep episodes to eliminate the effect of short night-time awakenings that should not affect the process of computing the circadian minima (in SleepChart)

cry it out method

a method of putting babies to sleep by teaching them that crying for the mom is futile. This "method" stands against human biology and can negatively affect baby's brain development

DMH

dorsal medial nucleus of hypothalamus, brain center responsible for the integration of circadian signals with information from other brain centers in control of circadian behaviors and circadian physiology

DR

[dorsal raphe](#), one of the arousal centers in the brain

DSPS

delayed sleep phase syndrome, tendency to wake up later and later each day

dual network theory

sleep theory, which says that the brain developed a system of two networks: one for short-term low-interference memories, and the other for long-term memory storage. Transfer of memories to the long-term storage happens during sleep

entrainment

the process in which one's natural sleep cycle is adapted to fit the 24-hour day with the waking hour early enough for one's work, school, social life, etc. Entrained sleep is sleep that does not require an alarm clock to "bring it into phase"

farmer's lifestyle

a lifestyle that favors good sleep. It consists in early rising (possibly with the sun), lots of hard work (or exercise) outdoors, and a relaxed evening without electricity (e.g. in a dim light of a fireplace). Departure from this ancient lifestyle is the source of the sleep disorder epidemic.

free running sleep

sleep that is not artificially controlled (e.g. with sleeping pills or alarm clocks)

garbage collection theory

a theory that says that the main function of sleep is cleaning up information garbage from memory. This theory is largely correct. See: [Neural optimization in sleep](#)

habitual napper

a person for who napping is a regular habit. A habitual napper does not need to be tired to get a good nap. Habitual nappers are often called appetitive nappers in sleep literature

hippocampus

a small part of the brain that is needed for development of long-term memories. It is involved in memory optimization during sleep. People with damage to the hippocampus can sleep, but they quickly forget nearly everything they learn

hypocretins

aka orexins, an important alertness hormone in the brain that takes part in regulating sleep. Mutations in the genes affecting the release of hypocretins can result in [narcolepsy](#)

homeostatic sleep component

component of sleep propensity. Homeostatic sleepiness can be compared to "tiredness of waking". It increases in the course of the day

homeostatic process - the process in which sleepiness increases during the day in proportion to mental effort (often denoted in literature as *Process S*)

homeostatic sleepiness - sleepiness that is a result of mental effort (as opposed to circadian sleepiness which usually comes in the night)

homeostasis - the process in which the body controls its internal variables in response to external stimuli (e.g. REM homeostasis is the buildup of REM sleep drive in proportion to REM sleep deficit)

hypnogram

graph which shows the progression of sleep stages throughout the night

insomnia

problems with falling asleep or maintaining sleep (see: [Insomnia](#))

LC

[locus coeruleus](#), one of the alertness centers in the brain

melatonin

natural sleep hormone released in the brain during the night

monophasic sleep

sleep pattern that includes only one long night sleep episode in 24 hours

MPO

Also **MPA**, **MPOA**

medial preoptic area, one of the brain centers responsible for integrating information needed for the initiation of sleep. MPOA is also involved in parenting and sexual behaviors (incl. sexual preferences)

NREM

non REM sleep that usually starts the night sleep

orexins

see: [hypocretins](#)

orexin receptor

receptor that detects the presence of orexins/hypocretins

phase shift

change in the phase of the circadian cycle. For example, 1 hour phase delay is equivalent to a delay in bedtime by one hour, delay in waking time by one hour, delay in minimum body temperature by one hour, etc.

pineal gland

group of cells in the brain that is involved in sleep control. It is responsible for the release of nighttime melatonin

[polyphasic sleep](#)

sleep pattern that consists of many sleep episodes in a single day (throughout this article, **biphasic sleep** is not considered part of **polyphasic sleep** patterns)

PRC

phase response curve, a curve that illustrates how body responds to signals that shift the sleep phase (e.g. how evening lights makes us get sleepy later, and wake up later)

PVN

*Also **PVH***

paraventricular nucleus of the hypothalamus, one of the brain centers responsible for the integration of sleep initiation stimuli

RAS

reticular activating system (in the brainstem), portion of the brain responsible for overall arousal

recall

the ability to bring information up from memory (see: [Memory recall](#))

REM

rapid eye movement sleep

REM deficit

debt in amount of **REM** sleep obtained. This debt must be paid as soon as possible, but usually after NREM sleep debt is paid

reverse learning theory

a theory that says that in sleep we forget less important things (see: [Sleep as neural optimizer](#))

siesta

mid-day nap

sleep apnea

absence of breathing in sleep

[SleepChart](#)

freeware application for charting sleep

sleep deprivation

chronic or acute lack of sleep

sleep latency

the time between going to bed and falling asleep

SPW

brain waves (sharp-waves) that show up in deep sleep and might be associated with the transfer of short-term memories to the neocortex

SWS

[slow-wave sleep](#), the deepest stage of sleep that is necessary for the **consolidation** of new experience with old memories. Stages 3-4 of NREM sleep

subjective night

the time when the body wants to sleep. It usually happens during the night, but for owls in may equally well be early morning, or even middle of the day

[SuperMemo](#)

program for accelerated learning that makes it possible for everyone to study the relationship between his or her own sleep and learning

THC

tetrahydrocannabinol, psychoactive compound found in marijuana

TMN

tuberomammillary nucleus of the hypothalamus, one of the alertness centers in the brain

TMS

transcranial magnetic stimulation, a method of stimulating portions of the brain without surgery with the help of a magnetic field

VLPO

ventrolateral preoptic nucleus, one of the main centers responsible for the initiation of sleep

Summary

ABC of sleep

- **Sleep is important for learning, and creativity!** **Sleep deprivation** results in intellectual deprivation!
- Sleep as much as you feel you need. In a well-aligned circadian cycle, you cannot get too much sleep.
- Sleep is not food. You cannot get more in advance and store it for later. (see: [Excessive sleeping](#))
- [Avoid alarm clocks](#). They are bad for learning and bad for health!
- Forget about trying to fall asleep at pre-planned time! Let your body decide!
- Forget about trying to fall asleep quickly! If your body decides it is the right time, quick sleep will come naturally!
- Do not try to make yourself sleepy! It is enough you stay awake and keep on working/learning long enough! Natural sleep will come! (see: [Insomnia](#))
- It is much better to eliminate the source of stress rather than to try to forget stressful situations right before the bedtime! (see: [Stress](#))
- If you cannot fall asleep in 30 minutes, get up! You are not yet ready for sleep! (see: [Insomnia](#))
- Remember that a bad night is a factor of life. Few can avoid it. However, religious adherence to the sleep hygiene rules will help you dramatically reduce the bad night occurrence. Life is beautiful if your sleep works out great!
- If you stick to the rules of healthy sleep, you should not know [sleep inertia](#)
- Even a small degree of **sleep deprivation** will add up over a period of days to severely reduce the performance
- **Sleep deprivation** carries [astronomical costs to society](#)
- [Shift-work and jetlag are bad](#) for health!
- Adult humans are [biphasic](#), but babies are [polyphasic](#). Non-nappers also show a dip in learning performance in mid-day typical to a biphasic individual.

Optimizing sleep

- The best weapon against [insomnia](#) is the appropriate timing of sleep. You should go to sleep only when you are tired enough.
- If you want to maximize the time spent in productive wakefulness, read about [free running sleep](#). Let your biology work for you, not against you
- Instead of minimizing sleep, you should optimize the amount of sleep. This means you should get exactly as much sleep as is needed to fulfill its [neural functions](#)
- Learn the details of your own sleep timing: how many hours you sleep, how many hours before you need to take a nap, or go to sleep again, etc. Use this article to find out how to compute your optimum schedule. Use [SleepChart](#) to get visual assistance for harder cases. Use [SuperMemo](#) if you want to see how your sleep affects your learning.
- Everyone experiences a substantial dip in their learning capacity in mid-day, roughly [7 hours from natural waking](#). This is a great time for a [siesta](#). Do not nap later than 8 hours from natural waking.
- If you sleep it out and still don't feel refreshed, be sure you do not sleep against your circadian rhythm. Try [free running sleep](#). Remember that you may need 1-2 weeks to synchronize all body functions before this starts working to perfection!
- If you cannot get refreshing sleep even in free-running conditions after at least a month of trying, consult a sleep expert. Remember that even [free running sleep](#) may be tricky for people with sleep phase disorders or highly irregular sleep. However, you probably stand at least 90-95% chance that it will answer most of your sleep quality

problems!

- Even if [free running sleep](#) is a near-solid guarantee of good sleep, the free-running schedule may be incompatible with your work or social life.
- Without sleep deprivation, you minimize total sleep if you run it free. Human tendency to sleep excessively is a myth. (see: [Excessive sleeping](#))

Sleep and learning

- [Alarm clocks are bad for learning!](#)
- Your [ability to learn depends on your circadian clock](#), not on the clock that hangs on your wall
- You should [adjust the timing of intellectual work to your circadian cycle](#)
- [Tapes for learning in sleep are a marketing ploy](#)
- After a healthy well-timed sleep, best [recall](#) occurs in the early morning hours. If you are a napper, the second good learning period is after the [siesta](#). (see: [Recall](#))
- After healthy well-timed sleep, best memory [consolidation](#) (best learning) occurs in the early morning hours (see: [Memory consolidation](#))
- For best learning results, you need good sleep before and after learning (Walker 2008^[174])
- Heavy learning impedes learning itself making cramming doubly counterproductive
 1. cramming leaves few long-term memory traces,
 2. cramming quickly inhibits short-term memory
- There is a big difference in learning capacity between being just alert and being crisply alert
- There is a substantial mid-day dip in learning performance. At that time, a nap is better than learning! (see: [Biphasic nature of human sleep](#))
- Naps are great for learning. Do not confuse natural naps of [biphasic sleep](#) with "designer naps", e.g. polyphasic "Uberman" sleep!
- Tools for learning in a relaxed state are conducive to napping. Their usefulness for actual learning is limited.

General

- Sleep is great for brain growth.
- [Exercise](#) is great for sleep if properly chosen and properly timed. Sleep is also great for exercise.
- [Learning](#) is great for sleep and sleep is great for learning
- [Stress](#), [alcohol](#), [recreational drugs](#) and [sleeping pills](#) are all bad for sleep, esp. when administered shortly before sleep
- Stick with good people! Few things can ruin sleep as effectively as bad people!
- If you experience racing thoughts at the time when your body calls for sleep, the best method is: get up and do something that tires you intellectually!
- If you want to contribute to sleep research, or to find more about your own sleep and learning, or if have new ideas in the subject, please [write to me](#)
- Not all scientists agree with facts presented in this article (see examples: [Jim Horne and Daniel Kripke](#), [Robert Vertes and Jerome Siegel](#))

Children

- Let babies sleep on demand, co-sleeping is vital for their emotional and intellectual development
- Given basic safety measures, bed-sharing is great for babies and it helps develop their circadian patterns (as long as the mom does not violate sleep hygiene rules herself)
- Don't ever wake babies or little children! This is bad for their brain growth! Unless specifically indicated by a pediatrician, feeding schedule must take a back seat. Sleeping patterns should rule the way the baby's day is organized
- If you must send kids to a kindergarten, make sure you entrain an appropriate sleep pattern so that to never need to wake the kids up! This is vital for their brain growth! If you cannot entrain their sleep, consider other options (incl. nursing kids at home)

Napping

- [Naps improve mental performance](#)
- [One nap per day is enough](#)
- Naps should be taken in the 7th hour of the day, earlier naps are inefficient, later naps can mess up the circadian cycle (see: [Best nap timing](#))

- Naps cannot make up for nighttime sleep deprivation, however, they are a great boost for a well-rested mind! (see: [Optimum nap duration](#))

Substances

- Be careful with [caffeine](#). Drink coffee only upon awakening (or after a nap, if you take one)
- Do not go beyond a single drink of alcohol per day (unless you exercise a lot). Avoid drinking before sleep (esp. in the last 2-3 hours before your night sleep)
- [Quit smoking!](#)
- [Marijuana](#) is a frenemy! It may help you sleep, but that sleep will not be refreshing!
- [Melatonin](#) can help you sleep earlier and advance the sleep phase, but it will also result in a less refreshing sleep

Role of sleep

- The main function of sleep is the [optimization of memories stored in the neural networks of the brain](#)
- [Sleep deprivation would result in death](#) if it was enforceable (probably in a matter of weeks)
- The fatal outcome of [sleep deprivation](#) is probably caused by a major neural network malfunction, and possibly also due to the secondary effects of the sleep protection program (see: [Why do we die without sleep?](#))
- Healthy people who never sleep are a myth. Either they sleep or they die.

DSPS

- A marked portion of the young studying generation is affected by a degree of a DSPS disorder
- The epidemic increase in DSPS case is most likely caused by the modern lifestyle based on the use of electricity that disrupts the traditional cycle of daylight and darkness, and the associated social cues (see: [Is DSPS a disease?](#))
- Normal people may experience a [phase shift](#) on a free running schedule revealing an epidemic mismatch between modern lifestyle and the biology of sleep

Polyphasic sleep

- Polyphasic sleep results in chaotic phase-shift responses
- It is likely that in polyphasic sleep attempts, [the circadian cycle is running in the background](#) as if in zeitgeber-free conditions with the chaotic phase-shifting inputs cancelling each other out
- Healthy humans cannot entrain polyphasic sleep, and cannot sustain a polyphasic schedule without [sleep deprivation](#). It is not possible to sleep polyphasically and retain one's maximum creativity, alertness, and health in the long run. Due to a lack of direct [entrainment](#) response from the sleep control mechanism, long-term healthy adaptation to a polyphasic sleep pattern is not possible
- Whoever claims to be on a perpetual polyphasic schedule must be either suffering from a sleep disorder, or be untruthful. Claims of successfully switching between monophasic, biphasic, and polyphasic lifestyle cannot possibly be truthful unless the switch is made at a serious cost to one's cognitive function and productivity

Physiology of sleep

- We fall into a healthy sleep only if two conditions are met:
 1. our tiredness from waking is high (high homeostatic sleep propensity), and
 2. our body clock says "bedtime" (high circadian sleep propensity)

(see: [Borbely model](#))

- [Sleep operates like a flip-flop](#) with sharp transitions and stable sleep or waking stages. Those healthy fast transitions from waking to sleep and back may be less efficient when sleep hygiene rules are violated
- Sleep alternates between two different modes in the night: [NREM sleep and REM sleep](#). Those keep changing in ~90 min. cycles. Both stages are very important and play different roles in the process of learning and creativity
- Brain undergoes a major reorganization in sleep. Some synaptic weights get weakened. Others get strengthened. [Neural connections are optimized](#) for consistent abstract associative memory with minimum interference
- Human sleep can be repositioned in reference to the clock by means of chronotherapy. The changes in the sleep phase proceed along a [phase response curve \(PRC\)](#)

Sources

The presented article has largely been compiled from other sources at supermemo.com. Those include:

- [Roots of creativity and genius](#)
- [FAQ: Good sleep for good learning](#)
- [Poor sleep = poor learning](#)
- [SleepChart: Formula for healthy sleep](#)
- [Polyphasic sleep: myths and facts](#)
- [Polyphasic Sleep: 5 Years Later!](#)
- [FAQ: Polyphasic sleep](#)
- [Good sleep, good learning, good life \(2000\)](#)
- [How to join sleep and learning research](#)

References

1. [^] National Commission on Sleep Disorders Research, Wake Up America: A National Sleep Alert--Report of the National Commission on Sleep Disorders Research, Department of Health and Human Services Pub. No. 92-xxxx; Washington, D.C.: Superintendent of Documents, U.S. Government Printing Office, 1992
2. [^] Mitler M.M., Carskadon M.A., Czeisler C.A., Dement W.C., Dinges D.F., and Graeber R.C., [Catastrophes, Sleep, and Public Policy: Consensus Report](#), Sleep / Volume 11 / Issue 1 (February 1999): 100-109
3. [^] ^{3.0} ^{3.1} Stickgold R., "[Sleep-dependent memory consolidation](#)," Nature / Volume 437 (October 27, 2005): 1272-1278
4. [^] ^{4.0} ^{4.1} Buzsáki G., "[Two-stage model of memory trace formation: A role for "noisy" brain states](#)," Neuroscience / Volume 31 / Issue 3 (1989): 551-570
5. [^] ^{5.0} ^{5.1} ^{5.2} ^{5.3} ^{5.4} Wozniak P.A., Gorzelanczyk E.J., and Murakowski J.A., "[Two components of long term memory](#)," Acta Neurobiologiae Experimentalis / Volume 55 (1995): 301-305
6. [^] ^{6.0} ^{6.1} Borbély A.A., "[A two process model of sleep regulation](#)," Human Neurobiology / Volume 1 / Issue 3 (1982): 195-204
7. [^] Rechtschaffen A., "[Current perspectives on the function of sleep](#)," Perspectives in Biology and Medicine / Volume 41 / Issue 3 (1998): 359-90
8. [^] Siegel J.M., "[Why we sleep](#)," Scientific American / Volume 289 / Issue 5 (2003): 92-97
9. [^] Hairston I.S., Little M.T.M., Scanlon M.D., Barakat M.T., Palmer T.D., Sapolsky R.M., and Heller H.C., "[Sleep restriction suppresses neurogenesis induced by hippocampus-dependent learning](#)," Journal of Neurophysiology / Volume 94 / Issue 6 (December 2005): 4224-4233.
10. [^] ^{10.0} ^{10.1} ^{10.2} ^{10.3} ^{10.4} Frank M.G., Issa N.P., and Stryker M.P., "[Sleep Enhances Plasticity in the Developing Visual Cortex](#)," Neuron / Volume 30 / Issue 1 (April 2001): 275-287
11. [^] Whitfield J., "[To sleep, perchance to learn](#)," Nature (April 2001), doi:10.1038/news010426-15
12. [^] Rhodes & Associates Inc., "[Fatigue Management Guide for Canadian Marine Pilots – A Trainer's Handbook](#)" (Wayne Rhodes, 2001)
13. [^] Cho K., "[Chronic 'jet lag' produces temporal lobe atrophy and spatial cognitive deficits](#)," Nature Neuroscience / Volume 4 / Issue 6 (June 2001): 567-568, doi: doi:10.1038/88384
14. [^] Cho K., Ennaceur A., Cole J.C., and Suh C.K., "[Chronic Jet Lag Produces Cognitive De?icits](#)," The Journal of Neuroscience / Volume 20 / Issue 6 (March 15, 2000): RC66
15. [^] Knutson K.L., PhD, Spiegel K., PhD, Penev P., MD, PhD and Van Cauter E., PhD, "[The Metabolic Consequences of Sleep Deprivation](#)," Sleep Medicine Reviews / Volume 11 / Issue 3 (June 2007): 163-178
16. [^] Allan J.S. and Czeisler C.A., "[Persistence of the circadian thyrotropin rhythm under constant conditions and after light-induced shifts of circadian phase](#)," The Journal of Clinical Endocrinology & Metabolism / Volume 79 / Issue 2 (August 1, 1994): 508-512, doi: 10.1210/jc.79.2.508
17. [^] Baumgartner A., Dietzel M., Saletu B., Wolf R., Campos-Barros A., Gräf K.J., Kürten I., and Mannsmann U., "[Influence of partial sleep deprivation on the secretion of thyrotropin, thyroid hormones, growth hormone, prolactin, luteinizing hormone, follicle stimulating hormone, and estradiol in healthy young women](#)," Psychiatry Research / Volume 48 / Issue 2 (August 1993): 153-178, doi: 10.1016/0165-1781(93)90039-J
18. [^] Mills E., Wu P., Seely D., and Guyatt G., [Melatonin in the treatment of cancer: a systematic review of randomized controlled trials and meta-analysis](#), Journal of Pineal Research / Volume 39 / Issue 4 (November 2005): 360-366
19. [^] Schernhammer E.S., Rosner B., Willett W.C., Laden F., Colditz G.A., Hankinson S.E., [Epidemiology of urinary melatonin in women and its relation to other hormones and night work](#), Cancer Epidemiology, Biomarkers & Prevention / Volume 13 / Issue 6 (June 2004): 936-943
20. [^] Dijk D.J., Lockley S.W., "[Functional Genomics of Sleep and Circadian Rhythm: Invited Review: Integration of human sleep-wake regulation and circadian rhythmicity](#)," Journal of Applied Physiology / Volume 92 / Issue 2 (2002): 852-862
21. [^] Wozniak P.A., Gorzelanczyk E.J., "[Formula for healthy sleep](#)" (2003)

22. [^] [Roberts R.D. and Kyllonen P.C., "Morningness–eveningness and intelligence: early to bed, early to rise will likely make you anything but wise!", Personality and Individual Differences / Volume 27 / Issue 6 \(December 1999\): 1123-1133](#)
23. [^] [23.0 23.1 Dinges D.F. and Broughton R.J., "Sleep and Alertness: Chronobiological, Behavioral, and Medical Aspects of Napping," \(New York: Raven Press, 1989\), 171-204](#)
24. [^] [Dinges D.F., "Adult napping and its effects on ability to function." In "Why we Nap: Evolution Chronobiology and Functions of Polyphasic and Ultrashort Sleep," edited by C. A. Stampi \(Boston: Birkhäuser, 1992\), 118–134](#)
25. [^] [Wertz A.T., BS, Ronda J.M., MS, Czeisler C.A., PhD, MD, and Wright K.P., Jr, PhD, "Effects of Sleep Inertia on Cognition," The Journal of the American Medical Association / Volume 295 / Issue 2 \(2006\): 163-164, doi: 10.1001/jama.295.2.163](#)
26. [^] [26.0 26.1 26.2 26.3 Oren D.A., M.D., Wehr T.A., M.D., "Hypertyctohemeral Syndrome after Chronotherapy for Delayed Sleep Phase Syndrome," The New England Journal of Medicine / Volume 327 / Issue 24 \(December 10, 1992\): 1762](#)
27. [^] [T. A. Wehr, D. E. Moul, G. Barbato, H. A. Giesen, J. A. Seidel, C. Barker, and C. Bender, "Conservation of photoperiod-responsive mechanisms in humans," American Journal of Physiology - Regulatory, Integrative and Comparative Physiology / Volume 265 / Issue 4 \(October 1993\): 846-857](#)
28. [^] [Ekirch, A.R., "Sleep We Have Lost: Pre-industrial Slumber in the British Isles," The American Historical Review / Volume 106 / Issue 2 \(2001\): 343-387](#)
29. [^] [Carskadon M.A., "Early school schedules modify adolescent sleepiness," Sleep Research / Volume 24: 92](#)
30. [^] [30.0 30.1 Golombek D.A. and Rosenstein R.E., Physiology of Circadian Entrainment," Physiological Reviews / Volume 90 / Issue 3: 1063-1102, doi: 10.1152/physrev.00009.2009](#)
31. [^] [Neubauer D.N., "Delayed sleep phase syndrome: Analysis of a 10-year sleep log," Johns Hopkins Sleep Disorders Center \(2000\)](#)
32. [^] [32.0 32.1 LivingWithN24, "Charting the course of N24," DSPS, a sleep disorder \(October 27, 2010\)](#)
33. [^] [Wyatt J.K., Ritz-De Cecco A., Czeisler C.A., and Dijk D.J., Circadian temperature and melatonin rhythms, sleep, and neurobehavioral function in humans living on a 20-h day," American Journal of Physiology - Regulatory, Integrative and Comparative Physiology / Volume 277 / Issue 4 \(October 1999\): 1152-1163](#)
34. [^] [Carskadon M.A., Labyak S.E., Acebo C., and Seifer R., Intrinsic circadian period of adolescent humans measured in conditions of forced desynchrony, Neuroscience Letters / Volume 260 / Issue 2 \(January 29, 1999\): 129–132, doi: 10.1016/S0304-3940\(98\)00971-9](#)
35. [^] [Weitzman E.D., MD, Czeisler C.A., MD, PhD, Coleman R.M., PhD, Spielman A.J., PhD, Zimmerman J.C., PhD, Dement W., MD, PhD, and Pollak C.P., MD, "Delayed sleep phase syndrome. A chronobiological disorder with sleep-onset insomnia," Archives of General Psychiatry / Volume 38 / Issue 7 \(July 1981\): 737–746, doi: 10.1001/archpsyc.1981.01780320017001\]](#)
36. [^] [Sergio Sensi and Fabio Capani, "Chronobiological Aspects of Weight Loss in Obesity: Effects of Different Meal Timing Regimens," Chronobiology International / Volume 4 / Issue 2 \(1987\): 251-261](#)
37. [^] [Rehm D.S., The Myopia Myth: The Truth About Nearsightedness and How to Prevent It," Ligonier: International Myopia Prevention Association, 1981](#)
38. [^] [Coghlan A. and Le Page M., "Eye correction is seriously short sighted," New Scientist \(November 20, 2002\)](#)
39. [^] [39.0 39.1 Sack R., Auckley D., Auger R.R., Carskadon M.A., Wright K.P., Vitiello M.V., Zhdanova I.V., "Circadian rhythm sleep disorders: Part II, advanced sleep phase disorder, delayed sleep phase disorder, free-running disorder, and irregular sleep-wake rhythm," SLEEP / Volume 30 / Issue 11 \(2007\):1484-1501](#)
40. [^] [Golombek D.A. and Rosenstein R.E., "Physiology of Circadian Entrainment," Physiological Reviews / Volume 90 / Issue 3 \(July 2010\): 1063-1102, doi: 10.1152/physrev.00009.2009](#)
41. [^] [Hayakawa T., Kamei Y., Urata J., Shibui K., Ozaki S., Uchiyama M., and Okawa M., "Trials of bright light exposure and melatonin administration in a patient with non-24 hour sleep-wake syndrome," Psychiatry and Clinical Neurosciences / Volume 52 / Issue 2 \(261–262\): 261-262](#)
42. [^] [Kripke D.F., Rex K.M., Ancoli-Israel S., Nievergelt C.M., Klimecki W., and Kelsoe J.R., "Delayed sleep phase cases and controls," Journal of Circadian Rhythms / Volume 6 / Issue 6 \(2008\), doi:10.1186/1740-3391-6-6](#)
43. [^] [Rao M.R., Brenner R.A., Schisterman E.F., Vik T., and Mills J.L., "Long term cognitive development in children with prolonged crying," Archives of Disease in Childhood / Volume 89 / Issue 11 \(2004\): 989-992, doi:10.1136/adc.2003.039198](#)
44. [^] [Odaa G.A., Torresb F., Buenob C., Weyb D., Duarteb L., and Menna-Barretobc L.S., "Breastfeeding, sleep and wake circadian rhythms show distinct temporal emerging patterns," Biological Rhythm Research / Volume 39 / Issue 4 \(2008\): 379-387, doi:10.1080/09291010701425397](#)
45. [^] [45.0 45.1 Rivkees S.A., Fox C.A., Jacobson C.D., and Reppert S.M., "Anatomic and Functional Development of the Suprachiasmatic Nuclei in the Gray Short-Tailed Opossum," The Journal of Neuroscience / Volume 8 / Issue 11 \(November 1988\): 4289-4276](#)

46. [^](#) Cubero J., Valero V., Sánchez J., Rivero M., Parvez H., Rodríguez A.B., and Barriga C., "[The circadian rhythm of tryptophan in breast milk affects the rhythms of 6-sulfatoxymelatonin and sleep in newborn](#)," Neuroendocrinology Letters / Volume 26 / Issue 6 (2005): 657-661
47. [^](#) Joseph Altman, Shirley A. Bayer, [Development of the diencephalon in the rat. I. An autoradiographic study of the time of origin and settling patterns of neuron of the hypothalamus](#)," The Journal of Comparative Neurology / Volume 182 / Issue 5 (December 15, 1978): 945-997, doi: 10.1002/cne.901820511
48. [^](#) Page T.L., "[Developmental manipulation of the circadian pacemaker in the cockroach: relationship between pacemaker period and response to light](#)," Physiological Entomology / Volume 16 / Issue 2 (June 1991): 243-248, doi: 10.1111/j.1365-3032.1991.tb00563.x
49. [^](#) McKenna J.J. and McDad T., "[Why babies should never sleep alone: A review of the co-sleeping controversy in relation to SIDS, bedsharing and breast feeding](#)," Paediatric Respiratory Reviews / Volume 6 / Issue 2 (June 2005): 134-152
50. [^](#) McKenna J.J., Ph.D, "[Is sleeping with my baby safe? Can it reduce the risk of SIDS?](#)," Horizons / Volume 1 / Issue 4 (Spring/Summer 1995)
51. [^](#) Walker M.P., PhD and Stickgold R., PhD, "[It's Practice, with Sleep, that Makes Perfect: Implications of Sleep-Dependent Learning and Plasticity for Skill Performance](#)," Clinics in Sports Medicine / Volume 24 / Issue 2 (April 2005): 301-317, doi: 10.1016/j.csm.2004.11.002
52. [^](#) Nishida M. and Walker M.P., "[Daytime Naps, Motor Memory Consolidation and Regionally Specific Sleep Spindles](#)," PLoS ONE / Volume 2 / Issue 4 (2007): e341, doi: 10.1371/journal.pone.0000341
53. [^](#) Werth E., Dijk D.J., Achermann P., Borbély A.A., "[Dynamics of the sleep EEG after an early evening nap: experimental data and simulations](#)," American Journal of Physiology / Volume 271 / Issue 3 (September 1996): 501-510
54. [^](#) [54.0](#) [54.1](#) Stampi C. "Why We Nap: Evolution, Chronobiology and Functions of Polyphasic and Ultrashort Sleep." Boston: Birkhäuser, 1992.
55. [^](#) Czeisler C.A., Duffy J.F., Shanahan T.L., Brown E.N., Mitchell J.F., Rimmer D.W., Ronda J.M., Silva E.J., Allan J.S., Emens J.S., Dijk D.-J., and Kronauer R.E., "[Stability, Precision, and Near-24-Hour Period of the Human Circadian Pacemaker](#)," Science / Volume 284 / Issue 5423 (June 25, 1999): 2177 - 2181, doi: 10.1126/science.284.5423.2177
56. [^](#) Khalsa S.B.S., Jewett M.E., Cajochen C., and Czeisler C.A., "[A phase response curve to single bright light pulses in human subjects](#)," The Journal of Physiology / Volume 549 / Issue 3 (June 15, 2003): 945-952, doi: 10.1113/jphysiol.2003.040477
57. [^](#) [57.0](#) [57.1](#) [57.2](#) Ruby N.F., Saran A., Kang T., Franken P., and Heller H.C., "[Siberian hamsters free run or become arrhythmic after a phase delay of the photocycle](#)," American Journal of Physiology - Regulatory, Integrative and Comparative Physiology / Volume 271 / Issue 4 (October 1996): 881-890
58. [^](#) Thaler J.P., Yi C.-X., Schur E.A., Guyenet S.J., Hwang B.H., Dietrich M.O., Zhao X., Sarruf D.A., Izgur V., Maravilla K.R., Nguyen H.T., Fischer J.D., Matsen M.E., Wisse B.E., Morton G.J., Horvath T.L., Baskin D.G., Tschöp M.H., and Schwartz M.W., "[Obesity is associated with hypothalamic injury in rodents and humans](#)," The Journal of Clinical Investigation / Volume 122 / Issue 1 (January 3, 2012): 153-162, doi:10.1172/JCI59660
59. [^](#) [59.0](#) [59.1](#) Swaab D.F., Hofman M.A., and Honnebier M.B.O.M., "[Development of vasopressin neurons in the human suprachiasmatic nucleus in relation to birth](#)," Brain research. Developmental brain research / Volume 52 / Issues 1-2 (March 1, 1990): 289-293, doi: 10.1016/0165-3806(90)90247-V
60. [^](#) Swaab D.F., Hofman M.A., Mirmiran M., Someren E.J.W. van, and Zhou J.N., "[The human suprachiasmatic nucleus \(SCN\) in a periodic environment](#)," Proceedings of the fifth Sapporo Symposium of Biological Rhythm (1994): 323-337
61. [^](#) Mirmiran M. and Ronald L. Ariagno, "[Influence of light in the NICU on the development of circadian sleep component rhythms in preterm infants](#)," Seminars in Perinatology / Volume 24 / Issue 4 (August 2000): 247-257
62. [^](#) Wozniak P.A., "[Polyphasic Sleep: Facts and Myths](#)" (2005)
63. [^](#) Zimmermann T., "[Miles to go before I sleep](#)," Outside Magazine (April 2005)
64. [^](#) Pryor M., "[MacArthur is caught not napping](#)," The Times (January 20, 2005)
65. [^](#) Sbragia G., "Leonardo da Vinci and Ultrashort Sleep: Personal Experience of an Eclectic Artist." In "Why we Nap: Evolution Chronobiology and Functions of Polyphasic and Ultrashort Sleep," edited by C. A. Stampi (Boston: Birkhäuser, 1992), 180-185
66. [^](#) Ruitenberg A. MD, Van Swieten J.C. MD, Witteman J.C.M. PhD, Mehta K.M. DSc, Van Duijn C.M. PhD, Hofman A. MD, Breteler M.M.B. MD, "[Alcohol consumption and risk of dementia: the Rotterdam Study](#)," The Lancet / Volume 359 / Issue 9303 (January 26, 2002): 281-286
67. [^](#) Solinas M., Ferré S., You Z.B., Karcz-Kubicha M., Popoli P., and Goldberg S.R., "[Caffeine Induces Dopamine and Glutamate Release in the Shell of the Nucleus Accumbens](#)," The Journal of Neuroscience / Volume 22 / Issue 15 (August 1, 2002): 6321-6324
68. [^](#) Landolt H.P., Werth E., Borbély A.A., Dijk D.J., "[Caffeine intake \(200 mg\) in the morning affects human sleep and EEG power spectra at night](#)," Brain Research / Volume 675 / Issues 1-2 (March 27, 1995): 67-74

69. [^](#) Van Praag H., Kempermann G., and Gage F.H., [Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus](#), Nature Neuroscience / Issue 2: 266 - 270, doi: doi:10.1038/6368
70. [^](#) Guzmán-Marín R., Suntsova N., Stewart D.R., Gong H., Szymusiak R., and McGinty D., [Sleep deprivation reduces proliferation of cells in the dentate gyrus of the hippocampus in rats](#), The Journal of Physiology / Volume 549 / Issue 2 (June 1, 2003): 563-571, doi: 10.1113/jphysiol.2003.041665
71. [^](#) Gambelunghe C., Rossi R., Mariucci G., Tantucci M., and Ambrosini M.V., ["Effects of light physical exercise on sleep regulation in rats,"](#) Medicine & Science in Sports & Exercise / Volume 33 / Issue 1 (2001): 57-60
72. [^](#) Feinberg I., Jones R., Walker J.M., Cavness C., March J., ["Effects of high dosage delta-9-tetrahydrocannabinol on sleep patterns in man,"](#) Clinical Pharmacology & Therapeutics / Volume 17 / Issue 4 (April 1975): 458-466
73. [^](#) Fujimori M. and Himwich H.E., ["delta⁹-Tetrahydrocannabinol and the sleep-wakefulness cycle in rabbits,"](#) Physiology & Behavior / Volume 11 / Issue 3 (September 1973): 291-295, doi: 10.1016/0031-9384(73)90003-6
74. [^](#) Knutson K.L., Spiegel K., Penev P., Van Cauter E., ["The metabolic consequences of sleep deprivation,"](#) Sleep Medicine Reviews / Volume 11 / Issue 3 (June 2007): 163-178, doi: 10.1016/j.smrv.2007.01.002
75. [^](#) Keim N.L., Van Loan M.D., Horn W.F., Barbieri T.F., and Mayclin P.L., ["Weight Loss is Greater with Consumption of Large Morning Meals and Fat-Free Mass Is Preserved with Large Evening Meals in Women on a Controlled Weight Reduction Regimen,"](#) The Journal of Nutrition / Volume 127 / Issue 1 (January 1, 1997): 75-82
76. [^](#) Wren A.M., Small C.J., Ward H.L., Murphy K.G., Dakin C.L., Taheri S., Kennedy A.R., Roberts G.H., Morgan D.G.A., Ghatei M.A. and Bloom S.R., ["The Novel Hypothalamic Peptide Ghrelin Stimulates Food Intake and Growth Hormone Secretion,"](#) Endocrinology / Volume 141 / Issue 11 (November 1, 2000): 4325-4328, doi: 10.1210/en.141.11.4325
77. [^](#) Norrelund H., [The metabolic role of growth hormone in humans with particular reference to fasting,"](#) Growth Hormone & IGF Research / Volume 15 / Issue 2 (April 2005): 95-122, doi: 10.1016/j.ghir.2005.02.005
78. [^](#) Roberts S., ["Self-experimentation as a source of new ideas: Ten examples about sleep, mood, health, and weight,"](#) Behavioral and Brain Sciences / Volume 27 / Issue 2 (April 2004): 227 - 262, doi: 10.1017/S0140525X04000068
79. [^](#) [79.0 79.1](#) Wozniak P.A., ["Can too much learning lead to Alzheimer's?"](#) (May 2002)
80. [^](#) SuperMemo World, ["SuperMemo User Survey"](#) (November 1994)
81. [^](#) Gorzelanczyk E.J., Wozniak P.A., Chrzastowska H., ["Investigating the correlation between the intelligence and the performance in repetitive learning tasks,"](#) 3rd Congress of the European Federation of Neurological Societies, Sevilla (1998)
82. [^](#) Cappuccio F.P., MD, D'Elia L., MD, Strazzullo P., MD, Miller M.A., PhD, ["Sleep Duration and All-Cause Mortality: A Systematic Review and Meta-Analysis of Prospective Studies,"](#) Sleep / Volume 33 / Issue 4 (2010): 585-592
83. [^](#) Cappuccio F.P., MD, D'Elia L., MD, Strazzullo P., MD, Miller M.A., PhD, ["Quantity and Quality of Sleep and Incidence of Type 2 Diabetes: A systematic review and meta-analysis,"](#) Diabetes Care / Volume 33 / Issue 2 (February 2010): 414-420, doi: 10.2337/dc09-1124
84. [^](#) Dinges D.F., Rogers N.L., and Baynard M.D., ["Chronic Sleep Deprivation."](#) In "Principles and Practice of Sleep Medicine," edited by Kryger M.H., MD, FRCPC, Roth T., PhD, and Dement W.C., MD, PhD (St. Louis: Saunders, 2000)
85. [^](#) De Koninck J., Lorrain D., Christ G., Proulx G., Coulombe D., ["Intensive language learning and increases in rapid eye movement sleep: evidence of a performance factor,"](#) International Journal of Psychophysiology / Volume 8 / Issue 1 (September 1989): 43-47, doi: 10.1016/0167-8760(89)90018-4
86. [^](#) [86.0 86.1 86.2](#) Smith C.T., Nixon M.R., and Nader R.S., ["Posttraining increases in REM sleep intensity implicate REM sleep in memory processing and provide a biological marker of learning potential,"](#) Learning Memory / Volume 11 (2004): 714-719, doi: 10.1101/lm.74904
87. [^](#) Lawton M., ["Too Little, Too Late,"](#) Education Week
88. [^](#) Wahistrom K., ["Changing Times: Findings From the First Longitudinal Study of Later High School Start Times,"](#) NASSP Bulletin / Volume 86 / Issue 633 (December 2002): 3-21, doi: 10.1177/019263650208663302
89. [^](#) [89.0 89.1 89.2 89.3](#) Hobson J.A., Pace-Schott E.F., and Stickgold R., ["Dreaming and the brain: Toward a cognitive neuroscience of conscious states,"](#) Behavioral and Brain Sciences / Volume 23 / Issue 6 (2000): 793-842
90. [^](#) Wozniak P.A., ["The roots of creativity and genius"](#) (2001)
91. [^](#) Porkka-Heiskanen T., ["Adenosine in sleep and wakefulness,"](#) Annals of Medicine / Volume 31 / Issue 2 (1999): 125-129
92. [^](#) Kong J., Shepel P.N., Holden C.P., Mackiewicz M., Pack A.I., and Geiger J.D., ["Brain Glycogen Decreases with Increased Periods of Wakefulness: Implications for Homeostatic Drive to Sleep,"](#) The Journal of Neuroscience / Volume 22 / Issue 13 (July 1, 2002): 5581-5587
93. [^](#) [93.0 93.1 93.2 93.3](#) Scammell T.E., Gerashchenko D.Y., Mochizuki T., McCarthy M.T., Estabrooke I.V., Sears C.A., Saper C.B., Urade Y., and Hayaishi O., ["An adenosine A2a agonist increases sleep and induces Fos in ventrolateral preoptic neurons,"](#) Neuroscience / Volume 107 / Issue 4 (November 28, 2001): 653-663, doi: 10.1016/S0306-4522(01)00383-9
94. [^](#) Krueger J.M., Obál F., Jr, and Fang J., ["Humoral regulation of physiological sleep: cytokines and GHRH,"](#) Journal

- of Sleep Research / Volume 8 / Issue S1 (March 1999): 54-59, doi: 10.1046/j.1365-2869.1999.00009.x
95. [^](#) Krueger J.M., Obál F., Jr, Fang J., Kubota T., and Taishi P., "[The Role of Cytokines in Physiological Sleep Regulation](#)," Annals of the New York Academy of Sciences / Volume 933 (March 2001): 211-221, doi: 10.1111/j.1749-6632.2001.tb05826.x
 96. [^](#) De A., Krueger J.M., and Simasko S.M., "[Glutamate induces the expression and release of tumor necrosis factor-alpha in cultured hypothalamic cells](#)," Brain Research / Volume 1053 / Issues 1-2 (August 16, 2005): 54-61, doi: 10.1016/j.brainres.2005.06.044
 97. [^](#) Daan S., Beersma D.G., and Borbely A.A., "[Timing of human sleep: recovery process gated by a circadian pacemaker](#)," American Journal of Physiology - Regulatory, Integrative and Comparative Physiology / Volume 246 / Issue 2 (February 1984): 161-183
 98. [^](#) Akerstedt T. and Folkard S., "A model of human sleepiness." In "Sleep '90," edited by J. A. Horne (Bochum: Pontenagel Press, 1990), 310-313
 99. [^](#) Scheer F.A.J.L., Wright K.P. Jr, Kronauer R.E., and Czeisler C.A., "[Plasticity of the Intrinsic Period of the Human Circadian Timing System](#)," PLoS ONE / Volume 2 / Issue 8 (2007): e721, doi:10.1371/journal.pone.0000721
 100. [^](#) Brunner D.P., Dijk D.-J., Tobler I., and Borbely A.A., "[Effect of partial sleep deprivation on sleep stages and EEG power spectra: evidence for non-REM and REM sleep homeostasis](#)," Electroencephalography and Clinical Neurophysiology / Volume 75 / Issue 6 (June 1990): 492-499, doi: 10.1016/0013-4694(90)90136-8
 101. [^](#) Daniel P. Brunner, Derk-Jan Dijk and Alexander A. Borbely, "[Repeated Partial Sleep Deprivation Progressively Changes In EEG During Sleep And Wakefulness](#)," Sleep / Volume 16 / Issue 2 (1993): 100-113
 102. [^](#) Werth E., Achermann P., and Borbely A.A., "[II. Muscle atonia in non-REM sleep](#)," American Journal of Physiology - Regulatory, Integrative and Comparative Physiology / Volume 283 / Issue 2 (March 2002): 527-532, doi: 10.1152/ajpregu.00466.2001
 103. [^](#) Swaab D.F. and Hofman M.A., "[An enlarged suprachiasmatic nucleus in homosexual men](#)," Brain Research / Volume 537 / Issues 1-2 (December 24, 1990): 141-148, doi: 10.1016/0006-8993(90)90350-K
 104. [^](#) [104.0](#) [104.1](#) [104.2](#) Saper C.B., Scammell T.E., and Lu J., "[Hypothalamic regulation of sleep and circadian rhythms](#)," Nature / Volume 437 (October 27, 2005): 1257-1263, doi: 10.1038/nature04284
 105. [^](#) Ohta H., Yamazaki S., and McMahon D.G., "[Constant light desynchronizes mammalian clock neurons](#)," Nature Neuroscience / Issue 8 (2005): 267-269, doi: 10.1038/nn1395
 106. [^](#) Fekete M., Van Ree J.M., Niesink R.J.M., and De Wied D., "[Disrupting circadian rhythms in rats induces retrograde amnesia](#)," Physiology & Behavior / Volume 34 / Issue 6 (June 1985): 883-887, doi: 10.1016/0031-9384(85)90008-3
 107. [^](#) Chou T.C., Scammell T.E., Gooley J.J., Gaus S.E., Saper C.B., and Lu J., "[Critical Role of Dorsomedial Hypothalamic Nucleus in a Wide Range of Behavioral Circadian Rhythms](#)," The Journal of Neuroscience / Volume 23 / Issue 33 (November 19, 2003): 10691-10702
 108. [^](#) Gooley J.J., Schomer A., and Saper C.B., "[The dorsomedial hypothalamic nucleus is critical for the expression of food-entrainable circadian rhythms](#)," Nature Neuroscience / Volume 9 (2006): 398-407, doi: 10.1038/nn1651
 109. [^](#) Lu J., Zhang Y.-H., Chou T.C., Gaus S.E., Elmquist J.K., Shiromani P., and Saper C.B., "[Contrasting Effects of Ibotenate Lesions of the Paraventricular Nucleus and Subparaventricular Zone on Sleep-Wake Cycle and Temperature Regulation](#)," The Journal of Neuroscience / Volume 21 / Issue 13 (July 1, 2001): 4864-4874
 110. [^](#) [110.0](#) [110.1](#) [110.2](#) Satoh S., Matsumura H., Koike N., Tokunaga Y., Maeda T., and Hayaishi O., "[Region-dependent difference in the sleep-promoting potency of an adenosine A_{2A} receptor agonist](#)," European Journal of Neuroscience / Volume 11 / Issue 5 (May 1999): 1587-1597, doi: 10.1046/j.1460-9568.1999.00569.x
 111. [^](#) Radulovacki M., Virus R.M., Djuricic-Nedelson M., and Green R.D., "[Adenosine analogs and sleep in rats](#)," The Journal of Pharmacology and Experimental Therapeutics / Volume 228 / Issue 2 (February 1984): 268-274
 112. [^](#) [112.0](#) [112.1](#) Strecker R.E., Morairty S., Thakkar M.M., Porkka-Heiskanen T., Basheer R., Dauphin L.J., Rainnie D.G., Portas C.M., Greene R.W., and McCarley R.W., "[Adenosinergic modulation of basal forebrain and preoptic/anterior hypothalamic neuronal activity in the control of behavioral state](#)," Behavioural Brain Research / Volume 115 / Issue 2 (November 2000): 183-204, doi: 10.1016/S0166-4328(00)00258-8
 113. [^](#) [113.0](#) [113.1](#) Ficca G., Lombardo P., Rossi L., and Salzarulo P., "[Morning recall of verbal material depends on prior sleep organization](#)," Behavioural Brain Research / Volume 112 / Issues 1-2 (July 2000): 159-163, doi: 10.1016/S0166-4328(00)00177-7
 114. [^](#) Siegel J.M., Manger P.R., Nienhuis R., Fahringer H.M., and Pettigrew J.D., "[The Echidna *Tachyglossus aculeatus* Combines REM and Non-REM Aspects in a Single Sleep State: Implications for the Evolution of Sleep](#)," The Journal of Neuroscience / Volume 16 / Issue 10 (May 15, 1996): 3500-3506
 115. [^](#) Beersma D.G.M., Dijkstra D.J., Bloka C.G.H., and Everhardusa I., "[REM sleep deprivation during 5 hours leads to an immediate REM sleep rebound and to suppression of non-REM sleep intensity](#)," Electroencephalography and Clinical Neurophysiology / Volume 76 / Issue 2 (August 1990): 114-122, doi: 10.1016/0013-4694(90)90209-3
 116. [^](#) Krueger J.M., Rector D.M., Roy S., Van Dongen H.P.A., Belenky G., and Panksepp J., "[Sleep as a fundamental property of neuronal assemblies](#)," Nature Reviews Neuroscience / Volume 9 / Issue 12 (December 2008): 910-919,

doi: 10.1038/nrn2521

117. [^ Van Cauter E., Polonsky K.S., and Scheen A.J., "Roles of Circadian Rhythmicity and Sleep in Human Glucose Regulation," Endocrine Reviews / Volume 18 / Issue 5 \(October 1, 1997\): 716-738, doi: 10.1210/er.18.5.716](#)
118. [^ De Koninck J., Lorrain D., Christ G., Proulx G., and Coulombe D., "Intensive language learning and increases in rapid eye movement sleep: evidence of a performance factor," International Journal of Psychophysiology / Volume 8 / Issue 1 \(1989\): 43-47](#)
119. [^ Saper C.B., Chou T.C., and Scammell T.E., "The sleep switch: hypothalamic control of sleep and wakefulness," Trends in Neurosciences / Volume 24 / Issue 12 \(December 1, 2001\): 726-731, doi: 10.1016/S0166-2236\(00\)02002-6](#)
120. [^ Fuller P.M., Saper C.B., and Lu J., "The pontine REM switch: past and present," The Journal of Physiology / Volume 584 / Issue 3 \(November 1, 2007\): 735-741, doi: 10.1113/jphysiol.2007.140160](#)
121. [^ Siegel J.M., Sleep viewed as a state of adaptive inactivity, Nature Reviews Neuroscience / Volume 10 \(October 2009\): 747-753, doi: doi:10.1038/nrn2697](#)
122. [^ Kräuchi K., "The human sleep-wake cycle reconsidered from a thermoregulatory point of view," Physiology & Behavior / Volume 90 / Issue 2-3 \(February 28, 2007\): 236-245, doi: 10.1016/j.physbeh.2006.09.005](#)
123. [^ Crick F. and Mitchison G., "The function of dream sleep," Nature / Volume 304 \(July 14, 1983\): 111-114, doi: 10.1038/304111a0](#)
124. [^ Stickgold R. and Walker M.P., "Sleep-Dependent Memory Consolidation and Reconsolidation," Sleep Medicine / Volume 8 / Issue 4 \(June 2007\): 331-343, doi: 10.1016/j.sleep.2007.03.011](#)
125. [^ Hobson J. A., M.D. and McCarley R.W., M.D., "The brain as a dream state generator: an activation-synthesis hypothesis of the dream process," The American Journal of Psychiatry / Volume 134 / Issue 12 \(December 1, 1977\): 1335-1348](#)
126. [^ Marshall L. and Born J., "The contribution of sleep to hippocampus-dependent memory consolidation," Trends in Cognitive Sciences / Volume 11 / Issue 10 \(October 1, 2007\): 442-450, doi: 10.1016/j.tics.2007.09.001](#)
127. [^ Wilson M.A. and McNaughton B.L., "Reactivation of hippocampal ensemble memories during sleep," Science / Volume 265 / Issue 5172 \(July 29, 1994\): 676-679, doi: 10.1126/science.8036517](#)
128. [^ Buzsáki G., "The Hippocampo-Neocortical Dialogue," Cerebral cortex / Volume 6 / Issue 2 \(March-April 1996\): 81-92](#)
129. [^ Goetz R.R., Goetz D.M., Hanlon C., Davies M., Weitzman E.D., and Puig-Antich J., "Spindle characteristics in prepubertal major depressives during an episode and after sustained recovery: a controlled study," Sleep / Volume 6 / Issue 4 \(December 1983\): 369-375](#)
130. [^ Takashima A., Petersson K.M., Rutters F., Tendolkar I., Jensen O., Zwarts M.J., McNaughton B.L., and Fernández G., "Declarative memory consolidation in humans: A prospective functional magnetic resonance imaging study," PNAS / Volume 103 / Issue 3 \(January 16, 2006\): 756-761, doi: 10.1073/pnas.0507774103](#)
131. [^ Peigneux P., Laureys S., Fuchs S., Collette F., Perrin F., Reggers J., Phillips C., Degueldre C., Del Fiore G., Aerts J., Luxen A. and Maquet P., "Are Spatial Memories Strengthened in the Human Hippocampus during Slow Wave Sleep?," Neuron / Volume 44 / Issue 3 \(October 28, 2004\): 535-545, doi: 10.1016/j.neuron.2004.10.007](#)
132. [^ Plihal W. and Born J., "Effects of Early and Late Nocturnal Sleep on Declarative and Procedural Memory," Journal of Cognitive Neuroscience / Volume 9 / Issue 4 \(July 1997\): 534-547, doi: 10.1162/jocn.1997.9.4.534](#)
133. [^ ^{133.0} ^{133.1} Wozniak P., PhD and Gorzelanczyk E.J., PhD, "Hypothetical molecular correlates of the two-component model of long-term memory" \(May 1998\)](#)
134. [^ Ellenbogen J.M., Hulbert J.C., Stickgold R., Dinges D.F., and Thompson-Schill S.L., "Interfering with Theories of Sleep and Memory: Sleep, Declarative Memory, and Associative Interference," Current Biology / Volume 16 / Issue 13 \(July 11, 2006\): 1290-1294, doi: 10.1016/j.cub.2006.05.024](#)
135. [^ Klemm W.R., "Why Does REM Sleep Occur? A Wake-up Hypothesis," Frontiers in Systems Neuroscience / Volume 5 \(September 2011\), doi: 10.3389/fnsys.2011.00073](#)
136. [^ Fryer J.C.J., "Is a purpose of REM sleep atonia to help regenerate intervertebral disc volumetric loss?," Journal of Circadian Rhythms / Volume 7 \(January 5, 2009\), doi: 10.1186/1740-3391-7-1](#)
137. [^ Aserinsky E. and Kleitman N., "Regularly Occurring Periods of Eye Motility, and Concomitant Phenomena, During Sleep," The Journal of Neuropsychiatry and Clinical Neurosciences / Volume 15 / Issue 4 \(November 1, 2003\): 454-455, doi: 10.1176/appi.neuropsych.15.4.454](#)
138. [^ Peigneux P., Laureys S., Delbeuck X., and Maquet, P., "Sleeping brain, learning brain. The role of sleep for memory systems," NeuroReport / Volume 12 / Issue 18 \(December 21, 2001\): 111-124](#)
139. [^ Peirano P.D. and Algarín C.R., "Sleep in brain development rem in development," Biological Research / Volume 40 / Issue 4 \(2007\): 471-478, doi: 10.4067/S0716-97602007000500008](#)
140. [^ Walker M.P., Liston C., Hobson J.A., and Stickgold R., "Cognitive flexibility across the sleep-wake cycle: REM-sleep enhancement of anagram problem solving," Cognitive Brain Research / Volume 14 / Issue 3 \(November 2002\): 317-324, doi: 10.1016/S0926-6410\(02\)00134-9](#)
141. [^ Castellini M.A., "Sleep in Aquatic Mammals." In "Sleep-Related Breathing Disorders - Experimental Models and Therapeutic Potential" edited by David W . Carley and Miodrag Radulovacki \(New York: Marcel Dekker, Inc.,](#)

- 2002), 279-294
142. [Fountain H.](#), "[Study Gives Key Role to Sleep in Helping Brain Learn Anew](#)," The New York Times
 143. [Vyazovskiy V.V.](#), [Olcese U.](#), [Lazimy Y.M.](#), [Faraguna U.](#), [Esser S.K.](#), [Williams J.C.](#), [Cirelli C.](#), and [Tononi G.](#), "[Cortical Firing and Sleep Homeostasis](#)," *Neuron* / Volume 63 / Issue 6 (September 24, 2009): 865-878, doi: 10.1016/j.neuron.2009.08.024
 144. [Tononi G.](#) and [Cirelli C.](#), "[Sleep function and synaptic homeostasis](#)," *Sleep Medicine Reviews* / Volume 10 / Issue 1 (February 2006): 49-62, doi: 10.1016/j.smrv.2005.05.002
 145. [Huber R.](#), [Ghilardi M.F.](#), [Massimini M.](#), and [Tononi G.](#), "[Local sleep and learning](#)," *Nature* / Volume 430 (July 1, 2004): 78-81, doi: 10.1038/nature02663
 146. [146.0](#) [146.1](#) [Massimini M.](#), [Ferrarelli F.](#), [Huber R.](#), [Esser S.K.](#), [Singh H.](#), and [Tononi G.](#), "[Breakdown of Cortical Effective Connectivity During Sleep](#)," *Science* / Volume 309 / Issue 5744 (September 30, 2005): 2228-2232, doi: 10.1126/science.1117256
 147. [Ribeiro S.](#) and [Nicolelis M.A.L.](#), "[Reverberation, storage, and postsynaptic propagation of memories during sleep](#)," *Learning & Memory* / Volume 11 / Issue 6 (November 2004): 686-696, doi: 10.1101/lm.75604
 148. [148.0](#) [148.1](#) [Walker M.P.](#), "[The Role of Sleep in Cognition and Emotion](#)," *Annals of the New York Academy of Sciences* / Volume 1156 (March 2009): 168-197
 149. [Siegel J.M.](#), "[Do all animals sleep?](#)," *Trends in Neurosciences* / Volume 31 / Issue 4 (April 1, 2008): 208-213, doi: 10.1016/j.tins.2008.02.001
 150. [Squire L.R.](#), [Cohen N.J.](#), and [Nadel L.](#), "The medial temporal region and memory consolidation: A new hypothesis." In "Memory Consolidation: Psychobiology of Cognition," edited by Weingartner H. and Parker E.S. (New Jersey: Lawrence Erlbaum Associates, 1984), 185-210
 151. [McClelland J.L.](#), [McNaughton B.L.](#), and [O'Reilly R.C.](#), "[Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory](#)," *Psychological Review* / Volume 102 / Issue 3 (July 1995): 419-457
 152. [French R.M.](#), [Ans B.](#), and [Rousset S.](#), "[Pseudopatterns and Dual-Network Memory Models: Advantages and Shortcomings](#)." In "Connectionist Models of Learning, Development and Evolution: The 6th Neural Computation and Psychology Workshop, Liege, Belgium, 16-18 September 2000," edited by French R.M. and Sougné J.P. (London: Springer-Verlag London Limited, 2001), 13-22
 153. [Pavlidis C.](#) and [Winson J.](#), "[Influences of Hippocampal Place Cell Firing in the Awake State on the Activity of These Cells During Subsequent Sleep Episodes](#)," *The Journal of Neuroscience* / Volume 9 / Issue 8 (August 1989): 2907-2918
 154. [Vinogradova O.S.](#), "[Hippocampus as comparator: Role of the two input and two output systems of the hippocampus in selection and registration of information](#)," *Hippocampus* / Volume 11 / Issue 5 (October 2001): 578-598, doi: 10.1002/hipo.1073
 155. [Smith C.](#), "REM Sleep and Learning: Some Recent Findings." In "The Functions of Dreaming," edited by Moffitt A., Kramer M., and Hoffmann R. (New York: State University of New York Press, 1993), 341-362
 156. [Perry E.K.](#) and [Perry R.H.](#), "Acetylcholine and hallucinations: disease-related compared to drug-induced alterations in human consciousness," *Brain and Cognition* / Volume 28 / Issue 3 (August 1995): 240-258
 157. [Hasselmo M.E.](#), "[Neuromodulation: acetylcholine and memory consolidation](#)," *Trends in Cognitive Sciences* / Volume 3 / Issue 9 (September 1, 1999): 351-359, doi: 10.1016/S1364-6613(99)01365-0
 158. [Lee A.K.](#) and [Wilson M.A.](#), "[Memory of Sequential Experience in the Hippocampus during Slow Wave Sleep](#)," *Neuron* / Volume 36 / Issue 6 (December 19, 2002): 1183-1194, doi: 10.1016/S0896-6273(02)01096-6
 159. [Sejnowski T.J.](#) and [Destexhe A.](#), "[Why do we sleep?](#)," *Brain Research* / Volume 886 / Issues 1-2 (December 15, 2000): 208-223, doi: 10.1016/S0006-8993(00)03007-9
 160. [Steriade M.](#) and [Timofeev I.](#), "[Neuronal Plasticity in Thalamocortical Networks during Sleep and Waking Oscillations](#)," *Neuron* / Volume 37 / Issue 4 (February 20, 2003): 563-576, doi: 10.1016/S0896-6273(03)00065-5
 161. [Drummond S.P.](#), [Brown G.G.](#), [Gillin J.C.](#), [Stricker J.L.](#), [Wong E.C.](#), and [Buxton R.B.](#), "[Altered brain response to verbal learning following sleep deprivation](#)," *Nature* / Volume 403 / Issue 6770 (2000): 655-657
 162. [Siegel, J.M.](#), "[The REM Sleep-Memory Consolidation Hypothesis](#)," *Science* / Volume 294 / Issue 5544 (November 2, 2001): 1058-1063, doi: 10.1126/science.1063049
 163. [Stickgold R.](#), [Hobson J.A.](#), [Fosse R.](#), and [Fosse M.](#), "[Sleep, Learning, and Dreams: Off-line Memory Reprocessing](#)," *Science* / Volume 294 / Issue 5544 (November 2, 2001): 1052-1057, doi: 10.1126/science.1063530
 164. [Maquet P.](#), "[The Role of Sleep in Learning and Memory](#)," *Science* / Volume 294 / Issue 5544 (November 2, 2001): 1048-1052, doi: 10.1126/science.1062856
 165. [165.0](#) [165.1](#) [Vertes R.P.](#) and [Siegel J.M.](#), "[Time for the Sleep Community to Take a Critical Look at the Purported Role of Sleep in Memory Processing](#)," *Sleep* / Volume 28 / Issue 10 (October 2005): 1228-1229
 166. [Vertes R.P.](#), "[Memory consolidation in REM sleep: Dream on](#)," *Sleep Research Society Bulletin* / Volume 1 / Issue 2 (April 1995): 27-32
 167. [Vertes R.P.](#), "[A life-sustaining function for REM sleep: A theory](#)," *Neuroscience & Biobehavioral Reviews* / Volume

- 10 / Issue 4 (Winter 1986): 371-376, doi: 10.1016/0149-7634(86)90002-3
168. [^](#) Vertes R.P. and Eastman K.E., "[The case against memory consolidation in REM sleep](#)," Behavioral and Brain Sciences / Volume 23 / Issue 6 (December 1, 2000): 867-876
169. [^](#) Wagner U., Gais S., Haider H., Verleger R. and Born J., "[Sleep inspires insight](#)," Nature / Volume 427 (January 22, 2004): 352-355, doi: 10.1038/nature02223
170. [^](#) Stickgold R., PhD and Walker M.P., PhD, "[Sleep and Memory: The Ongoing Debate](#)," Sleep / Volume 28 / Issue 10 (October 2005): 1225-1227
171. [^](#) Qin X., Byrne M., Xu Y., Mori T., and Johnson C.H. [Coupling of a Core Post-Translational Pacemaker to a Slave Transcription/Translation Feedback Loop in a Circadian System](#)," PLoS Biology / Volume 8 / Issue 6 (June 15, 2010): e1000394, doi:10.1371/journal.pbio.1000394
172. [^](#) Tomita J., Nakajima M., Kondo T., and Iwasaki H., [No transcription-translation feedback in circadian rhythm of KaiC phosphorylation](#)," Science / Volume 307 / Issue 5707 (January 14, 2005): 251-254
173. [^](#) Xu Q, MD, PhD, Song Y, MD, ScD, Hollenbeck A., PhD, Blair A., PhD, Schatzkin A., MD, PhD, and Chen H., MD, PhD, "[Day Napping and Short Night Sleeping Are Associated With Higher Risk of Diabetes in Older Adults](#)," Diabetes Care / Volume 33 / Issue 1 (January 2010): 78-83. doi: 10.2337/dc09-1143
174. [^](#) Walker M.P., [Cognitive consequences of sleep and sleep loss](#)," Sleep Medicine / Volume 9 / Supplement 1 (2008): 29-34