

Feedback loops for exercise (VO2Max)

by Elizabeth 17th Mar 2025

The perfect exercise doesn't exist. The good-enough exercise is anything you do regularly without injuring yourself. But maybe you want more than good enough. One place you could look for insight is studies on how 20 college sophomores responded to a particular 4 week exercise program, but you will be looking for a long time. What you really need are metrics that help you fine tune your own exercise program.

VO2max (a measure of how hard you are capable of performing cardio) is a promising metric for fine tuning your workout plan. It is meaningful (1 additional point in VO2max, which is 20 to 35% of a standard deviation in the unathletic, is correlated with 10% lower annual all-cause mortality), responsive (studies find exercise newbies can see gains in 6 weeks), and easy to approximate (using two numbers from your fitbit).

In this post I'm going to cover the basics of VO2max, why I estimate such a high return to improvements, and what kind of exercise can raise it the fastest.

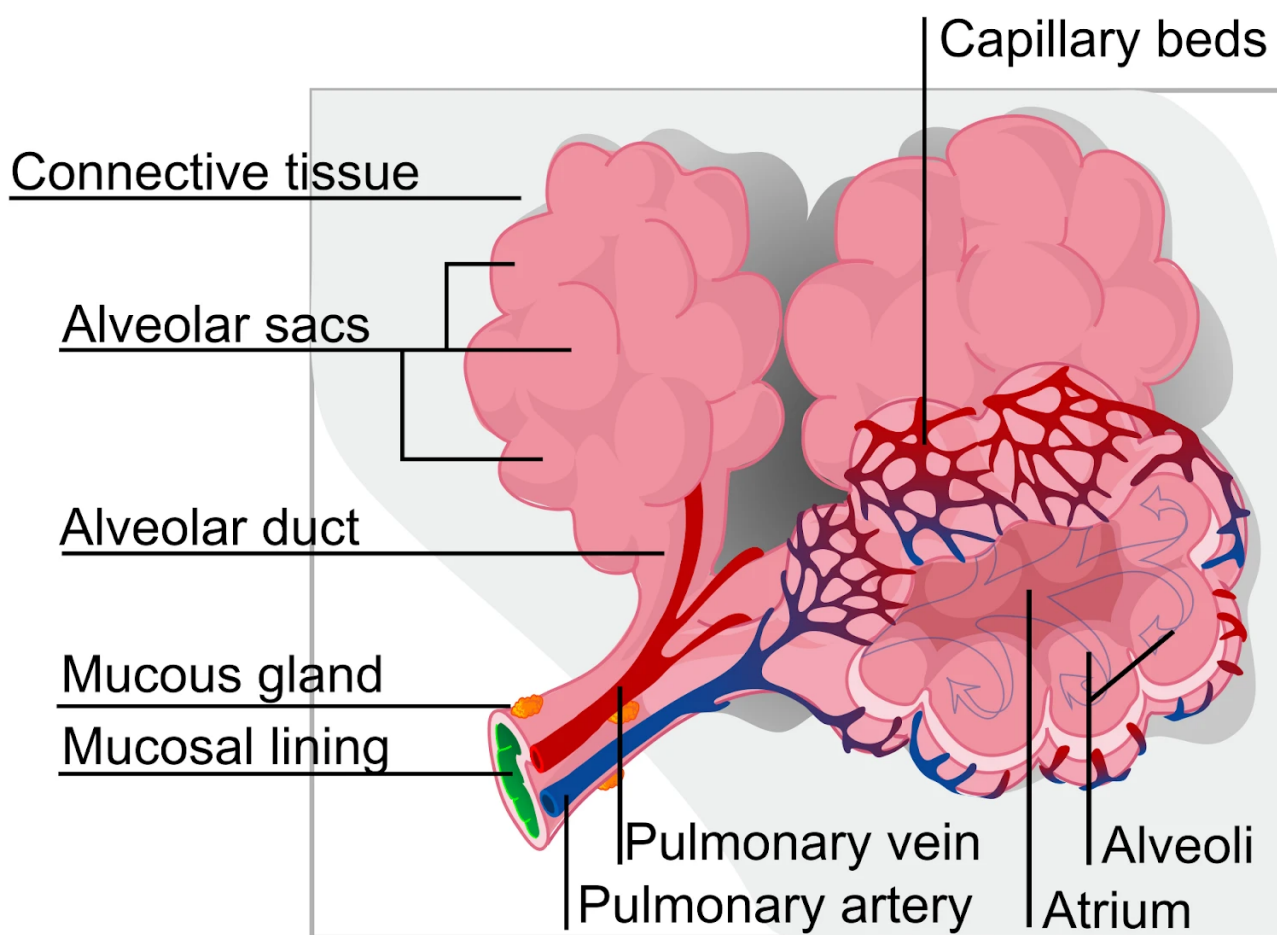
What is VO2max?

A person's VO₂ max is the maximum volume of oxygen they can consume in one minute. Higher VO2max lets you cardio more intensely, and is correlated with better health and longer lifespan (we'll quantify this later). This is 100% of what you need to know, the rest is thrown in for fun.

VO2max is measured in ml O₂/kg bodyweight/minute. It is sometimes given in Metabolic Equivalents (METs). 1 MET = 3.5ml O₂/kg of bodyweight/minute. This is approximately your metabolic expenditure while sitting still.

What physically causes increase in VO2max? It's a mix of many factors:

1. Strengthened heart allows you to pump blood faster
2. Improved lung capacity, which breaks down to
 - a. Expansion of the chest cavity, in part due to strengthening of the diaphragm and rib muscles.
 - b. Recruitment of new alveoli (the features in your lungs that exchange carbon dioxide and oxygen)



([source](#))

3. Improved lung elasticity
4. Production of a surfactant that maintains alveoli in fighting form
3. Increased mitochondrial activity allows cells (especially muscle cells) to use more oxygen
4. More blood to carry the oxygen
5. New capillaries grow to deliver more blood to your muscles

What can induce these changes? Exercise, especially high intensity interval training. We'll talk more about that in a bit.

Why do I care about VO2Max?

Obligatory boring part: VO2max is a crude measurement whose impact depends on many factors blah blah blah

Shocking headline: **1 MET (aka 3.5 points VO2max) = 10% reduction in relative risk of all-cause mortality.** So if your normal risk of death is 1%, gaining one MET would lower it to 0.9%).

The catch: that meta-analysis averaged together results from multiple studies of very different durations. "That's okay, they could correct for that, at least crudely" you might be saying to yourself, in which case, congratulations on being better at meta-analysis than these authors, who AFAICT dumped every study into a bag and shook it.

More realistic, yet more shocking headline: an increase of 1 point in VO2max is correlated with 10% lower annual all-cause mortality

correlated with 10 % lower annual all cause mortality.

This is based on the largest study in the meta-analysis, [Kokkinos et al.](#) Important facts from this study include:

1. In [male veterans](#), going from low fitness to moderate fitness (defined below) lowered risk of dying by 40%. This was shockingly consistent across age groups, and whether you considered a 5 year or 10 year period. Getting to a high fitness level dropped their mortality rate by another 30%.
2. I too am wondering why the % change in risk of death doesn't get larger when you consider a longer period of time.

Table 4. Average 5- and 10-Year Mortality Risks Across Fitness Categories for the Different Age Groups

Age, y	>2 METs Below Threshold (Least-Fit), %		2 METs Below Threshold (Low-Fit), %		Threshold Category, %		2 METs Above Threshold (Moderate-Fit), %		>2-4 METs Above Threshold (Fit), %		>4 METs Above Threshold (High-Fit), %	
	5-y Risk	10-y Risk	5-y Risk	10-y Risk	5-y Risk	10-y Risk	5-y Risk	10-y Risk	5-y Risk	10-y Risk	5-y Risk	10-y Risk
<50	6.0	13.2	4.8	10.7	4.0	8.9	2.9	6.5	2.5	5.7	2.0	4.5
50-59	10.2	22	8.3	18	6.9	15.2	5.0	11.1	4.4	9.9	3.4	7.7
60-69	15.6	32.3	12.7	26.8	10.7	22.8	7.7	16.9	6.9	15.1	5.4	11.9
≥70	24.8	48.1	20.4	40.7	17.2	35.2	12.6	26.7	11.3	24.0	8.8	19.1

3. MET indicates metabolic equivalent.
 - a. The middle (“threshold”) range for 4 age categories were 8 to 9, 7 to 8, 6 to 7, and 5 to 6 METs for <50, 50 to 59, 60 to 69, and ≥ 70 years, respectively. Another source gives [average MET](#) for those categories (substituting 40-50 for <50 and 70-80 for >70) as 10, 8.6, 7.3, and 6.1, so the threshold starts 1-2 points lower than average and they converge by your 70s.
4. Low fitness is the range between the floor of the threshold, and 2 METs lower than that, moderate fitness is the ceiling of the threshold plus 2 METs. If distribution within buckets were uniform, we could treat moving from low fitness to moderate fitness as an increase of 2 METs. If you assume a normal distribution centered around the threshold, it's somewhat smaller than that.I went with the latter assumption, but not very rigorously.

Caveats

VO2max is measured per kg of total body weight, not lean weight. That means that if you lost 10% of your bodyweight via liposuction but otherwise stayed exactly the same, your VO2max would rise by 1/0.9. This makes VO2max a partial proxy for weight. However the relationship between weight and health, and weight and exercise, is much more complicated than is typically acknowledged.

VO2 is also a proxy for exercise. Right now we don't have enough information to say that increased VO2, or increased aveoli surfactant, increases lifespan or is merely downstream of exercise that does some other helpful thing.

I'm going to ignore both of these for now, but when you're doing your own math you should not add effects from potential weight loss, because that might be double counting.

Exercise science sucks. Lifespan is affected by 1000 different factors, none of which scientists can properly control. Lots of researchers have their bottom line already written.

While we're at it, I should note that I haven't done deep investigations on any other metrics. Very early in the process I considered others, and VO2max won due to a combination of being promising and easy to measure at home. I don't have the information to say if VO2max is more or less accurate than other metrics.

How can I measure my VO2Max?

(note: this section is based primarily off of Client's research, not mine)

The official way involves a mask and measuring equipment and 20 minutes of excruciatingly intense exercise. This is technically the most accurate, but only if it's set up properly, and is expensive. If you'd like to trade accuracy for ease, use this formula

$$\text{VO2max} \approx (\text{HRmax}/\text{HRrest}) * \text{magic_constant}$$

If you would like to get a number without understanding it, you can enter your heart rate in this [spreadsheet](#). If you would like to learn about the magic constant, I've defined the terms below.

- HRRest is your lowest heart rate when measured first thing in the morning, or ask your friendly neighborhood wearable.
- HRMax is your heart rate after exercising at ever increasing intensity until you cannot stand it. If you don't know this, you can use $208 - 0.7 * \text{age}$. However if you do so you'll miss any gains that come from increasing your maximum heart rate, which I'd expect to be at least half.
- $\text{magic_constant} = 17.27 - 0.08 * \text{age} - 0.59 * \text{BMI_category} - 0.40 * \text{smoking_status} + 0.14 * \text{TPA}$
- BMI_category =
 - normal: 0
 - overweight: 1
 - obese: 2
- smoking_status:
 - never: 0
 - former: 1
 - current: 2
- TPA (total physical activity) =
 - moderate: 2 (< 43 MET hours / day)
 - active: 1 (43 – 50 MET hours / day)
 - highly active: 0 (> 50 MET hours / day)
 - This definition is circular, because MET hours is a function of hours exercised * exertion level. A decent level of physical fitness will burn 10 MET per hour of very intense exercise.

You may be tempted to use wearable-calculated VO2Max. This is a bad idea because your

you may be tempted to use wearable-calculated VO_2Max . This is a bad idea because your device has no way to separately track how hard you are working from how hard your heart is beating (Apple Watch attempts this, but simplifies things by assuming all exercise is running on a flat surface).

What are you aiming for? Here is a convenient chart ([source](#)). This is measured in ml/kg/min, not METs.

Normative data (Heywood 2006)^[7] for Female (values in ml/kg/min)

Age	Poor	Fair	Good	Excellent	Superior
20 - 29	<36	36 - 39	40 - 43	44 - 49	>49
30 - 39	<34	34 - 36	37 - 40	41 - 45	>45
40 - 49	<32	32 - 34	35 - 38	39 - 44	>44
50 - 59	<25	25 - 28	29 - 30	31 - 34	>34
60 - 69	<26	26 - 28	29 - 31	32 - 35	>35
70 - 79	<24	24 - 26	27 - 29	30 - 35	>35

Normative data (Heywood 2006)^[7] for Male (values in ml/kg/min)

Age	Poor	Fair	Good	Excellent	Superior
20 - 29	<42	42 - 45	46 - 50	51 - 55	>55
30 - 39	<41	41 - 43	44 - 47	48 - 53	>53
40 - 49	<38	38 - 41	42 - 45	46 - 52	>52
50 - 59	<35	35 - 37	38 - 42	43 - 49	>49
60 - 69	<31	31 - 34	35 - 38	39 - 45	>45
70 - 79	<28	28 - 30	31 - 35	36 - 41	>41

How can I raise my VO_2Max ?

The best exercise is still the one you do consistently without injuring yourself.

Optimization within that is for people who have many choices they enjoy, or who don't enjoy any but can nonetheless force themselves to work out reliably.

The next best exercises appear to be rich people sports (lifespan wise, you're better off being an amateur racquetballer than an olympic marathoner, despite racquetball's barely-above-average VO_2max). I didn't find numbers for polo players but I assume they're stunning. We're going to ignore these findings even though the papers claim to have controlled for income.

After that, you have two choices: high intensity interval training (HIIT), and using cross country skiing as your regular mode of transportation.

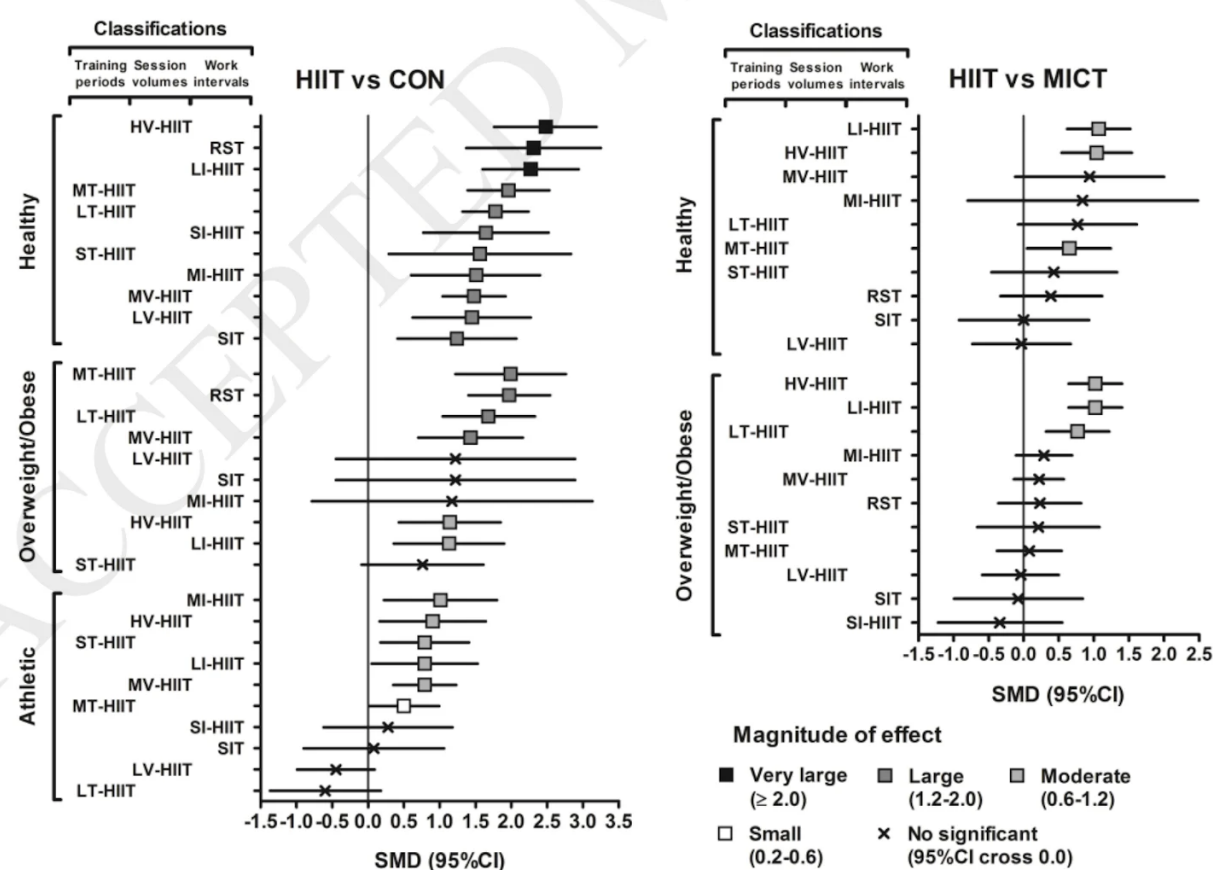
Why those two? No one has proven an answer, but my wild ass speculation is that you raise VO_2max by proving to your body that your existing VO_2max is insufficient. You do this by operating at capacity. Since it's impossible to operate at peak capacity for very long, this can be done in the form of interval training, or by working at near-peak capacity for so long that it uses up your reserves. Or so I surmise.

Back to the literature: within interval training, the number one most important property is still that you do it at all, followed by how much you do it, with one possible cheat. According to this [meta-analysis](#) even short interval, low volume, low calendar-time was beneficial, but in order to beat moderate-intensity exercise you need to work a little harder: intervals of >2 minutes, total time of >15 minutes, and at least 4 weeks (number of times per week was not specified, but in other papers it was 2-3).

What's the cheat? Repeated Sprint Training (RST), in which you go absolutely balls out for 10 seconds and then take a nice 2-4 minute gentle stroll. I love RST because there's a little bit of lag between working very hard and being miserable, and that lag is longer than the interval. By the time the misery catches up with me I've already stopped trying. So I'd really like to believe this, but ShortIT (10-30 second intervals) scored poorly relative to longer intervals, so there's either some sort of horseshoe effect or the success of RST is a mirage.

Here is the full chart from that paper, which is beautiful except for its absolutely incomprehensible labels. Translations below.

Fig. 2 Magnitude of effect by different protocols of HIIT in different population



Within Training Periods (how many weeks people exercised according to the plan), the options are short (≤ 4 weeks), medium, and long term (≥ 12 weeks).

Within Session Volume, the options are low (≤ 4 cumulative minutes under load), medium, and high (≥ 16 minutes of work). Please join me in a moment of annoyance that L sometimes mean smallest and sometimes biggest.

Within Work Intervals (duration of a single intense bout), the options are short, medium, long, very very short (SIT) (10-30s) and itty bitty (RST) (10s).

MICT stands for “moderate intensity cardio training”, aka non-HIIT exercise. CON stands for control. The longer you go (in calendar time) the less of an advantage HIIT has over MICT, which suggests they are both approaching the same asymptote, HIIT just gets there faster.

SMD stands for “standard mean difference”, which is the difference of the means of the treatment and control groups, divided by the standard deviation. The size of SMD differs

between the treatment groups, but you can round it to 3 ml O₂/kg body weight/person.

What if I already exercise?

In [one study](#), even Olympic athletes were able to raise VO₂max via HIIT training (albeit slower than couch potatoes). If you're not specifically targeting peak capacity, you can probably improve it. However I believe this asymptotes, so if you're already doing HIIT in particular there may not be much gains left on the table. The client who commissioned this research was a hard-core pilates practitioner and he did not find HIIT to increase his VO₂.

Next Steps

I am not a doctor, nor do I hold any other relevant qualifications. But if you're full of inspiration to follow up on this, here is my suggested plan:

1. Estimate your VO₂Max as described above, or use the [spreadsheet](#).
2. Identify a form of exercise that is highly accessible to you, that can be done safely at very high intensity.
 - a. The more of your body it uses the better, but prioritize lowering obstacles. if your office only has an exercise bike that's better than needing to travel to an elliptical, even though the elliptical uses your arms and the bike doesn't.
3. If you're new to exercise, spend a few sessions playing around on your activity of choice, to get a sense of where your limits are.
4. If you believe the research on RST (10 seconds of peak exertion followed by 3 minutes of barely moving. If your environment is cold enough you shouldn't even sweat), do that.
5. If you don't believe the research on RST, gradually increase your time under intensity until you reach 4 non-continuous minutes under intense load.
 - a. If your intense intervals are longer than 2 minutes they're probably not actually peak intensity, so you should have at least 2.
 - b. Especially at first, aim for sustainability rather than peak achievement. If going 20% slower is the difference between quitting or sticking through it, slower is obviously the correct choice. You can build up over time.
6. After 6 weeks, estimate VO₂max again. The meta-analysis described above suggests you can expect at least 1 MET (3.5 ml O₂/kg body weight/min) over 6 weeks.

Thanks to anonymous client and my [Patreon patrons](#) for supporting this post.

13 comments, sorted by top scoring

[-] **Richard_Kennaway** 1y* ▼ 7 ▲ ✕ 0 ✓

The measure of fitness I use for my own training, because measuring it is built into the exercise bike, is Functional Threshold Power, or FTP. It is defined as the maximum power output that you can sustain for 1 hour, measured in watts. The obvious way of measuring this is to get on the bike for an hour, but there are shorter ways of estimating it, e.g. do 20 minutes as hard as you can, and the bike will derate your average output by some fixed amount.

Any comments on the usefulness of this compared with VO2max? VO2max measures the very hardest effort you can reach, even momentarily, while FTP measures the hardest you can sustain indefinitely.

[-] **MichaelDickens** 1y ▼ 2 ▲ ✕ 0 ✓

Not OP but I think Functional Threshold Power is fine. I don't know of any literature directly comparing it to VO2max, but much of the literature on VO2max didn't actually measure VO2max, it used proxies like "maximum gradient at which a participant can walk for 3 minutes" (called the [Balke treadmill test](#)). When meta-analyses report that VO2max strongly predicts health outcomes, what they usually* mean is "VO2max, and also various proxies for VO2max, when thrown together into a meta-analysis, strongly predict health outcomes". So as far as I can tell from what (little) research I've looked at, there are a lot of metrics that work and it's not clear which ones work better than others. And FTP seems like as good a measure as any.

For example, have a look at Table 2 in [Impact of Cardiorespiratory Fitness on All-Cause and Disease-Specific Mortality: Advances Since 2009](#), which gives a list of studies and what measure each study used. You can see that they used a variety of fitness metrics.

*I've only actually looked at two meta-analyses

[-] **rai** 8mo ▼ 2 ▲ ✕ 0 ✓

Do you have any idea of how to use FTP as a proxy if one cares about longevity? I have a bike so installing a power meter would be way easier than doing VO2 max tests and the calculator you provided is too coarse to give me confidence that I'm hitting thresholds I want to hit.

[-] **Shri Samson** 1y* ▼ 2 ▲ ✕ 0 ✓

TPA (total physical activity) =

- moderate: 2 (< 43 MET hours / day)
- active: 1 (43 – 50 MET hours / day)
- highly active: 0 (> 50 MET hours / day)
- This definition is circular, because MET hours is a function of hours exercised * exertion level. A decent level of physical fitness will burn 10 MET per hour of very intense exercise.

Is this backwards? I'd expect higher numbers for activity to be associated with greater VO2 max in the regression formula, and in the [spreadsheet you've given](#) the label indicates a 0 for low activity and 2 for highest activity, so one of these should be corrected.

[-] **Elizabeth** 1y ▼ 3 ▲ ✕ 0 ✓

Thank you, I'm going to investigate this.

[-] **williawa** 1y ▼ 2 ▲ ✕ 1 ✓

Why not just use resting heartrate? That also has very good empirical backing as a good proxy for overall health, and its much easier to measure.

[–] **Hide** 1y 4 ^ 1 ✓

A high VO2 Max is a superior metric. It is harder to achieve, and more predictive of health outcomes.

It's possible and even somewhat common to have a low resting heart rate with a below average VO2 max, but it's virtually impossible to have a high VO2 max and a high resting heart rate.

[–] **CamillePerrin** 1y 1 ^ 0 ✓

VO2max is not always the limiting factor to performance. For beginner, technique improvement can deliver increase in endurance due only to the increased efficiency of movement form. Similarly, as you don't operate close to VO2max for long, other factors are important such as lactate tolerance, or even just psychological tolerance to distress.

This last point is particularly relevant for VO2max estimation, as a beginner is liable to feel that an effort is, subjectively, insurmountable, when objectively they still had metabolic reserve. Which will lead to overestimation of progress through initial underestimation of HRmax. I personally speculate this is what is behind the HIIT results, given its "taxing" nature.

So I would advocate for using as trainable number-go-up metric the normal performance figure of your sport of choice (minute per mile, rowing split time...), possibly supplemented with a percentile table for your age.

[–] **Mo Putera** 1y 1 ^ 0 ✓

Your second paragraph is a great point, and makes me wonder how much to adjust downward the post's main "why care?" argument (that 1 additional point in VO2max ~ 10% lower annual all-cause mortality). It's less clear to me how to convert marginal improvements in my sport of choice to marginal reduction in all-cause mortality though.

[–] **philip_b** 1y* 1 ^ -2 ✓

What benefits does raising VO2Max give one in normal life? I think we'll probably either die from AI in 2 to 20 years, or transform ourselves in the singularity, hence prolonging my life via improving health is not important. Thus I ask: what benefits does raising VO2Max give me now?

[–] **Dennis Towne** 1y 2 ^ 0 ✓

It's a risk hedge, it has social benefits, and it has capacity / functionality benefits.

Risk hedge: If AI doesn't kill us, there will be a time lag between now and when we can transform ourselves/ obsolete our biology. Maintaining your current biological hardware increases the odds of getting to the transformation state. If you're old (like me), this matters *a lot*.

Social benefits: Being in shape changes how you look, and that improves how other people treat you. Depending on how social you are, this may have a lot or very little impact.

Capacity / functionality: If you can run a mile, you can walk a mile without getting tired. You can climb stairs more easily, you can rush across an airport to catch a flight, you can carry your groceries in one trip instead of two. It's like the saying goes: if you're deadlifting 250 pounds, you're not going to throw out your back picking up your kid.

For me, the big one is hardware maintenance until I can upload. Uploading is at least two decades out (probably more like five). My odds of getting there are materially better if I put effort into hardware maintenance now.

[–] **Grayson Chao** 1y 2 ^ 0 ✓

It's thought that having a higher VO2Max can improve various 'quality of life' markers like cognitive functioning (particularly sustained attention and working memory) and sleep quality.

[+] **Deii** 1y -6 -1

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