Cardio

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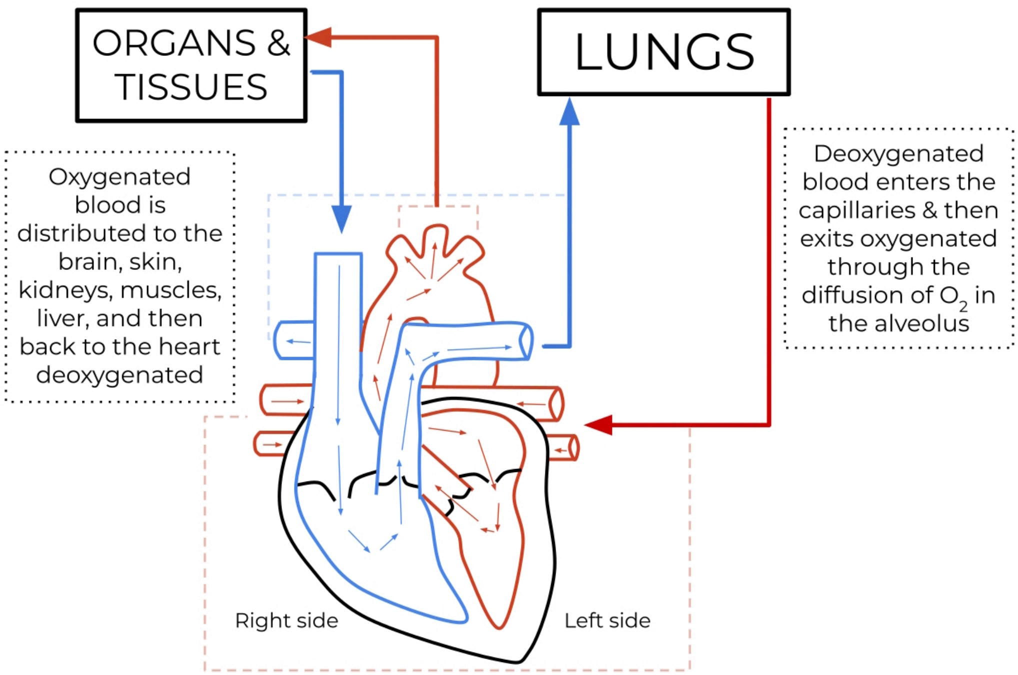
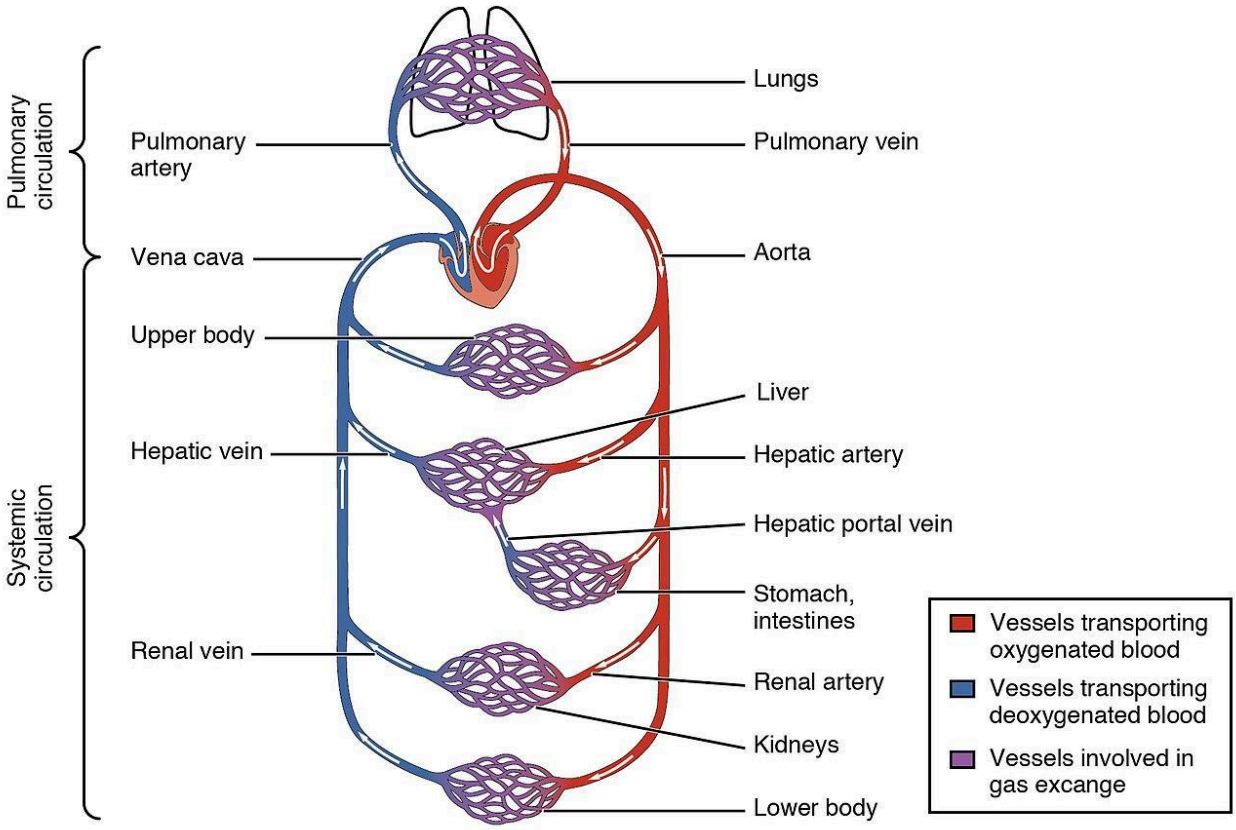
The cardiorespiratory system

The cardiorespiratory ('heart and breathing') system includes the heart, blood vessels, lungs and associated structures. Its main job is to deliver oxygen to tissues and remove carbon dioxide and other waste products. The heart muscle, in particular its left ventricular chamber, pumps oxygen-rich blood to our skeletal muscles and other organs. The blood travels there via our arteries and smaller arterioles. Capillaries transfer the oxygen (O_2) and nutrients to our organs while receiving cardio dioxide and metabolic waste products (gas exchange). The deoxygenated blood returns to the heart via our veins and smaller venules. The heart then pumps the blood out into the lungs so that they can expel the carbon dioxide and soak up new oxygen. This blood goes back to the heart and so the cycle repeats.





Cardiopulmonary circulation in the body.

Good question: how does blood flow back to the heart without the pumping force of the heart, often against gravity?

The cardiorespiratory system is ingenious. Veins have one-way valves and the veins compress when nearby muscles contract, pushing blood towards the heart. This automatically improves blood flow during physical activity, when it's needed most. In addition to this muscle pump effect, there's also a respiratory pump effect. As we breathe in (inspiration), our lunges fill with air and our diaphragm moves down. This increases abdominal pressure while reducing chest pressure, thereby causing upward pressure in the circulatory system, pushing blood from the abdominal organs towards the heart. Expiration occurs largely passively at rest as the air leaves our lungs, so everything is highly efficient.

Muscles need oxygen for aerobic energy production and removing waste products delays fatigue, so cardiorespiratory training ('cardio') increases your endurance. Cardio for performance is therefore also called endurance training. Training the cardiorespiratory tissues is also great for your health, especially cardiovascular health. The third main reason people do cardio is to burn fat. Let's go into each to determine whether you should do cardio and if so, how to implement it in your training program.

Cardio for health

You learned about the health benefits of cardio in the health science module of the course, but here we'll go into the specifics of how much and what in a bit more detail. Aerobic exercise offers unique health benefits compared to strength training, especially for the cardiovascular system, but the optimal amount of cardio is complicated to estimate, because there's significant overlap in health benefits from strength training, cardio and our general physical activity level (e.g. step count). The US Office for Disease Prevention and Health Promotion has done a reasonable, evidence-based job of synthesizing the evidence with its physical activity guidelines.

Official guidelines

- "Adults should move more and sit less throughout the day. Some physical activity is better than none. Adults who sit less and do any amount of moderate-to vigorous physical activity gain some health benefits.
- For substantial health benefits, adults should do at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) a week of moderate-intensity, or 75 minutes (1 hour and 15 minutes) to 150 minutes (2 hours and 30 minutes) a week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity. Preferably, aerobic activity should be spread throughout the week.
- Additional health benefits are gained by engaging in physical activity beyond the equivalent of 300 minutes (5 hours) of moderate-intensity physical activity a week.
- Adults should also do muscle-strengthening activities of moderate or greater intensity and that involve all major muscle groups on 2 or more days a week, as these activities provide additional health benefits."

These guidelines generally align with a 2025 global consensus statement on optimal exercise recommendations for enhancing healthy longevity in older adults, which recommended 2-3 workouts of resistance training and 3-7 sessions of moderate aerobic exercise per week. Moderate intensity aerobic exercise is generally defined as being at 50-70% of your maximum heart rate, around half of maximum mental effort with an oxygen consumption of 3 to 6 times resting levels (= Metabolic Equivalent of Task or MET). Practically speaking, this means you can still talk but not sing. Very brisk walking or light jogging tends to fall into this category, depending on your fitness level.

These guidelines are supported by a great deal of evidence.

- High-intensity aerobic exercise is more time-efficient to induce cardiovascular adaptations than moderate-intensity, steady-state cardio, according to a 2024 systematic review of RCTs. So need less time of higher-intensity exercise to get maximal health benefits.
- A meta-analysis of cohort studies by Arem et al. (2015) found that meeting the lower end of the activity guidelines (75 vigorous-intensity or 150 moderate-intensity min/wk) was associated with nearly the maximum longevity benefit, consisting of a 31% lower mortality risk. Going up to 3-5x the minimum only reduced mortality by an additional 8%.
- A massive meta-analysis of prospective cohort studies by Garcia et al. (2023) had similar findings. Physical activity equivalent to the recommended 150 min/week of moderate-to-vigorous aerobic physical activity (8.75 mMET-hours/week) was associated with 31% lower all-cause mortality. Double the physical activity was associated with a small further risk reduction. Beyond that, any effects became unclear.
- A large-scale cohort study of over 400k adults by Coleman et al. (2022) found near-maximal mortality risk reduction (29%) was achieved with 3 hours per week of aerobic activity, with additional benefits from 1 hour of strength training. Over

half the risk reduction from aerobic activity was achieved in the first hour of aerobic exercise per week.

However, individual study results vary greatly. Some studies have essentially found that the fitter you are, the longer you'll live. For example, a huge 2011 meta-analysis of cohort studies by Samitz et al. found no clear evidence of a plateau in health benefits. 5 Hours of moderate to vigorous physical activity per week resulted in almost double the reduction in all-cause mortality of 2.5 hours. A 2022 meta-analysis of cohort studies by Han et al. also found that individuals in the top third of cardiorespiratory fitness had substantially lower all-cause mortality (risk ratio 0.67 vs low fitness) than individuals with intermediate fitness (risk ratio 0.47 vs low fitness). In contrast, other studies have found far lower ceiling effects in health improvements from exercise. For example, a meta-analysis by Pedisic et al. (2020) on prospective cohort studies on joggers/runners found no significant dose-response at all. Runners had 27% lower all-cause mortality than non-runners, but training frequency, volume or intensity did not seem to have any further effects. All in all though, the US guidelines are very reasonable.

Strength training

The US guidelines recommend 5 hours of weekly aerobic exercise, or 2.5 hours if it's of high intensity, on top of strength training 2x per week, to be in near-perfect health. For *optimal* health, you indeed probably need to do both cardio and strength training, as they provide different health benefits to some degree. In support of this, a 2018 meta-analysis and a large-scale 2022 prospective analysis found that individuals who adhered to both strength and endurance training official physical activity guidelines had lower all-cause mortality than people who adhered to only either or neither one. Similar findings have been reported for cancer mortality.

However, for lifters doing more than 2 hours of strength training per week, adding 5 more hours of cardio may be excessive due to its overlapping health effects. Strength training provides some level of cardiovascular fitness too, in particular if you do full-body workouts with combo sets and moderate-to-higher reps [2, 3, 4]. In fact, 10-rep squat sets technically qualify as high-intensity cardiovascular activity: “the levels of VO2 relative to VO2max and the highest heart rate relative to maximal heart rate clearly showed that multiple sets of resistance exercise could be considered as vigorous- or high-intensity cardiovascular activity.” Similarly, bodybuilding posing “meets the criteria for vigorous exercise intensity” based on its Metabolic Equivalents (METs) and heart rate responses. Therefore, strength training workouts beyond 2 a week should logically qualify for some of the total weekly physical activity target. However, strength training will only give you a certain level of aerobic fitness, including VO_2max. Endurance training is required to elevate it into the excellent range. So some cardio will most likely remain necessary for those seeking perfect health. Near-maximal health benefits will probably be obtained in an hour of vigorous cardio for lifters already training 5+ times per week, if you do full-body workouts with combo sets.

Daily physical activity level

High daily step counts, or physical activity of any kind, can also offer similar health benefits as aerobic exercise. Epidemiological research supports that the total weekly volume of physical activity is more important than the intensity and frequency: high step counts can reduce all-cause mortality and hypertension as much as endurance training [2]. A 5-year RCT study on older adults by Stensvold et al. (2020) even found no significant effect of adding 2 days of either moderate-intensity cardio or high-intensity interval training (HIIT) on all-cause mortality in subjects who were already moderately active for at least 30 minutes a day. Endurance training is very time-efficient for health benefits, but you can compensate for lack of endurance training with a higher step count to a large extent, especially if you also do strength training.

Conclusion

In sum, for absolutely perfect health, you'll likely need to perform some volume of strength training, endurance training and regular daily physical activity. However, your total weekly volume of physical activity is likely most important, with higher-intensity exercise counting more than lower-intensity physical activity. Moreover, there are strong diminishing returns to higher volumes of physical activity. Most benefits are obtained in the first few hours per week. Beyond that, the increase in your longevity is most likely below the time spent exercising, so forcing yourself to do more exercise than you like just for the health benefits will at that point result in a negative return on investment in terms of time input vs life extension.

Now let's turn to cardio for performance, i.e. endurance training.

Cardio for performance

Endurance training is not the primary focus of this course, but we'll provide you with the fundamentals based on current consensus knowledge. The cardiovascular system can become more efficient with exercise via various mechanisms. Interestingly, our pulmonary system (incl. our lungs) does not adapt much to exercise, as ventilation and pulmonary respiration are generally not limiting factors for oxygen transport until someone reaches elite training status.

Breathing, ventilation and respiration: what's the difference?

Ventilation and respiration are technical terms for different parts of breathing.

- Ventilation refers to the airflow in the lungs, the mechanical process of breathing.
- Respiration refers to the metabolic transport of gases, specifically oxygen going into the blood and carbon dioxide coming out, either in the lungs (external respiration) or in the tissues (internal respiration).

Cardiovascular adaptations

- The heart muscle enlarges (left ventricular hypertrophy). A bigger heart chamber consisting of stronger muscle makes it a stronger pump with a higher stroke volume: it can eject more blood with each heartbeat.
- Our plasma volume, the liquid portion of our blood, expands, increasing total blood volume and reducing its viscosity. This less viscous blood moves more easily through our blood vessels. A higher venous return automatically results in a higher stroke volume (Frank-Starling mechanism): the increased blood inflow stretches the heart muscle, putting it at a more favorable length-tension relationship and increasing its force output per contraction, resulting in a higher

stroke volume and higher cardiac output (= stroke volume × heart rate). A higher plasma volume also provides more hydration available for sweating. Sweating helps cool us off and prevent heat-related fatigue. Controlling temperature is called thermoregulation.

- Our blood vessels become bigger to improve blood flow. They also develop thinner walls, making them more elastic and easier to expand (vasodilation) to increase blood flow. Reduced blood vessel stiffness and improved arterial compliance also decreases resting blood pressure.
- We produce more red blood cells. Red blood cells contain hemoglobin to transport oxygen.

Muscular adaptations

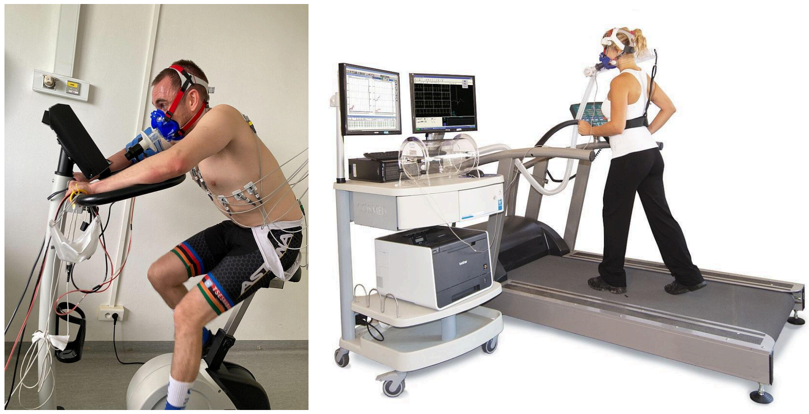
- Capillary density in our muscles increases, improving gas exchange so that our muscles can more easily absorb oxygen and nutrients while getting rid of carbon dioxide and metabolic waste products.
- Mitochondrial density in our muscles increases. Mitochondria are our muscles' energy production centers, so more mitochondria means more energy can be produced.
- Our muscles store more myoglobin, a protein that stores and facilitates the release of oxygen, similar to hemoglobin's role in blood, but within muscle cells.
- Our muscles store more glycogen and triglyceride as fuel reserves.
- Economy of movement improves: less oxygen is used for the same workload due to higher neuromuscular and biomechanical efficiency.

These endurance training adaptations will show up in the following measures of performance. Compared to strength training adaptations, endurance training adaptations occur quickly. Very robust improvements in endurance performance can be achieved in just 3 months. However, you also lose the gains relatively quickly with significantly reduced performance in as little as 2 weeks without exercise.

- Improved time to exhaustion: you'll tolerate any given workload longer due to delayed fatigue.
- Improved recovery: after exercise and in between sets, your heartrate and lactate levels return to baseline faster.
- The respiratory exchange ratio (RER) during exercise increases: given a certain submaximal training intensity, endurance-trained individuals burn more fat as fuel.
- The lactate threshold moves up to a higher percentage of VO_2max: you can exercise at a higher intensity without accumulating metabolic stress.
- VO_2max increases.

VO_2max

The best single measure of overall cardiorespiratory fitness is generally considered to be someone's rate of maximal oxygen uptake. The most common metric is VO_2max ('maximum volume of oxygen uptake'), measured in milliliters of oxygen per kilogram of body mass per minute (mL/kg/min). It's essentially the endurance equivalent of 1RM strength to bodyweight. VO_2max also strongly predicts mortality risk. While very meaningful in theory, VO_2max is like body fat percentage in that you generally don't actually use the number for anything in practice. It's hard to estimate it accurately and knowing the number often doesn't provide actionable information.

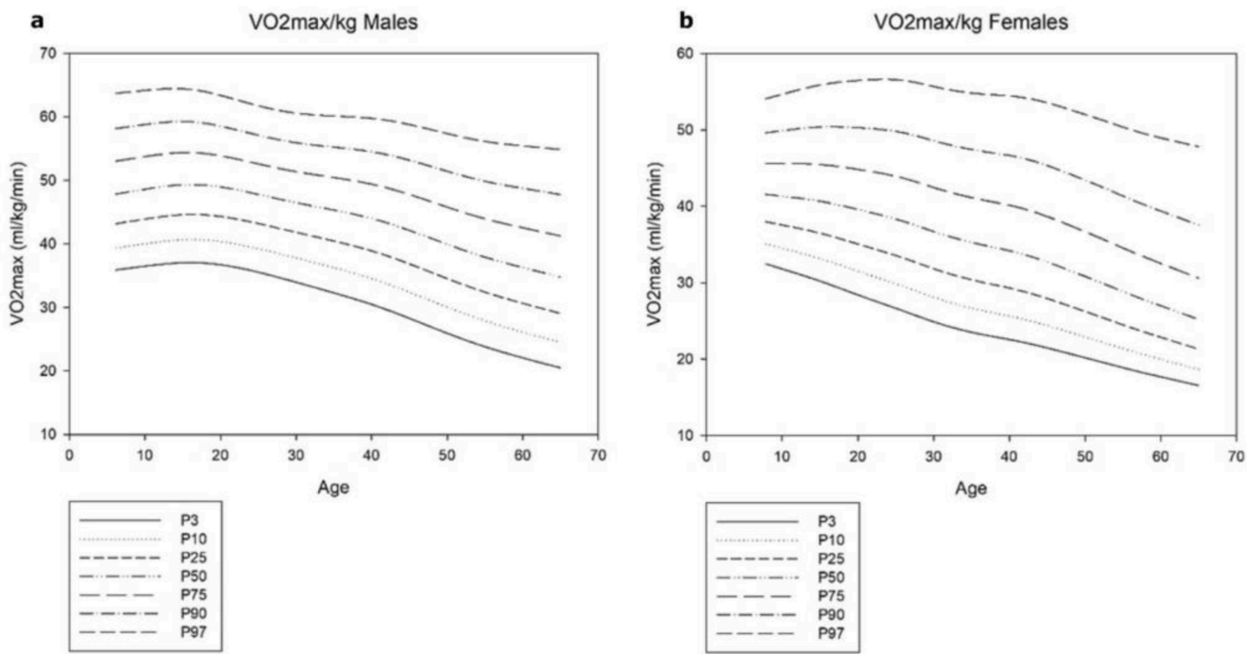


Testing VO_2max directly requires not only extremely high-effort exercise but also laboratory equipment.

There are also many popular endurance tests to estimate VO_2max outside of the lab. The following table provides an overview of some of the most practical and popular ones.

Test Name	Purpose	How to Conduct	Formula	Validity
1.5-Mile Run Test	Simply estimate VO_2max in athletes used to running.	Run 1.5 miles (2.4 km) as fast as possible on a flat surface; record the total time in minutes.	VO_2max = 3.5 + 483 / time (in minutes) – [Calculator here]	High correlation with lab-based VO_2max tests in athletes.
Cooper Test / 12 Minute Run Test	Simply estimate VO_2max in athletes used to running.	Run for 12 minutes for maximum distance.	VO_2max = (distance in meters - 504.9) / 44.73 – [Calculator here]	Validated in the military to correlate strongly with VO_2max.
Rockport 1-Mile Walk Test	Estimate VO_2max for less fit, older, or high-risk populations	Walk 1 mile (1.6 km) as fast as possible. Record time	VO_2max = 132.853 - (0.0769 × weight in lb) - (0.3877 × age) + (6.315 for males	Good reliability and validity for general and deconditioned populations.

	based on heart rate.	and HR immediately at finish.	or 0 for females) - (3.2649 × time in minutes) - (0.1565 × HR) – [Calculator here]	
YMCA Cycle Ergometer Test	Estimate VO_2max from heart rate on bicycle ergometer. Complicated but usable for most populations.	Cycle at 50 rpm through 2 to 4 3-minute stages with increasing resistance. [Instructions here]	Graph-based extrapolation of workload at estimated max HR, then converted to VO_2 using standard equations. [Calculator here]	Strong correlation with direct VO_2max in most populations.



Reference ranges of VO_2max in healthy Dutch/Flemish subjects by age and sex tested via cycle ergometry. P50 is the population average. P97 is the 97% percentile, i.e. the fittest 3% of the population. Treadmill tests tend to give ~20% higher VO_2max values.

[*Source*]

Specificity

Cardiovascular adaptations may appear largely systemic, but they're still very specific to the type of cardio you do. Just like for strength training, the principle of Specific Adaptations to Imposed Demands applies to endurance training. Therefore, if you perform cardiovascular exercise primarily for performance, the first and foremost thing to clarify is what exact performance you're interested in. Training for ultra-marathons is very different from training for kickboxing. You should implement cardio in line with the demands placed on your cardiovascular system during your sport of choice. Think of the work-to-rest ratio, intensity, duration and modality: mimic those in your training. If you train for kickboxing matches that last 3 minutes per round for 3 rounds total with a 1-minute rest interval, your program should probably include kickboxing-like drills that match those work conditions. On the other hand, a soccer player training for 90-minute matches with a 15-minute break in between should probably include 45-105 minute workouts consisting of jogging and interval sprints. Mechanistically, VO_2max is always foundational, but for longer-duration exercise, being able to stay below the lactate threshold and movement economy can be even more important for an athlete if their VO_2max is already decent.

Training impulse

In terms of training volume, there's an [interaction between training intensity, training duration and training frequency]() that together determine the total physiological training stress. There's a clear dose-response relationship for all 3 variables and training adaptations: longer training durations, higher training intensities and more frequent training all tend to improve training adaptations. There are diminishing returns to training duration and frequency though: at some point, more exercise does very little to stimulate additional gains. Duration, frequency and intensity can compensate for each other to a significant extent, so there is no '1 perfect program' but rather a wide range of possible combinations of program variables that result in the desired training stress. Multiple methods have been developed to quantify this total 'training impulse' (TRIMP). A popular model is the Banister TRIMP. It calculates the TRIMP based on someone's training duration multiplied by its intensity, which is calculated based on someone's heart rate during exercise compared to their resting HR and maximum HR as follows.

$$\text{TRIMP} = \text{Duration training (min)} \times \Delta\text{HR} \times 0.64e^{(b \times \Delta\text{HR})}$$

$$\Delta\text{HR} = (\text{HR}_{\text{MEAN}} - \text{HR}_{\text{REST}}) / (\text{HR}_{\text{MAX}} - \text{HR}_{\text{REST}})$$

$$b = 1.92 \text{ for men or } 1.67 \text{ for women}$$

$$e = \sim 2.72 \text{ (Napier's constant)}$$

You don't have to use this model in practice, but it's good to understand what it means. The Banister TRIMP model shows there's not just a linear but an exponential dose-response of training intensity. Training at 90% of maximum heart rate is thus more than 50% more stressful than training at 60% of maximum HR. This should be quite intuitive, as it also feels this way. Exercising at 60% of max HR can be sustained for hours, whereas near maximum heart rates, we're talking about minutes. Accordingly, research has found that multiplying training duration by session perceived exertion – how difficult the workout felt – is also effective to estimate the training impulse and it's much more practical than the complicated math of the Banister model.

Training intensity is particularly important to improve VO_2max, especially in endurance-trained individuals. Higher training intensities tend to improve VO_2max even when total work is matched to lower-intensity protocols [2], meaning the training intensity itself stimulates cardiovascular adaptations, not just the resultant increase in work output. A 2012 scientific review by Wenger & Bell found that the most effective combination of program variables to improve VO_2max was a training intensity of 90-100% of VO_2max, a training frequency of 4x per week and exercise durations of

35-45 minutes. Exercising at 90-100% of VO_2max means you're doing high-intensity interval training with sets lasting about 1 to 8 minutes. Most individuals need to rest at least half that long, or just as long, afterwards to maintain performance across multiple sets. Workouts at that intensity for over half an hour are quite brutal. One of the most successful training programs in exercise science, the classic Hickson et al. (1977) study, also involved highly rigorous training. The participants exercised for 40 minutes per day, 6 days per week for 10 weeks. On 3 days they performed 6 × 5-min intervals of bicycling on an ergometer at VO_2max with 2-min intervals of exercise at 50-60% of VO_2max. On the other 3 training days, they ran as far as they could in 40 minutes. The participants, most of which were already trained, generally found this program unsustainable in terms of training stress, but their gains were amazing. The total increase in VO_2max averaged 16.8 ml/kg per min (44%), resulting in half the participants approaching or exceeding 60 ml/kg per min, which is in line with competitive athletes.

The 2012 scientific review by Wenger & Bell found that less fit individuals could get good results with just half the optimal training frequency and thereby total training impulse, but more trained individuals needed higher total weekly training stresses to make further improvements to their VO_2max. The more advanced you are, the higher your training stress has to be to get even fitter.

Workout durations beyond 35 minutes could effectively compensate for lower training intensities. A decent rule of thumb is that with steady-state cardio, you'll need double the duration of high-intensity interval training (HIIT) to get equivalent cardiovascular adaptations. However, duration can only compensate for intensity up to a point. On average in the literature, HIIT tends to result in greater VO_2max increases than steady-state endurance training [2], although this obviously depends on the volume of HIIT and the intensity of the steady-state cardio. HIIT is particularly effectiveness to reduce the proportion of non-responders to exercise, people who didn't achieve any gains. Lower-intensity steady-state endurance training has a considerable percentage of non-responders. A dose-response study by Montero & Lundby (2017) found that when exercising at 60% of maximal work rate, healthy adults need to train for 4 hours per week to completely avoid non-response to VO_2max. The non-response rate was as high as 69% with 1 hour per week of exercise and still 29% at 3 hours per week. It thus takes a non-trivial amount of exercise to make *any* improvements to your VO_2max if you don't train very hard. And this amount increases substantially as your cardiovascular conditioning gets better and you get closer to your genetic ceiling.

The good news is that non-response to endurance training is almost entirely dependent on training stress. Some people need to work harder than others for the same gains, but everyone can make substantial improvements to their cardiovascular fitness. Age, sex and baseline VO_2max together explain less than 10% of the response variability to endurance training. Being older makes it harder to improve your VO_2max, but the effect is much smaller than commonly believed, insignificant in many studies even. Men tend to have higher baseline VO_2max levels than women and experience similar percentage increases in VO_2max from training as women, thereby achieving slightly greater absolute increases, but relative increases are very similar. The higher baseline VO_2max in men is primarily because men have a bigger heart and more red blood cells.

Overall, the training impulse dose-response for endurance performance is not that different from that for optimal health. This makes sense, because many of the same adaptations that are good for our health, such as improved blood flow, and also good for performance. If we take the official US guidelines for health and replace the word 'health' with 'performance', the result is in line with the research: "For substantial performance benefits, adults should do at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) a week of moderate-intensity, or 75 minutes (1 hour and 15 minutes) to 150 minutes (2 hours and 30 minutes) a week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity." Athletes likely need to be on the higher end of these ranges and incorporate high-intensity training to make significant improvements to their VO_2max.

Progressive overload

Progressive overload is also important for endurance training, just like for strength training. The difference is that you're usually tracking either time or work output of some kind instead of weight x repetitions.

1. You can progress by doing the same work in less time, such as running a mile or kilometer progressively faster.
2. You can progress by increasing the work output in a given time. If you're on a machine that displays your work rate, you can target that directly. Work rate is commonly measured in Watts (= work rate in kg/meter/minute/6.12). If you're cycling, you can speed up your revolutions per minute (rpm). On a treadmill, you can either run faster or increase the incline. Many cardio machines also have a direct difficulty setting that makes it easy to increase the resistance.

Now let's turn to cardio for fat loss.

Cardio for fat loss

Many people do cardio because it burns fat. However, the actual amount of fat that is oxidized during a training session isn't that impressive. You're often looking at only a 2-digit number of grams of fat. More importantly, it's not about how many grams of fat you burn during the session. Cardio's effect on fat loss is entirely mediated by energy balance. It doesn't matter if you reduce your energy balance by doing cardio or by eating less: given the same energy balance, weight and fat loss are the same [2]. Thus, doing cardio only helps you lose significant amounts of body fat if you end up in greater energy deficit.

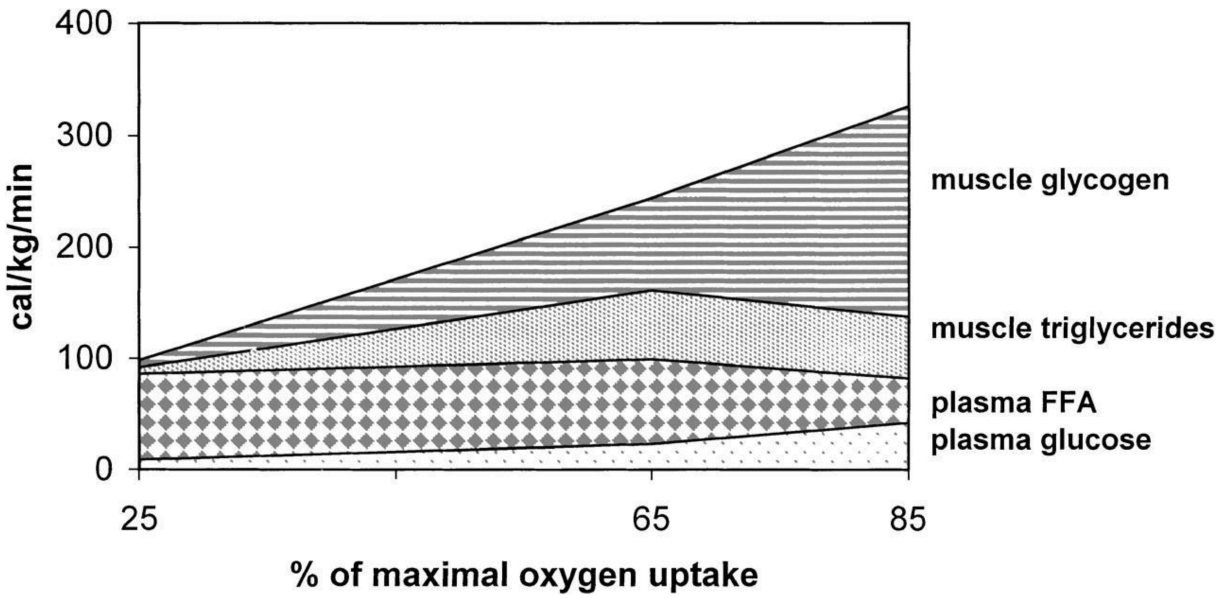
The fat burning zone

To make cardio more effective for fat loss than you would predict based on its energy expenditure, one common strategy is to perform cardio at a low intensity referred to as 'the fat burning zone'. The idea for the fat burning zone originated from looking at how fuel substrates change as a function of exercise intensity. It's good to understand exactly what the rationale for the fat burning zone is, so let's backtrack briefly for a lesson in human metabolism.

Your body normally prefers to use fat as fuel for everyday tasks. Specifically, it oxidizes the fatty acids floating around in your blood, which can come from your body fat stores or a prior meal. Fat stored within your muscles is another underappreciated source of energy.

Yet fat burning is an aerobic process: it requires oxygen. When your exercise intensity is high enough that you cross the 'anaerobic threshold', the body can no longer rely primarily on fat and must burn more carbohydrates alongside fat, specifically muscle glycogen and blood sugar (glucose).

The contribution of various substrates to total energy expenditure as a function of exercise intensity is illustrated below.



The more intense the exercise, the more your body has to rely on carbohydrates instead of fat as fuel. (Data from arbitrary study protocol to illustrate the trends.)

Based on the above, it was thought that cardio should thus be done at a sufficiently low intensity AKA 'in the fat burning zone' so that all the energy you burned was fat.

If you understood the course topics on human metabolism, you should already see the problem here: for the sake of fat loss it doesn't matter how much fat you burn acutely but rather how your energy balance (and nutrient partitioning) is affected over time. You can do all the cardio in the world, but if you don't sufficiently reduce your energy balance, physics dictate that you won't lose net body fat mass.

So given the same energy expenditure, high- and low-intensity cardio result in the same fat loss, as confirmed by a 2021 meta-analysis [2].

Fasted cardio

The rationale for fasted cardio to burn more fat is flawed similarly to the fat burning zone myth. Given the same energy deficit, fat loss is the same regardless of whether you do your cardio in the fasted or fed state [2, 3, 4]. It doesn't matter if you burn more fatty acids during the cardio session: that means you burn less glucose, which means you need to resynthesize less afterwards and there's more glucose left to fuel other bodily functions, including fat storage. In the end, regardless of which substrate you burn when, the total energy balance still governs total body energy change. In fact, fasted cardio can theoretically reduce fat loss, because a 2021 meta-analysis found the energy expenditure of intensive cardio is lower when you train fasted compared to fed, likely due to reduced performance and lower anabolism. So given the same energy intake, doing your cardio fasted could reduce your energy deficit.

So the benefit of cardio is not direct fat loss. It's energy expenditure. How much energy expenditure are we talking about?

How many calories does cardio burn?

Energy expenditure during a cardio session typically ranges from a few hundred Calories up to 600 kcal per hour. That's in line with the energy expenditure of strength training, although strength training sessions typically take longer to burn that many calories. Per minute of exercise, cardio generally burns more calories than strength training, but most people don't sustain their cardio intensities for as long as they can do a strength training workout. Strength training workouts also cause a greater excess post-exercise energy expenditure throughout the subsequent anabolic window than lower-intensity cardio workouts, though the magnitude of this isn't large, as we'll discuss later. So in practice, the total energy expenditure per session isn't that large. It may feel like cardio burns far more calories than strength training, but the difference for most forms of cardio isn't that striking, especially not when you contrast it with typical bodybuilding style workouts with compound exercises, high reps and short rest intervals in a strength- but not endurance-trained individual. Strength-trained individuals can achieve very high work outputs during strength training because they can lift heavy weights, but they generally can't sustain a high work output for long during cardio.

For example, Falcone et al. (2015) compared the energy expenditure of 30 minutes of weight training (3 sets of 10 full-body workout), HIIT/circuit style resistance training (HRS) and steady-state cardio at 70% of maximum heart rate. See the graph below for the energy expenditure and amount of fat burned during the sessions. There was no significant difference in energy expenditure between the weight training and steady-state cardio forms.

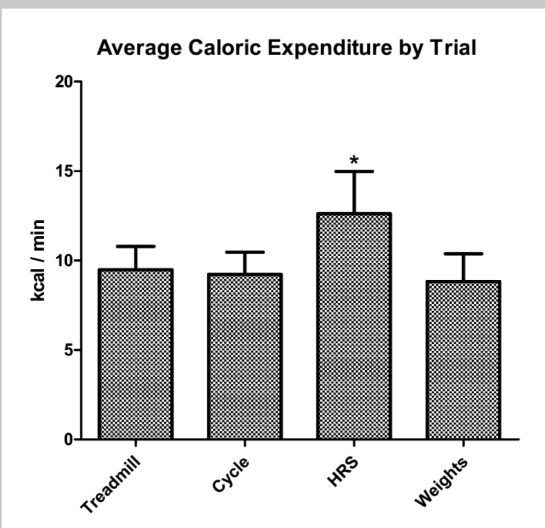


Figure 1. Average caloric expenditure by trial. Data represent mean ± *SD*. Statistical significance set at $p \leq 0.05$. Significant differences between groups are represented as *, significantly different from treadmill, cycle, and weights.

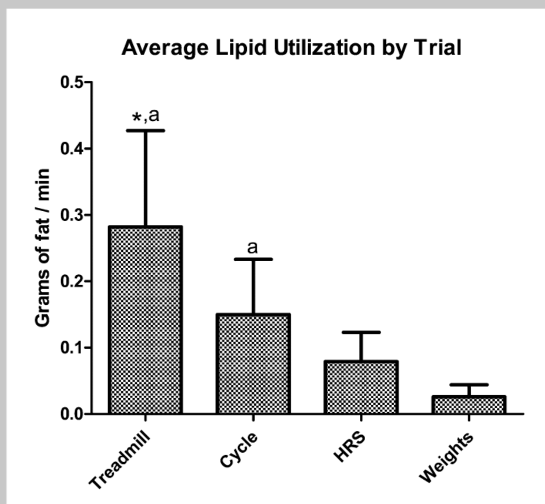


Figure 2. Average lipid use by trial. Data represent mean ± *SD*. Statistical significance set at $p \leq 0.05$. Significant differences between groups are represented as *, significantly different from HRS; a, significantly different from weights.

Below you can see the heart rates (HR) and perceived exertion levels (RPE). Average heart rate during the cardio was similar to the weight training and perceived exertion was only a little less.

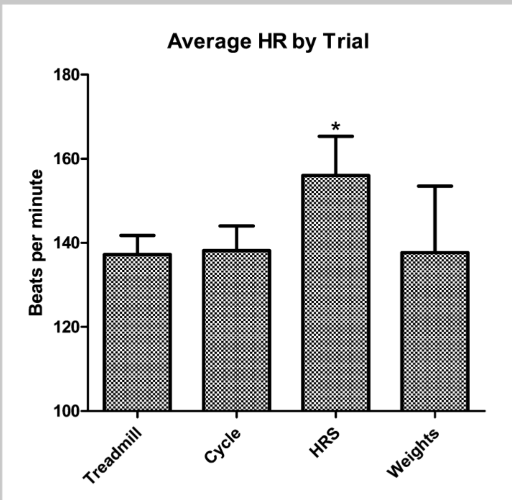


Figure 4. Average heart rate (HR) by trial. Data represent mean ± *SD*. Statistical significance set at $p \leq 0.05$. Significant differences between groups are represented as *, significantly different from treadmill, cycle, and weights.

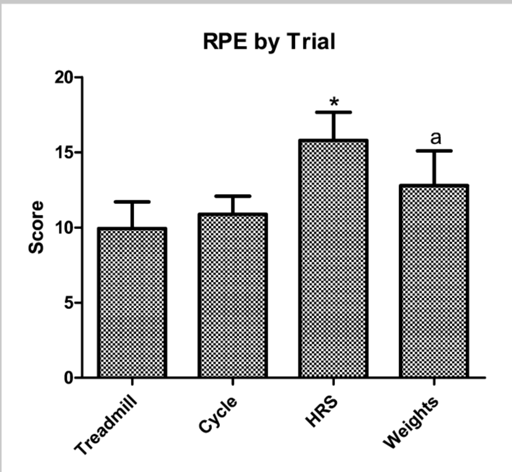


Figure 5. Rating of perceived exertion by trial. Data represent mean ± *SD*. Statistical significance set at $p \leq 0.05$. Significant differences between groups are represented as *, significantly different from treadmill, cycle, and weights; a, significantly different from treadmill and cycle.

Many people grossly overestimate how many calories they burn with cardio. The often overly optimistic estimates shown on the machines by their manufacturers probably don't help. For example, people have been found to overestimate the energy expenditure of a BodyPump class by 67%. The actual energy expenditure was only 5 kcal/min. That's on the low end of strength training energy expenditure. In fact, men with a similar BMI have been found to burn 2.9 times as many calories per minute during strength training. Zumba classes get much closer to heavy strength training in terms of energy expenditure, but they still don't fully bridge the gap.

Other forms of cardio clearly exceed traditional strength training in terms of energy expenditure, however. Below you'll find an overview of the energy expenditure of various forms of cardio. Note that these values are total energy expenditure, not above basal, so these amounts include the calories expended by doing the actual movements in addition to your basal metabolic rate over that time period. (See the course topic on carbohydrates for the difference between total and above basal energy expenditure: for 1 hour cardio you generally need to subtract 1/24th of your REE to get above basal energy expenditure).

Activity	**Gender**	**Total energy expenditure (kcal/kg/min)**	**Measurement**	**Study**
Cycling (recreational)	Men	0.06	VO2 and VCO2 measurements	Gao et al. (2012)
	Women	0.08		
Jogging (recreational)	Men	0.12	VO2 and VCO2 measurements	Gao et al. (2012)
	Women	0.16		
Walking (recreational)	Men	0.05	VO2 and VCO2 measurements	Gao et al. (2012)
	Women	0.06		
Rowing (high intensity - ergometer)	Men	0.19	Open circuit spirometry	Moyna et al. (2001)
	Women	0.21		
Rowing (low intensity - ergometer)	Men	0.13	Open circuit spirometry	Moyna et al. (2001)
	Women	0.14		
Cycling (high intensity)	Men	0.16	Open circuit	Moyna et

	Women	0.17	spirometry	al. (2001)
Cycling (low intensity)	Men	0.09	Open circuit spirometry	Moyna et al. (2001)
	Women	0.08		
Treadmill running (high intensity)	Men	0.23	Open circuit spirometry	Moyna et al. (2001)
	Women	0.20		
Treadmill running (low intensity)	Men	0.19	Open circuit spirometry	Moyna et al. (2001)
	Women	0.16		
Climbing a stair-machine (high intensity)	Men	0.20	Open circuit spirometry	Moyna et al. (2001)
	Women	0.20		
Climbing a stair-machine (low intensity)	Men	0.14	Open circuit spirometry	Moyna et al. (2001)
	Women	0.09		
Running on elliptical trainer (high intensity: 78.6 – 85.6% of maximal HR)	Men	0.13	Respiratory exchange ratio and total VO2	Brown et al. (2010)
	Women	0.12		

As an additional reference, the following table lists the energy expenditure of cardio exercise in endurance trained populations. As you can see, their higher work capacity enables them to burn more calories per minute.

Activity	Gender	Total energy expenditure (kcal/kg/min)	Measurement	Study
Ergometer cycling (high intensity: 75% VO2 max.)	Men	0.18	VO2 and VCO2 measurements	Knechtle et al. (2004)
	Women	0.18		
Ergometer cycling (low intensity: 55% VO2 max.)	Men	0.13	VO2 and VCO2 measurements	Knechtle et al. (2004)
	Women	0.13		
Treadmill running (high intensity)	Men	0.18	VO2 and VCO2 measurements	Knechtle et al. (2004)
	Women	0.18		
Treadmill running (low intensity)	Men	0.13	VO2 and VCO2 measurements	Knechtle et al. (2004)
	Women	0.13		
Rowing (moderate intensity: 84% aerobic)	Men	0.29	Respiratory analysis	De Campos Mello et al. (2009)
HIIT: CrossFit	Men	0.22	Open circuit spirometry	Babiash, (2013)
	Women	0.17		

EPOC

Popular bro theory is that a heavy workout ramps up your metabolism by several hundreds of Calories a day for several days after the workout. There is indeed an 'afterburn' effect after exercise, more formally known as excess post-exercise oxygen consumption (EPOC).

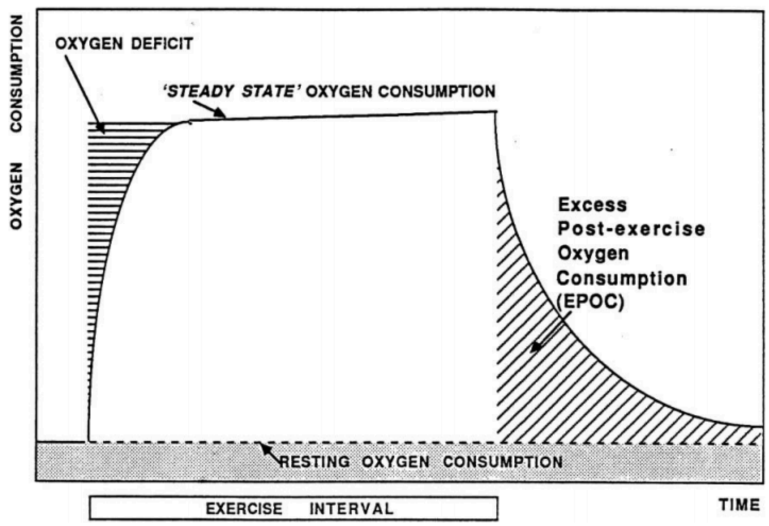


Figure 1. Identification of the excess post-exercise oxygen consumption (EPOC) following submaximal exercise.

Unfortunately, EPOC after even extreme cardio protocols typically lasts only 3 to 24 hours and comprises just 6 to 15% of the net total oxygen cost of the exercise session. That's a paltry number of calories. Even strength training sessions of 50 to 60 sets (!) don't cause more EPOC than 114 Calories. A HIIT or strength training session's EPOC is generally closer to 50 kcal and lower intensity cardio causes minimal EPOC. In practice, EPOC after high-intensity exercise may be enough to offset the basal energy expenditure that it displaces, but that's it. For lower intensity cardio, EPOC may be trivial and it's good to be conservative with the energy expenditure estimation or subtract basal energy expenditure, as you learned in the course module on carbohydrates.

EPOC and basal energy expenditure aren't the only reasons cardio's energy expenditure doesn't always lead to the energy deficit you'd expect from a static metabolism. In reality, the energy deficit induced by cardio, especially on top of strength training, is much smaller due to constrained energy expenditure.

Why is cardio not that effective for fat loss?

The effect of cardio on long-term fat loss tends to be even less than you'd expect based on its energy expenditure. Of course cardio can help with long-term weight loss [2, 3, 4] and weight maintenance after weight loss and more aerobic exercise generally results in more fat loss according to a 2024 meta-analysis. However, the long-term effect is generally only a few kilograms and the effect varies widely across individuals and studies. In many studies there's no significant effect on weight loss in the long run at all. A 2011 review and meta-analysis that looked at aerobic training for weight loss without a corresponding diet program concluded cardio is ineffective to achieve weight loss in overweight individuals. In contrast, a 2021 meta-analysis found that people that start strength training tend to lose fat relatively reliably.

Why is cardio not nearly as effective for fat loss as you'd expect based on its energy expenditure?

The effect of exercise on your appetite

One theory is that our appetite increases after exercise, thereby negating the creation of an energy deficit in ad libitum diet settings. However, research does not support this theory. Several reviews show that exercise does not significantly affect our appetite or energy intake throughout the day [2, 3, 4, 5, 6]. Exercise should even curb your hunger in the short term, as exercise puts your nervous system in fight-or-flight mode instead of rest-and-digest mode.

However, the exact effect of exercise on your appetite appears to depend on your total daily activity level. Several lines of research have found there is an optimum level of physical activity for maximum appetite suppression. Compared to being sedentary, which is an evolutionarily alien level of activity for humans, a more active lifestyle decreases your appetite (win-win). However, as your activity level increases to very high levels, as commonly researched in high level endurance training, your body tries to offset the increased energy expenditure by stimulating you to consume more food. See the graph below for the relation between activity level and ad libitum energy intake.

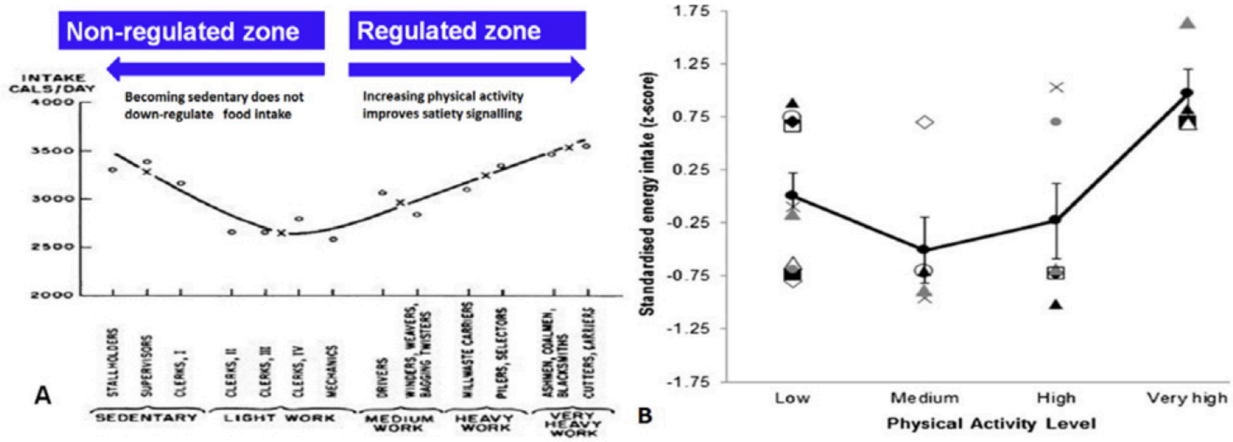


Figure 5 **J-shaped relationship between physical activity level and energy intake**
(**A**) Regulated and non-regulated zones of appetite with varying levels physical activity [120]. Model based on Jean Mayer's study in Bengali jute mill workers [118]. Figure previously published in Blundell [120]. (**B**) Standardized energy intake versus physical activity level from ten cross-sectional studies comparing energy intake between active and inactive individuals. Trend analysis confirmed significant linear ($P < 0.05$) and quadratic ($P < 0.01$) relationships between physical activity level and energy intake. The thick black line indicates the mean of the *z*-scores. Figure previously published in Beaulieu et al. [125].

Most people consume the least amount of energy when they're active but not involved in manual labor or endurance training. [Source]

Energy compensation via hunger could thus explain the relative inefficacy of high volumes of cardio on fat loss, but it can't explain why some people don't lose any fat at all from doing cardio without a diet intervention. Most people aren't that active. All in all, cardio's less-than-expected effect on fat loss is most likely not primarily driven by an increase in appetite for most people.

(See the ad libitum dieting module for more details regarding the effect of exercise on appetite.)

Constrained energy expenditure

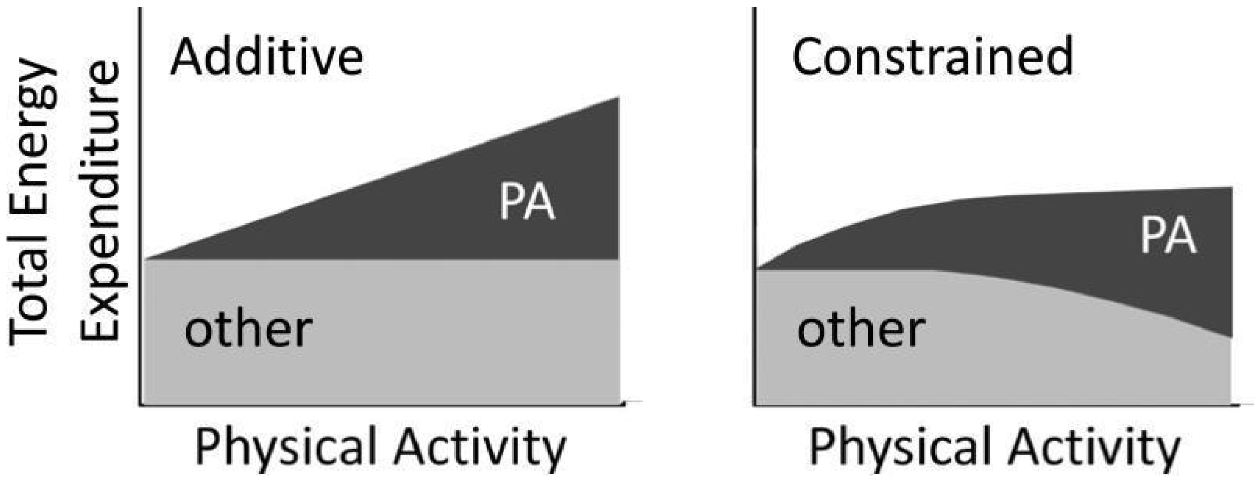
The more likely reason for cardio's relatively poor weight loss track record is a compensatory reduction in energy expenditure afterwards, similar to the adaptive thermogenesis that occurs during weight loss diets. Energy expenditure is constrained: high activity energy expenditure at one point reduces energy expenditure later [2, 3]. Many individuals subconsciously reduce their energy expenditure, particularly their non-exercise physical activity level (NEAT), after (aerobic) exercise so that more exercise does not result in as much fat loss as you'd expect; sometimes extra aerobic physical activity doesn't even increase total daily energy expenditure or fat loss at all [2, 3, 4, 5, 6, 7, 8, 9, 10]. There is still a lot of debate on which components of energy expenditure decrease in response to high aerobic activity levels, but the evidence is strongest for NEAT. BMR reductions generally only occur when bodyweight also decreases, indicating that it's likely the decrease in body mass that's driving the BMR reduction, not energy compensation. The mechanism of energy compensation may be very similar to adaptive thermogenesis with weight loss.

A large analysis by Careau et al. (2021) estimated that "energy compensation by a typical human averages 28% due to reduced basal energy expenditure; this suggests that only 72% of the extra calories we burn from additional activity translates into extra calories burned that day." This figure is in line with an average estimate of 18% compensation from Riou et al. (2015). Some people seem to have a much more adaptive metabolism than others though. Both analyses found that in certain individuals, the compensation is over 80%.

The compensation seems to be more pronounced in active individuals with less or no compensation in previously sedentary individuals [2, 3]. In sedentary individuals, there isn't as much NEAT to suppress, so cardio should be more effective.

Energy expenditure is also more constrained in individuals in energy deficit; in energy surplus there is little evidence of constrained energy expenditure [2].

Energy compensation seems to be a long-term process, with more consistent evidence over longer time periods than for acute interventions. For example, modern populations have similar energy expenditures as much more active farmers and hunter-gatherers. Similarly, animals in captivity have been found to have similar energy expenditures as animals in the wild.



Constrained energy expenditure: high levels of physical activity decrease other energy expenditure, most likely spontaneous physical activity (SPA)/non-exercise activity thermogenesis (NEAT). Source

Based on data from overfeeding studies, pregnancy and ultra-endurance training, the maximum sustainable energy expenditure of humans seems to be around 2.5 x BMR due to limits in energy provision of the digestive tract. Above this 'maximum scope' or metabolic ceiling, additional energy expenditure has to be fueled by catabolizing body energy reserves. Based on this theory, a person with a BMR of 1500 kcal is unlikely to effectively maintain an energy expenditure above 3750 kcal. However, energy expenditure can start being constrained to some degree in some individuals well before it approaches this metabolic scope.

Low-intensity exercise seems to be more strongly constrained, with the most consistent compensation seen for high general physical activity levels and less compensation after high-intensity exercise. In fact, there is generally no NEAT compensation after pure strength training [2].

Endurance training also doesn't increase our resting metabolic rate, whereas strength training does: the more muscle you gain, the higher your metabolic rate gets.

Cardio vs. strength training for fat loss

To recap, strength training has 3 potential advantages over endurance training that seem to make up for the generally lower acute energy expenditure.

1. Strength training does not seem to suffer from constrained energy expenditure, whereas endurance training does.
2. Strength training may be more appetite suppressing, although research findings are very mixed and we lack tightly controlled research (see ad libitum dieting module for details).
3. Strength training increases your energy expenditure not just acutely but also in the next days (EPOC) and long-term by increasing your muscle mass and associated total daily energy expenditure.

Are these advantages enough to compensate for cardio's higher calorie burn? It seems so, although not all studies agree. On average, any type of physical activity seems to be similarly effective for fat loss, given the same exercise time and intensity, but strength training tends to come out on top more often than cardio.

- A 2015 meta-analysis and a subsequent RCT by Shakiba et al. (2018) found that in ad libitum diets on a time-equated basis, strength training is more effective for fat loss than cardio or a combination of cardio and strength training.
- In contrast, a study by Willis et al. (2012) with the same energy intake in the aerobic and strength training groups found superior fat loss with aerobic training.
- Bales et al. (2012) found an aerobic and a strength training program were equally (in)effective for both absolute and relative fat loss. Neither resulted in significant fat loss.
- Sillanpää et al. (2010) found 21 weeks of high-intensity interval cycling or full-body strength training programs led to similar reductions in DXA body fat percentage.
- A 12-week RCT by Guelfi et al. (2013) found no significant difference in fat loss from a strength or endurance training program.
- A 2021 RCT by Said et al. found no difference in the effectiveness of 240 minutes per week of cardio, strength training or a mixture on fat loss, but the strength training group didn't train nearly to failure and actually managed to lose just as much fat-free mass as the cardio group, so this study is not representative of serious strength training.
- A 2021 cohort study with ~12k participants also suggests strength training is better at preventing fat gain than cardio. Those who did at least 2 strength training workouts per week but no cardio became obese less often than those who did no strength training but did at least 500 MET-minutes of endurance training per week.
- In 2022, a meta-analysis found weight training on average resulted in more fat loss than endurance training, although a direct comparison was not made in their limited number of available studies.

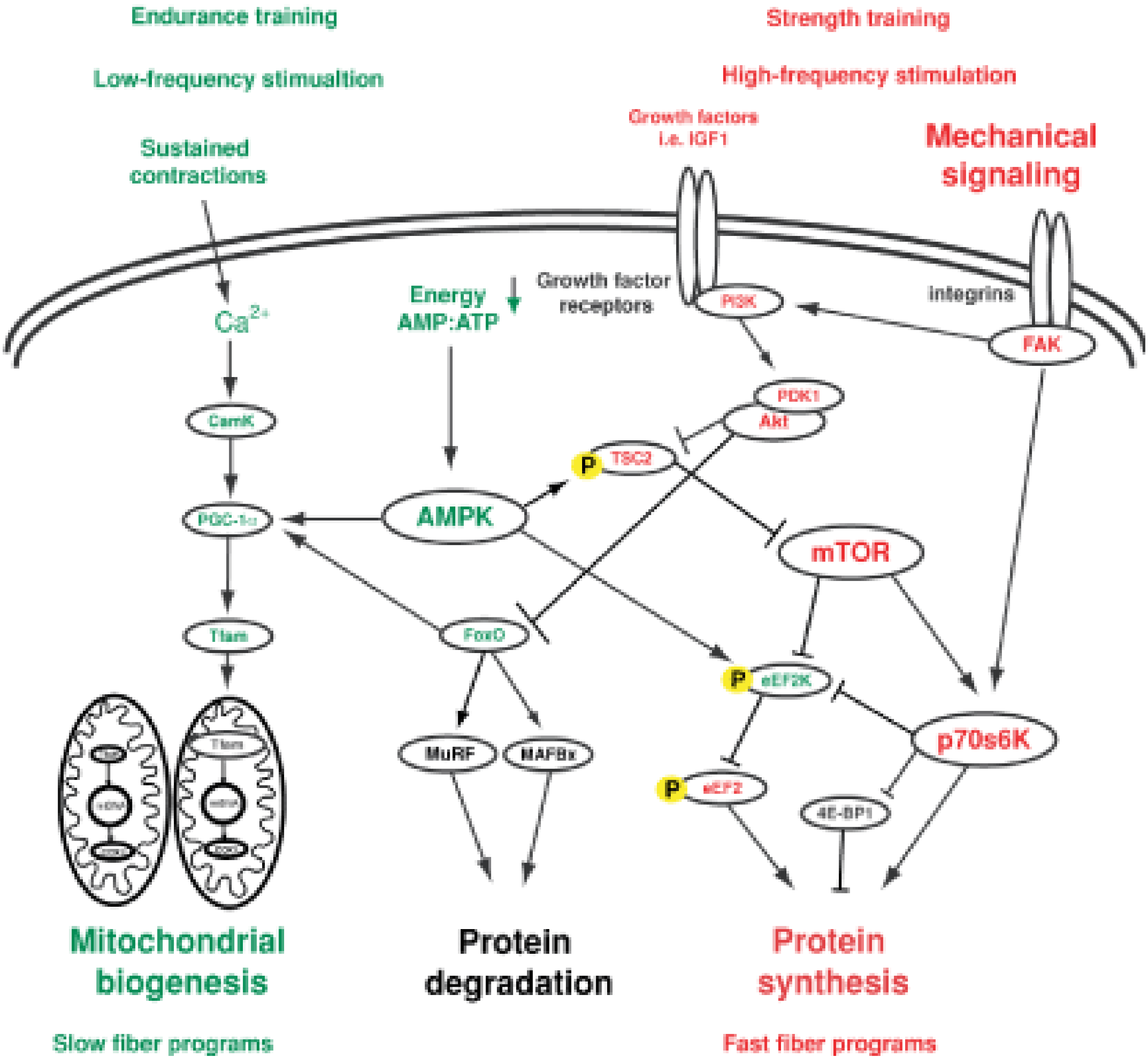
- A 2023 meta-analysis also found slightly greater fat loss (mass as well as percentage) in studies employing resistance training than studies employing aerobic exercise, both with and without combined dietary energy restriction.
- A 2023 RCT by Kobayashi et al. found strength training is superior to endurance training or a combination of the two for body recomposition. Fat loss specifically was greatest in the strength training group, but the difference between groups was not statistically significant. The exercise programs were equated for time and macronutrient intakes reportedly did not differ between groups.
- A 2024 RCT by Lee et al. found strength training, cardio and a 50-50 mix of the two are equally effective to reduce body fat percentage on a time-equated basis in a year-long study of 406 overweight adults. The cardio and concurrent training groups experienced a greater decrease in waist circumference, suggesting more total fat loss, but this was compensated for in the lifters by a significantly greater increase in lean body mass. Worth noting is that although macronutrient intakes did not significantly differ across groups, the strength trainees were consuming 100-200 kcal more per day throughout most of the study.
- A 2024 RCT by Davis et al. compared obese women doing time-matched full-body strength training or steady-state endurance. After 12 weeks, they lost a similar amount of fat mass and waist size. Body fat percentage decreased more in the weight training group due to their greater fat-free mass increase.

Of course, only a certain amount of strength training can be done without overreaching. Thus, cardio can become useful to increase energy expenditure for fat loss after strength training volume is already optimized. Up until that point, strength training seems to be at least as effective as endurance training at aiding fat loss per minute of exercise.

The cost of cardio: the interference effect

As you learned in the course topic on understanding muscle growth, when you impose stress on your body, the body adapts and this adaptation is specific to the demands placed on it (SAID: specific adaptations to imposed demands). Strength training and endurance training create adaptations towards opposite ends of the strength-endurance continuum. Endurance and strength training adaptations are activated by different stressors, they occur via different pathways and they result in different performance outcomes, as the table and image below illustrate.

	Endurance adaptations	Strength adaptations
Primary adaptations	VO2Max, resting heart rate, ventilatory threshold, work economy	Muscular cross-sectional area and force production
Primary mechanism	Substrate depletion	Myofiber disruption
Primary gene transcription pathways activated	AMPK	Akt/mTOR/$p70^{S6K1}$
Primary proteins synthesized	Mitochondria, sarcoplasm	Myofibers



Strength and endurance training activate different gene signaling pathways that result in different adaptations. For example, AMPK activation can inhibit mTOR activation, thereby suppressing muscle protein synthesis and growth. [Source]

The adaptations to strength and endurance training are so different that they can be in part mutually exclusive. Research has found this in particular for central changes in cellular pathway signaling, gene activation and enzyme concentrations. Although human research findings are more mixed and often limited by the use of untrained participants, animal research clearly shows strong interference between the cellular signaling pathways promoting improved muscle strength and size vs. improved muscle endurance. Specifically, endurance training adaptations can reduce strength training adaptations. Strength training does not seem to interfere directly with endurance training adaptations at a cellular level [2]. In fact, any form of exercise stimulates some degree of endurance training adaptations, as it puts demands on your cardiorespiratory system that you can measure in your heart rate and oxygen uptake. However, endurance training can interfere with strength training adaptations in multiple ways.

- Protein kinase B/Akt (PKB) decreases protein breakdown and activates protein synthesis, making its presence very desirable for muscle gains. AMP-activated protein kinase (AMPK) increases mitochondrial protein, glucose transport, and several other factors that result in increased endurance and cardiorespiratory fitness. The problem is, AMPK and PKB can block each other's downstream signaling.
- AMPK can also inhibit mTOR activity.
- Other signaling pathways activated by metabolic stress, notably SIRT1, can inhibit mTOR signaling.
- Endurance training can interfere with strength training without affecting mTOR signaling by promoting protein catabolism.
- Combining strength training with endurance training can blunt satellite cell activity. Satellite cells can aid muscle repair and myonuclear addition, as per the course module on understanding muscle growth.

Cardio can also indirectly reduce muscular development from strength training by causing central nervous system (CNS) fatigue. Endurance training can reduce systemic voluntary activation and consequently the muscle strength of completely unrelated muscle groups. Endurance training generally causes considerably greater and more prolonged CNS fatigue than strength training, as we'll discuss in more detail in the module on Periodization.

As a result of the above interference mechanisms, concurrent strength and endurance training can obstruct the development of power, strength and muscle growth compared to only performing strength training [2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. This observation is called the interference effect or the concurrent training effect (concurrent meaning 'in the same program'). From an engineering perspective, it makes sense that it's difficult to make tissue both better suited for low, prolonged force production and high, rapid force production at the same time, just like it's difficult to create a car for Formula One racing (strength) that uses only a small amount of gas (endurance).

No interference for muscle growth?

Based on the strength-endurance continuum, the interference effect of endurance training is expected to be strongest for power, then strength, then muscle hypertrophy. Power is the polar opposite of endurance in terms of force production over time: force production is high, brief and rapidly developed during power movements like the Olympic lifts, in contrast to endurance exercise like jogging which involves relatively low and continuous force production that is sustained for a long period of time.

Some people have gone so far as to say that the interference effect does not exist at all for muscle growth, since 'only' Jones et al. (2013), Kikuchi et al. (2016), Fyfe et al. (2016), de Souza et al. (2014) and and Izquierdo et al. (2005) have demonstrated a statistically significant reduction in muscle growth as a result of concurrent training. The latter had a training frequency of 2 in the pure strength training group compared to one strength training and one endurance training session in the combined group, so the lower strength training volume may have been the cause of their reduced muscle growth instead of the interference effect.

Moreover, several studies have actually demonstrated increased muscle growth when strength training was combined with endurance training, notably bike ergometer training [2]. Other research has also found that AMPK activation did not inhibit mTOR activity.

However, the studies where concurrent training increased muscle growth or did not affect mTOR were all in untrained or recreationally (read: poorly) trained individuals. (Apró et al. (2013) is a potential exception, as these individuals were 'moderately trained', but no body composition or free-weight strength levels reported and the endurance exercise was not at maximal capacity, not enough to activate AMPK pathways more with the cycling + leg press workout than with the pure leg press workout.)

Any exercise, even endurance training can promote muscle growth in completely untrained individuals, regardless of whether you do strength training at the same time or not. The adaptation process to any kind of training in beginners is still very general. In fact, some research finds that cardio and strength training do not even stimulate significantly different body composition changes in completely untrained individuals. So in untrained individuals, adding endurance training to a low volume of strength training can add to the stimulus for muscle growth, but this increased effect dissipates within a matter of weeks as the endurance work ceases to become an efficient stimulus for further muscle growth.

We can see the onset of the interference effect in cellular signaling pathways. In untrained individuals, strength and endurance training activate very similar anabolic gene pathways, but the adaptation process starts differentiating rapidly within the first 8 to 10 weeks [2, 3] and that's when concurrent training starts blunting mTOR signaling.

When we look at highly-trained endurance or strength trainees, we can see endurance vs. strength training activate much more clearly divergent cellular signaling pathways [2]. Correspondingly, after 8 to 10 weeks, post-workout myofibrillar vs. mitochondrial protein synthesis start to differentially activate after strength vs. endurance training. Strength training is required to maximize myofibrillar protein synthesis at this point, whereas endurance training will still cause significant myofibrillar protein synthesis in an untrained individual. Correspondingly, we see the interference effect in strength development from concurrent training only becomes significant after 8 weeks in some studies [2].

Considering the timeline of the divergence of training adaptations, it's not surprising that beginners don't suffer from an interference effect yet. The greater surprise is that in some studies beginners **already** suffer from an interference effect.

4 Meta-analyses confirm the existence of the interference effect between aerobic exercise and strength training [2, 3, 4]. The first meta-analysis also confirmed what you learned earlier in this course: strength development and muscle growth are much more similar adaptations than most people claim. Only power and endurance require clearly distinct training adaptations. Specifically, the first meta-analysis found that the interference effect was indeed greatest for power development: combined training groups developed only 60% of the power that pure strength training groups did. In terms of strength development, the combined groups managed a respectable 82%

compared to the groups performing nothing but strength training. For muscle growth, however, it was only 69%. The second meta-analysis showed that the interference effect is stronger in trained vs. untrained individuals. In fact, in untrained individuals the meta-analysis found no significant interference for lower-body strength development yet. (Note: A 2021 meta-analysis by Schumann et al. found no interference effect at all for muscle growth or strength development, only for power, but this was a very poorly done analysis. They did not include 4 of the 5 studies that found an interference effect for muscle growth and they grouped all people that were physically active in some form together as ‘active’, which meant many of the ‘active’ individuals were not strength-trained.) The fourth meta-analysis from 2022 found that concurrent training significantly reduced type I and type II muscle fiber growth, although they found no statistically significant effect at the whole-muscle level. Unfortunately, they did not perform a subgroup analysis on untrained vs. trained individuals.

As such, both theory and the empirical evidence strongly indicate that while beginners don’t need to worry much about the interference effect yet, it’s a serious concern for muscle growth for trainees beyond the novice level.

Kikuchi et al. (2016) provides convincing evidence of the interference effect on muscle growth even in unrelated muscle groups. Interval sprint cycling performed before arm workouts impaired biceps growth by 35% and strength development by 31% in strength-trained men. In fact, the concurrent training group did not achieve a statistically significant increase in strength or size at all. Interference in different muscle groups may be due to central nervous system fatigue induced by the endurance training.

The benefits of cardio for muscle growth

While cardio has mostly negative effects on strength training results, it might also have positive effects. A 2022 RCT by Thomas et al. found that “short-term aerobic conditioning prior to resistance training augments muscle hypertrophy”. However, this conclusion is only weakly supported by their data. The researchers had a group of untrained individuals perform 6 weeks of aerobic cycling training with one leg, after which both legs performed 10 weeks of strength training. The researchers reported no significant between-group differences in total leg fat-free mass or bilateral 1RM strength in the leg press and squat. (Unilateral strength testing would have made more sense.) There were also no strictly significant between-group differences in any muscle fiber type’s cross-sectional area (CSA; a measure of muscle size), but all fiber types showed a trend for greater gains in the aerobically-preconditioned legs. The trend for greater gains after cardio was supported by greater satellite cell pool expansion and capillarization. You learned how satellite cells can support muscle growth in the ‘understanding muscle growth’ module. Capillarization refers to the formation of capillaries, small blood vessels, in the muscle. The degree of capillarization from cardio correlated with the subsequent amount of muscle growth from strength training, though the association was weak.

Even aside from the statistical weakness of the data, these were untrained individuals. As per the previous section, untrained individuals have been found to gain muscle from cardio, whereas trained individuals don’t and are more likely to experience an interference effect. And even if these benefits would apply to trained individuals, you’re almost certainly better off doing more strength training than adding cardio. To the extent that cardiovascular fitness improves muscle growth, strength training will already stimulate these cardiovascular adaptations. That’s how the body adapts: it makes the specific adaptations that are beneficial to resist the training stress. You can feel the cardiorespiratory stress in particular after a set of squats or deadlifts.

A second purported benefit of better cardiorespiratory fitness is that it improves recovery capacity. Ratamess et al. (2014) found some support a relationship between VO2max and work capacity. VO2max measures maximal oxygen uptake and is often considered the best measure of cardiorespiratory fitness. It's kind of the cardio equivalent of 1RM strength. Work capacity refers to how well you can maintain your reps across sets: it’s fatigue resistance. Concretely, the study found that VO2max significantly influenced how many reps strength-trained men could do during a workout. The workout was particularly demanding on the cardiorespiratory system though. They did 5 supersets of up to 10 reps of squats and bench presses performed back-to-back without rest with rest intervals of 1, 2 or 3 minutes. Even then, aerobic conditioning was only significantly positively related to squat reps, not bench press reps. For total reps, there was a moderate trend. A confounding factor was that lifters with higher VO2max were significantly weaker and lower strength generally makes it easier to maintain a high work capacity.

A 2024 study by Lundberg et al. also investigated the relationship between VO2max and recovery in between sets of strength training. A group of strength-trained men and women performed a leg day with squats and leg extensions. The researchers measured how many reps they could do at the training intensity and the changes in power and torque within and across sets as measures of neuromuscular fatigue. There were no significant, consistent relationships between VO2max and any recovery measure. "Our study suggests that aerobic capacity is weakly associated with within-set fatigue and between-set recovery in resistance training in both men and women."

In conclusion, good aerobic conditioning might improve your work capacity during workouts in which you’d otherwise be too out of breath. However, the effect seems to be too weak and inconsistent to materially impact conventional strength training. Given the much more established negative effects of cardio on strength training performance, i.e. the interference effect, cardio is highly unlikely to be net positive for muscular gains.

Conclusion: cardio yay or nay?

Since cardio training is no more effective for fat loss than eating equivalently fewer calories and cardio also has the cost of interfering with your strength training, cardio is not a good fat loss method in training programs aiming to maximize strength or hypertrophy.

However, cardio is sometimes necessary for health or sports reasons, such as for athletes and people training primarily for health improvement. Moreover, in order to reach contest shape without cardio, some individuals have to decrease their energy intake to the point that 2 problems arise:

1. Excessive hunger no matter how good their diet is.
2. Nutrient deficiencies, at the micro- as well as the macro level.

Both problems can be largely counteracted of course. In the course topic on ad libitum dieting you learned how to manage hunger. Suffice to say here, most people outside of physique contest prep should never have to experience intense, regular hunger when cutting in an optimized program. In the course topics on micronutrition and health science you learned how to cover all nutritional needs.

Macros, however, remain a problem. Protein intake cannot be compromised on for optimal results under any circumstance. Carbohydrate intake often can, but ketosis may not be desirable. Fat intake can be compromised on in the short-term, but over the course of weeks or months this will most likely impair the competitor’s results and health. Since most people will be left with at least some issues at very low energy intakes, a reasonable guideline is to not decrease energy intake below 1200 kcal on training days for women or 1800 kcal for men unless you absolutely need to. Beyond this point, the costs of cardio may be less than the costs of further decreases in energy intake.

Strategies to reduce the interference effect

If you want to perform cardio and strength training in the same program, strategic programming is needed. This is particularly relevant for mixed athletes. Fortunately, we have several ways to implement cardio with minimal interference effect. Always keep in mind that the goal of cardio for fat loss is simply to expend energy, not to get fatigued or to develop endurance, on the contrary in fact.

Cardio duration

The interference effect results from simultaneous endurance and strength stimuli, essentially trying to push the body into adapting into 2 opposing directions along the strength-endurance continuum. The most effective method to prevent the interference effect is thus to prevent endurance training adaptations. If your cardio is not intensive or long enough to stress your body into developing greater endurance, your strength training adaptations will not suffer. The longer your cardio sessions, the worse the interference, as you move further away from the strength end of the strength-endurance continuum. The interference effect for cardio sessions below 20 minutes is generally small. More generally, the greater the total volume of cardio you do, the worse the interference. So don't perform more cardio than necessary.

If you have to perform a high volume of cardio because it's not feasible to decrease energy intake further, it's generally a good idea to spread it out over many sessions. As long as your cardio sessions are sufficiently short that they don't require much, if any, endurance adaptations to take place, you will minimize the interference effect.

Timing

Another strategy to reduce the interference effect is to perform your cardio at least 6 hours after your strength training. You ideally do not want any overlap between the anabolic windows of the cardio session and your strength training for any muscle. In theory, there should be no interference at all that way and research finds that there is indeed little interference effect when (HIIT) cardio and strength training are performed at least 24 hours apart. However, even 30-second all-out sprint training with several minutes of rest in between, separated by at least 24 hours from strength training, can still cause some interference effect.

When you have to perform cardio and strength training for a muscle on the same day, the question becomes: do you want to perform the cardio before or after your strength training? If you perform the cardio first, the substrate depletion, neuromuscular fatigue and in particular the muscle damage can negatively affect your strength training and thereby exacerbate the interference effect by directly interfering with your strength training performance. However, performing the cardio after your strength training may also make the effect of the training session even more endurance oriented, as you'll be performing endurance training in a glycogen depleted and fatigued state. So before or after?

If your primary goal is fat loss, you can do both. If you spread the cardio around your workout, your pre-workout cardio can serve as an extensive warm-up for the strength training. Don't overdo it: when you get to the point of it becoming endurance training, save the remainder of the cardio for after the strength training. By splitting up the cardio session into 2 parts, you can achieve the same total work output while reducing the endurance adaptations, as neither session should be sufficient to require significant endurance training adaptations.

In case you have to perform a lot of cardio, so much that it cannot be just '2 warm-ups' anymore, it's best to perform the majority of the cardio post-workout. The interference effect is stronger for pre-workout than post-workout cardio, as pre-workout cardio interferes with the strength training session directly but strength training has minimal effect on the quality of the cardio. Li et al. (2025) found that in concurrent training programs, performing strength work first did not significantly reduce VO2max improvements, whereas doing endurance training before strength work significantly reduced improvements in body fat percentage, explosive strength and muscular endurance.

However, if you have the option to perform endurance training earlier in the day but not much later in the day than your strength training, it's likely most beneficial to separate your cardio and strength workouts as much as possible. Most AMPK signaling dissipates within 3 hours after endurance training, depending on the precise cardio workout, so if after this time the interference effect should be reduced compared to performing the cardio and strength work closer together.

Separating endurance and strength training is often the most important strategy to minimize the interference effect in athletes, as they cannot compromise on the intensity or volume of their endurance training.

Intensity: HIIT vs. LISS

High intensity interval training (HIIT) is cardio 2.0. Since making its way into the fitness world, the picture of cardio as jogging has been replaced by repeated sprinting and activities we used to think of as Strongman training. We are bombarded with pictures of 'sprinting vs. running', showing an emaciated long-distance runner alongside a sprinter that could win a bodybuilding contest. But is this comparison between HIIT and steady-state cardio justified? Is HIIT the preferred form of cardio to get lean?

It's quite evident that sprinters are considerably more muscular than long distance runners. Not only that, they're usually leaner too. Case closed: to look like a sprinter, do HIIT, right?

Wrong. The idea that HIIT resembles the training of a sprinter is misguided. The training practices of elite level sprinters are comparable to those of other strength and power athletes like Olympic weightlifters and powerlifters: short, high-intensity exercise followed by long rest periods. The popular Tabata HIIT protocol has 20 seconds of sprinting followed by 10 seconds of walking. Olympic level sprinters run the 100 meters in fewer than 10 seconds and can easily rest 5 minutes in between sprints. Thus, the sprinter's relative rest period is over *60 times* as long as the person performing Tabata

HIIT. There is a significant difference in muscular and metabolic demands between sprinting for even 5 and 15 seconds. The metabolism of repeated sprint training is much closer to team-based sports like soccer than it is to strength or power training. The first sprint is highly explosive and relies almost entirely on anaerobic ('without oxygen') energy production. Across repeated sprints, this rapidly transitions to the metabolism of endurance training with decreases in power output up to 73% after 10 sprints. The same has been found in sprinting during bicycling. All-out sprints and HIIT produce significantly different metabolic effects. So when you do HIIT, you're not training like a sprinter. You're training like a soccer player.

So will HIIT make you look like a soccer player? Numerous studies have researched the effects of HIIT on your body composition. The media has picked out (and often misrepresented) a few as 'the revolutionary new way to lose fat in a fraction of the time'. However, a 2021 meta-analysis showed that both fat loss and muscle hypertrophy are similar between steady-state cardio and HIIT: most studies find that no muscle hypertrophy occurs beyond the novice level and minimal fat loss occurs. A 2023 meta-analysis of 11 RCTs confirmed that HIIT does not significantly differ from continuous aerobic training for fat loss.

HIIT is just not that different from steady-state cardio for the body. So HIIT sprinting will indeed not give you the physique of an Olympic level sprinter. It will give you the physique of an amateur soccer player.

Since HIIT causes strong endurance adaptations, it can cause a major interference effect with strength training, just like LISS. In fact, the higher the intensity of a given duration of concurrent endurance training on top of strength training, the worse the strength development. Even 30-second all-out sprint training with several minutes of rest in between, separated by at least 24 hours from strength training, can still cause an interference effect. It thus does not seem possible to make your HIIT close enough to strength training to make it cause strength training adaptations.

Fyfe et al. (2016) compared the acute interference effect of HIIT vs. work-matched steady-state cardio before a strength training workout. While the absolute interference wasn't major in these 'relatively training-unaccustomed subjects', HIIT reduced post-exercise expression of miRNAs that are active during muscle growth, whereas stead-state cardio did not. In other words, HIIT seemed to result in a greater interference effect than the same volume of steady-state cardio.

Another study by Fyfe et al. (2016) found that HIIT results in greater interference than the same volume of steady-state cardio. The study groups were:

- RT only (3x per week full-body weight training)
- RT + bicycling steady-state cardio
- RT + bicycling HIIT cardio

Compared with RT performed alone, both concurrent training groups experienced reduced strength and power gains similarly. The RT group gained 4.1% lower body lean body mass (LBM), whereas there was only a trend of significance for the concurrent training groups. The steady-state group still reached a respectable 3.6% gain, but the HIIT group lagged behind the other 2 groups with only 1.8% LBM growth. (There was no significant increase in any group's upper body LBM so also no between-group difference.) In short, the interference effect seemed to be worse with the addition of HIIT vs. the same amount of work done with steady-state cardio.

Petré et al. (2018) also found combining strength training with HIIT was no more effective than combining it with LISS for the development of 1RM squat strength and lean body mass. This was a 6-week study in 16 athletes that were already highly trained in both endurance and strength work (rugby and ice-hockey players).

If cardio is kept to a sufficiently low intensity, you minimize the interference effect, because no endurance adaptations are required in the first place then. If you can measure your heart rate, any intensity below 60% of maximum heart rate shouldn't cause much interference. Walking, for example, is unlikely to cause any interference. With HIIT, limiting the intensity is inherently impossible.

To illustrate HIIT's great potential for strength interference, de Souza et al. (2014) compared the effects of strength training twice a week with and without the addition of HIIT sprint training. The pure strength training group gained over 17% in size in all their major muscle fiber types. However, in the group that also performed HIIT there was no significant increase in muscle mass at all. The researchers also looked at a group only performing HIIT and again there was no increase in muscle mass. The most striking aspect of this study is that the participants were healthy, untrained men. You'd expect them to grow no matter what.

A 2022 meta-analysis found that HIIT induces a significantly greater interference effect on muscle growth than LISS endurance training.

As an additional argument for low-intensity cardio, in some research steady-state cardio is more effective for fat loss. This is not surprising, because steady-state cardio simply tends to burn more calories than HIIT, because it can be maintained for a much longer duration. Since energy expenditure is the primary purpose of cardio for fat loss, this is another advantage for low intensity steady-state cardio (LISS). Of course, HIIT does have the advantage of being more time-effective.

Interestingly, in contrast to the hype, in research people perceive HIIT as less enjoyable than steady-state cardio or equally enjoyable and preferable. In another study, when participants were given the choice between LISS and HIIT, most people choose LISS, though the people that choose HIIT did report greater enjoyment of exercise. Adherence to the HIIT protocol over a year was terrible with only a small minority staying adherent. HIIT used to be the exciting new form of cardio, but as a long-term – think years – strategy to increase energy expenditure, it's often not sustainable. People that prefer HIIT over steady-state cardio are often better off increasing their strength training frequency (see the course topic on training frequency).

HIIT for women

HIIT is often a particularly bad idea for women. While women typically have great endurance, the female nervous system is not as efficient as that of men. Men are more explosive than women: they can generate force quicker. The area in the brain that controls movement (the motor cortex) is in fact literally larger in men, even after correcting for height. This results in not just poorer performance during explosive exercise but also a less efficient adaptation. The adaptation process seems to be less efficient in terms of duration as well as in actual adaptation. Women don't build as much muscle protein after high-intensity sprints as men and women recover less well after HIIT type exercise like sprints. High-volume sprint training can take over 72 hours to recover from in women.

Psychologically, mood improvements from aerobic exercise tend to be greater in women than in men.

Women also seem to experience smaller health benefits from HIIT than men, notably a smaller increase in VO_{2max}.

Overall, women have more to gain from LISS and more to lose from HIIT than men, so LISS is the preferred default cardio type.

Conclusion on HIIT vs. LISS

Low-intensity cardio has a greater potential for total energy expenditure, is generally better tolerated psychologically over the long-term and it can minimize the interference effect, whereas HIIT will generally result in significant interference. HIIT sessions are thus often better replaced with more strength training sessions or low intensity cardio, especially for women. The interference effect of LISS can be minimized by keeping the cardio below the threshold of significant fatigue. Some cues for this are as follows.

- You should still be able to breathe through your nose.
- You should be able to maintain the pace indefinitely.

Modality

Just like muscle growth itself, the interference effect is mostly a local process (see the course topic on strength training adaptations). For example, treadmill running after strength training reduced lower body strength development by 42% in one study, but there was no significant effect on upper body strength development. Similarly, a HIIT cycling session has been found to acutely decrease squat but not bench press power. So if you have certain muscle groups that don't need to become bigger, it's best to choose a form of cardio that relies primarily on these muscle groups. For example, Men's Physique competitors wear board shorts on stage, so they may be able to compromise on their thigh and glute development and perform bike ergometer cardio.

Some of the interference effect seems to be central in nature though, so doing cardio for your less important muscle groups does not absolve the rest of your body from the interference effect entirely. In Kikuchi et al. (2016)'s study, bicycle ergometer interval training on the same day as an arm workout reduced biceps growth and strength development by over 30% in effect size. Lower body cardio could interfere with upper body strength training via central fatigue.

In addition to which muscle groups are exercised, there are a few more considerations for the optimal cardio modality.

- Muscle damage: Forms of cardio that involve eccentric muscle actions seem to result in more muscle damage and central nervous system fatigue than purely concentric cardio modalities. Since muscle damage can impair strength training performance and prolong recovery times, concentric-only forms of cardio are preferred. Examples include bicycling, stair walking, cross-training, rowing and skiing machines.

- Injury risk: Cardio modalities that involve high impact forces come with greater stress for your connective tissue and a resulting greater injury risk. So while jump rope training might make you feel like Rocky, it's probably not worth doing during contest prep when your recovery capacity is already being taxed greatly.
- Temperature: Cold water immersion can increase your appetite [2, 3], as can exercising in cold environments, such as swimming in cold water, resulting in higher ad libitum energy intakes afterwards. Swimming cardio has been found to stimulate hunger and energy intake (more than bicycling). Swimming water is generally below skin temperature (33-37° C), so your body has to expend energy to produce heat and this seems to result in a compensatory increase in appetite and energy intake afterwards. Swimming is thus generally not an ideal form of cardio to help you get leaner.

Somewhat ironically given its popularity, since jogging has both a high injury risk and great potential for muscle damage, running induces a significantly worse interference effect than other forms of cardio, especially bicycling [2, 3] according to 3 meta-analyses. Another study by Mathieu et al. (2022) found that sprint running but not bicycling increased ratings of perceived exertion during a strength training session 4 hours later in rugby players. Although objective performance did not differ, the higher perceived exertion suggests a greater potential for interference. According to a different meta-analysis, HIIT sprinting may be an exception, as it seems to have the same interference effect as HIIT bicycling for the lower body. However, several studies have found significant interference from HIIT sprinting, as you've learned, so sprinting certainly isn't exempt from the interference effect.

Conclusions & practical application

Whether to implement cardio depends on your goals.

- If your primary goal is health, you should implement at least some cardio in your workout routine.
- If your primary goal is sports performance, you should implement cardio in line with the demands placed on your cardiovascular system during your sport in question. Think of the work-to-rest ratio, intensity, duration and modality and mimic that in your training.
- If your primary goal is aesthetic/bodybuilding, you don't strictly need cardio. Cardio's only use for fat loss is to expend energy, making it easier to reach a target energy deficit. Given the potential for an interference effect and its use of recovery capacity, cardio should ideally only be implemented for fat loss when the costs of eating less, namely hunger and nutritional deficiencies, are greater than the costs of cardio.

Regardless of your goals, the following strategies help minimize the interference effect.

- Choose a concentric-only and low impact cardio modality that exercises relatively unimportant muscle groups, unless you need a different modality for your sport, such as running for soccer.
- Perform the cardio workouts as far away from your strength training work as possible. If you combine the cardio and strength training in the same workout, split up the cardio work into a pre- and a post-workout session and take as much time as you want in between the sessions.