Exercise performance

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Contents

In this module you'll learn how to perform your exercises in the gym. We'll discuss what constitutes good exercise technique, the mind-muscle connection, how to breathe, how fast to perform your repetitions (repetition tempo) and how close to failure you should train.

➢ Lecture

How to perform your exercises for maximum gains

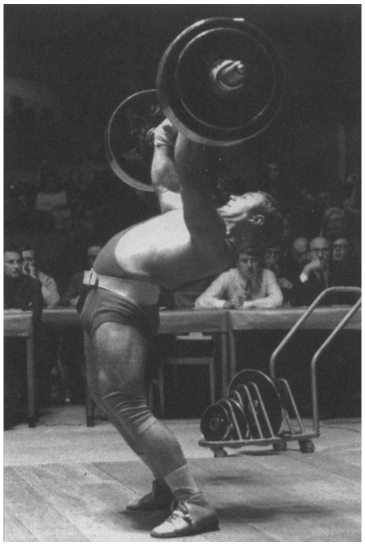
This lecture is optional: all contents are covered in the text.

What is good exercise technique?

Many people have some intuitive idea of what good technique looks like, but they can't define it. Good technique is often thought of as strict, pretty and smooth, but none of those things necessarily stimulate muscle growth or strength development. Augustin et al. (2024) had a group of 25 untrained individuals train 1 arm with strict technique and 1 arm with 'cheating' technique. The strict arm did biceps curls and triceps pushdowns with their elbow at their side, moving purely at the elbow joint. The 'cheating' arm was trained with body momentum, swinging the weights up during the curls and pressing down on the weight during the pushdowns. After 8 weeks, both arms grew equally well with no statistically meaningful differences between them. In defense of stricter technique, the strict arm got equal gains with lower weights, so you could argue they achieved a better stimulus-to-fatigue ratio with lower injury risk.

For muscle growth, good technique means exposing your target musculature to high mechanical tension, preferably without too much injury risk. For a strength athlete, good technique should primarily enable you to lift as much weight as possible. More broadly speaking, good technique means performing a movement in such a way that it stimulate the desired training adaptations. That means there is no 1 universal best way to perform any exercise.

Another highly desirable feature of good exercise technique is consistency. If your technique is not consistent every time you perform an exercise, measuring progress over time and implementing progressive overload becomes difficult. For example, the barbell overhead press used to be a part of Olympic weightlifting, but lifters started bending over backward to turn it into a 'standing incline press', also called the Russian Press. Most progress in the lift became attributable to 'cheating' more rather than becoming stronger. The press was therefore removed from the Olympic games in 1972.



Even if you're not a competitive weightlifter, being consistent with how you perform each movement is important to monitor progressive overload. If your technique changes with heavier weights, you don't know if you're really getting stronger or if you're just cheating more. Ideally, every exercise should have your body go from a defined position A to a defined position B to measure progress objectively. It also makes sure you stimulate the target musculature every rep without compensating with other body parts. For this reason, you'll see that the exercise in the course's exercise library generally define the top and bottom position of each exercise.
Here are some examples of poor exercise technique with respect to progressive overload.

- Varying the distance you step forward during lunges (or backwards for reverse lunges) when you become more fatigued or when you use your other leg.
- Having your feet slide away during push-ups or glute bridges.
- Doing pull-ups until your 'chin is over the bar'. This endpoint is quite imprecise and often results in people lifting their head with an explosive 'kip' at the end. A more consistent endpoint is pulling yourself up until your shoulders hit your hands or the bar (good for chin-ups with a neutral or supinated grip) or until you place your chin directly onto the bar (good for pull-ups with a pronated grip).

In the following lecture, you'll learn what exactly good technique entails and what a good default technique is for some of the most complicated and common compound movements.

➢ Lecture [vital]

Exercise technique

And here are 2 additional guides you can use to correct common problems with the squat and upper body pushing exercises.

➢ Guides

Fixing common problems with presses

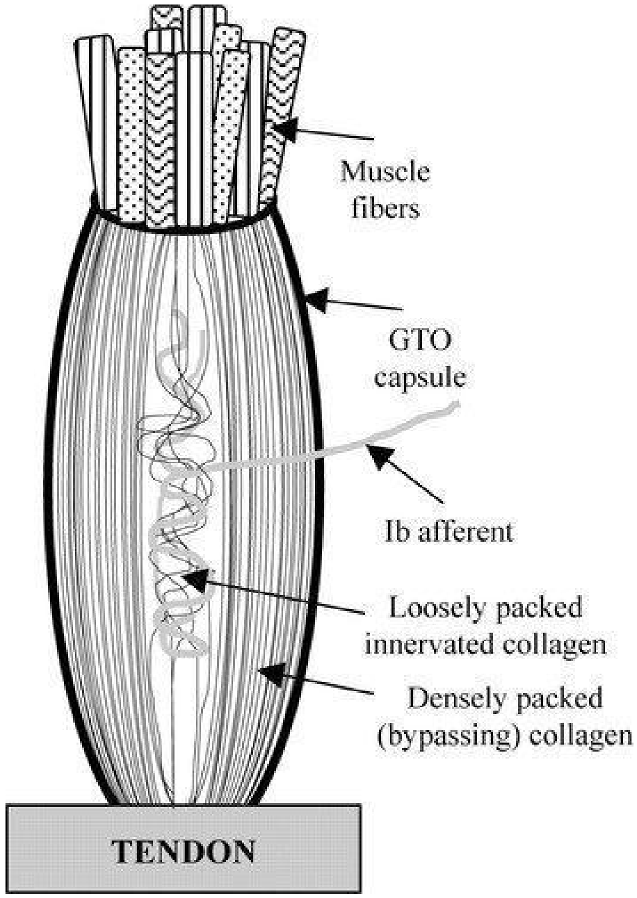
Fixing posterior pelvic tilt in the squat

The mind-muscle connection

The mind-muscle connection is a concept from bodybuilding circles that made it into exercise science. The mind-muscle connection refers to our ability to sense how well a muscle is being trained and our ability to selectively activate that target muscle during an exercise. The idea is that a good neural connection between your brain and a muscle allows you to feel how well you're training that muscle and preferentially recruit it. By focusing on the target muscles while you exercise, you can feel them more, and this is taken as a sign those muscles are activated more. But can we really activate certain muscles more by focusing on them and if so, is that a good idea? More fundamentally, can we accurately sense mechanical tension in our muscles in the first place?

Can we feel muscle tension?

Our bodies are equipped with the ability to sense mechanical tension, the primary stimulus for muscle growth. This sense falls under what scientists call proprioception: our sense of our own body position, movement and force production. Proprioception is why you can walk up stairs in pitch black darkness: you know what your legs are doing without seeing them. Proprioception is achieved by proprioceptors: sensors in our muscles and connective tissues that detect mechanical stimuli, such as muscle stretching and tension ('mechanosensors'). The sense of muscle tension comes from our Golgi Tendon Organs (GTOs).



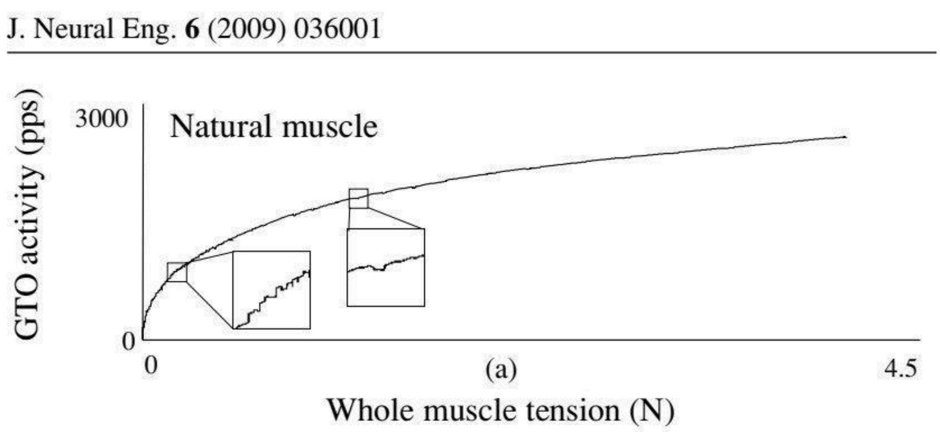
The Golgi Tendon Organ (GTO). GTOs are primarily located deep in our muscles, in between our tendons and our muscles. GTOs encapsulate bundles of muscle fibers and monitor how these fibers pull on the tendon. *Source*

While GTOs can sense active mechanical tension in our muscles very accurately, the signals that they send to the brain do not linearly correspond with the total tension the muscle experienced for multiple reasons [2].

1. GTOs are very insensitive to passive muscle tension. They can detect it, but they only activate at very high levels of passive tension. GTOs may thus underestimate stretch-mediated hypertrophy, although the sensation of muscle stretch can be detected well by other sensors.
2. Not all muscle fibers are connected to GTOs. 95% of GTOs are connected to no more than 25 muscle fibers and most muscles have fewer than 100 GTOs. If we

compare that to the 253.000 muscle fibers in a muscle like the biceps, that means fewer than 1% of muscle fibers are connected to a GTO. Also, these GTOs are located deeply within our muscles, where there are relatively more slow-twitch muscle fibers. However, it's estimated that most motor units are strategically connected to at least 1 GTO. Since all muscle fibers in a motor unit should fire at the same time, total GTO activity probably represents total muscle tension reasonably well.

3. Non-linear summation. The strength of the GTO signal to the brain is not linearly related to muscle tension. It's more logarithmic, as you can see below. This means GTOs strongly distinguish between low and medium muscle tension, but they don't distinguish as much between high and very high tension.4. 4.



4. Adaptation effects. GTOs respond not just to tension but also the time under this tension: GTOs habituate to constant tension. GTOs essentially somewhat ignore constant tension, whereas they respond very sharply to sudden increases active in tension. GTOs also desensitize after high tension. Therefore, GTOs respond better to *changes* in tension than absolute tension.
5. Subconscious processing. The biggest problem of all, much of the GTO's signal to the brain seems to be processed by the subconscious parts of our brain, like most motor functioning. GTO afferent feedback is processed mostly subconsciously, although it can reach the conscious parts of our cortex. Just

> think of how difficult it is to feel which muscles exactly we use when we throw a ball or throw a roundhouse kick, let alone *to what degree* those muscles are active.

The lack of conscious processing is particularly strong for sensations resulting from self-generated movement ('reafferent signals'): our body predicts the results of our own movements and therefore does not respond to its resulting signals. This is why we cannot tickle ourselves: expected movements don't generate nearly the same sensations as unexpected ones. The lack of processing of self-generated proprioceptive stimuli is also the reason for findings of force escalation. For example, imagine you put your hand on a table. Now somebody presses down on your hand and afterwards you have to apply that same amount of force on their hand on the table. Most people apply significantly more force on the other person's hand, because they cannot feel as well how much force they're applying themselves as they can feel from external sources. We're blind towards the stimuli resulting from our own movements. Since practically all exercise is self-initiated movement, our brains do not consciously process a great deal of the internal signals resulting from exercise.

Perhaps the clearest example of proprioception gone wrong is phantom limb sensations. In some cases, we can experience sensations in a limb that doesn't exist. For example, after a hand amputation, many people still feel things in the hand that's no longer there. The brain clearly didn't get the memo in these cases.

In conclusion, our bodies are biologically equipped to sense muscle tension, but the system is very imperfect for bodybuilding purposes. As it turns out, it was more important for humans to throw a spear accurately than to know how much this stimulated their biceps.

If you think about it, it's obvious humans don't have a 'tension stat' in their muscles. If we did, we wouldn't need so much education about which exercises train which muscles. There are many debates online about which exercises train which muscles. Take pull-overs: do they train the pecs or the lats better? How about the long head of the triceps? One of the first questions new trainees ask is: "Which muscles does this exercise train?" And while we like to think we get better at this with experience, it's hard to determine if we're actually getting better or we just *remember* which muscles are supposed to be trained by an exercise. Are you 'feeling' your lower traps during a pulldown because you can sense the internal muscle tension or do you think you feel something there because you expect to feel something there? Analogously, we also like to think we get better with experience at estimating how close to failure we're training, yet most research finds training experience and even experience with estimating reps to in reserve (RIR) not improve the accuracy of our RIR estimates.

We also generally can't feel our smooth muscles contract, yet fortunately our heart and intestines are working around the clock to keep us alive.

Theory aside, what do the data say? We currently only have 1 study that directly associated subjective and objective muscle activity. Mitsuya et al. (2023) found that even bodybuilders could only accurately feel rectus femoris activity during leg extensions in one of 3 measurement sites. In the vastus lateralis and medialis, there was an increasing trend of subjectively perceived muscle activity with increasing hip flexion angles despite constant objective muscle activity. The bodybuilders thus had a limited ability to detect true differences in muscle activity while also being prone to experience differences in muscle activity that did not actually exist. The researchers concluded their "results suggested that […] the subjective sensation of muscle contraction […] was inconsistent with […] objective muscle activity." And that's the group average of highly experienced bodybuilders. At the individual level, the relationship between subjective and objective muscle activity becomes even more tenuous.

Menno has also co-authored a study with Plotkin et al. (2024) on subjective glute muscle activity in relation to long-term muscle growth when doing either squats or hip thrusts. Virtually all our participants said they felt hip thrusts more in their glutes, yet squats produced just as much muscle growth in the glutes over the course of the study.

Clearly though, we feel something in our muscles when training. So what is that something if not muscle tension? Metabolic stress and stretch seem to be much easier to feel than muscle tension. There are many training practices which stimulate a great pump, burn or stretch in our muscles, enriching the mind-muscle connection, while not being particularly effective and sometimes even counterproductive for muscle growth.

- You can get a great pump and mind-muscle connection by performing mid-range partial reps for a muscle, yet full ROM training is generally superior to stimulate muscle growth.
- Using short rest intervals similarly increases the pump and burn you get from training, but short rest periods actually reduce muscle growth in research.
- Pre-exhausting the pecs with the pec deck before doing chest presses doesn't increase pec muscle activity, but you'll probably feel your pecs more during the subsequent bench press.
- Blood flow restriction training also majorly amplifies how much you feel the occluded limb, but counterintuitively, muscle activity levels and muscle growth increase just as much in the non-occluded agonists [2].
- Most people feel much more in their muscles when doing higher-rep sets than lower-rep sets. What they feel is metabolic stress, not muscle activity. Muscle

activity and tension are of course higher during high-intensity than low-intensity exercise.

We're also prone to mistaking stretching for mechanical tension. For example, most people feel a stiff-legged deadlift much better in their hamstrings than a regular deadlift even without any added weight. What you feel is the hamstrings running into passive insufficiency. Passive insufficiency means there is major muscle stretching but actually very low capacity to produce active tension. Research shows muscle activity levels do not significantly differ between stiff-legged and conventional deadlifts.

In contrast, we often don't feel muscles that in fact are clearly highly active. For example, many people think they have gluteal amnesia: their glutes supposedly aren't firing. If you think you have gluteal amnesia, ask yourself: how can I squat? The glutes are the primary, almost exclusive, hip extensor during squats. Clearly, something's producing a high hip extension torque. Squats consistently produce very high muscle activity and muscle growth in research. You're just not *feeling* the glutes. Many men in particular don't feel their glutes during squats in my experience.
Moreover, many people do glute activation drills in their warm-ups to solve this supposed gluteal amnesia. These glute activation drills make some people feel their glutes more, but the science is clear that glute activation drills do not increase actual glute activity, force production or strength development over time.

Attentional focus

Can we intentionally change our muscle recruitment levels by focusing on that muscle, and if we can, will that make the muscle grow more? A study by Calatayud et al. (2016) put the first question to the test in a group of men benching over 2 plates on average. They investigated how bench press EMG muscle activity in the triceps and chest changed when the men pressed without instructions compared to when they tried to isolate their chest or triceps. The researchers tested this at various intensities from 20% to 80% of 1RM. The result was a clear trend in decreasing effectiveness of attentional focus at higher training intensities. At 20-40% of 1RM, the trainees experienced higher pec activity when focusing on their chest and higher triceps activity when focusing on their triceps, with no other differences in muscle activity. They certainly didn't isolate the pecs, but they did emphasize them. So overall a win for the mind-muscle connection. However, at 50% and 60% of 1RM, something unintended happened. Trying to isolate the pecs still successfully emphasized the pecs, but trying to isolate the triceps started to increase not just triceps but also pec activity by an identical amount (4-5%: more on this later). At 80% of 1RM, the mind-muscle connection failed entirely: there was no more effect of either instruction on either muscle. The men only performed 3 reps at each intensity, so these results suggest that the mind-muscle connection is only effective when training with lighter weights. It ceases to be effective when training heavy.

A replication study by Paoli et al. (2019) found similar trends, although they found no significant effect of the mind-muscle focus on pec activity at either 50% or 80% of 1RM yet still a significant effect on triceps activity at both intensities.

Similar but slightly different results have been found for rows as well. Fujita et al. (2020) compared 2 groups of untrained men performed seated rows at 70% of 1RM until they lost movement velocity (so quite submaximal but not nearly as submaximal as the previous study), either with no instructions or with the instruction to 'pull from the back'. During the set as a whole, muscle activity as measured by median EMG frequencies did not significantly differ between the groups for any muscle. The researchers concluded: "Verbal instruction seems to have little effect on increasing myoelectric activity of these targeted muscles in an entire set of resistance training."

When we zoom in on the muscle activity over time, we do see some effect at the start of the set. Pulling from the back increased lat activity during the first 2 reps by 15%. Interestingly, pulling from the back also *decreased* posterior deltoid activity by 14%. Midway through the set, posterior delt activity was still suppressed compared to the control group, whereas lat activity was no longer increased. At the end of the set there was no difference in either muscle's activity anymore, nor was there any difference in any other muscle throughout the whole set. Overall, these findings confirm that we can only enhance target muscle activity with attentional focus during very submaximal training. The effect fades as we get anywhere close to muscle failure.

Lifting explosively also seems to negate any effects of the mind-muscle connection. Calatayud et al. (2018) replicated their study on trying to isolate the pecs or triceps during the bench press with a new variable: lifting tempo. One group benched with a controlled 2-2 tempo: lifting the weight up over 2 seconds and lowering it for 2 seconds. The other group used an explosive tempo, pushing the weight up as fast as possible and then lowering it over 2 seconds. Both groups performed 3 reps at 50% of 1RM. The controlled tempo group could emphasize their pecs or triceps by thinking about them, but the explosive tempo group could not. Thus, it seems that an explosive lifting tempo decreases our ability to target muscle groups with our mind, just like a higher training intensity or getting closer to muscle failure.

You may argue these participants simply didn't have a good mind-muscle connection, because they weren't trained enough. However, training experience does not seem to improve our ability to isolate muscle groups by focusing on them. Daniels et al. (2017) replicated the above bench press study design in a group of well-trained (average bench 126 kg / 278 lb) and a group of untrained participants. Neither group successfully managed to increase muscle activity in their triceps or chest by focusing on them. Again they only performed 3 reps at 80% of 1RM. There was even a negative effect when the 2 groups' data were combined: trying to emphasize the chest decreased activation of the short head of the triceps without increasing activation of the chest or anterior deltoids. These findings suggest that the mind-muscle connection could even be counterproductive with heavier weights, regardless of how well-trained you are.

Fujita et al. (2019) again found no effect of internal attentional focus on muscle activity, neither in untrained nor trained participants, during a set of seated rows to failure at 70% of 1RM. The control group was simply instructed to perform as many reps as possible, while the internal cue group was given the instruction to pull with their back and focus on pulling their elbows back. An instructor also palpated their lats to enhance the mind-muscle connection, evidently to no avail.

Overall, paying attention to the mind-muscle connection during your training doesn't appear to be effective to emphasize the muscle groups you're focusing on, unless your idea of 'training hard' means having some difficulty reading your Instagram feed during leg extensions. When training explosively, with heavy weights or close to failure, most research finds no effect of a mind-muscle focus on that muscle's level of activation. Why isn't focusing on the mind-muscle connection effective?

It's because our brains are too awesome. The motor cortex – the part of our brain that coordinates movement – is really good at its job. Your brain's motor cortex functions like a Bayesian system that has been finetuned over millions of years of evolution. Most movements, like walking, are so complex in terms of muscle recruitment pattern that our conscious thought can't remotely govern this task as well as you can do intuitively. Even the brightest mathematicians can still barely create robots that walk with a semblance of elegance across uneven terrain. In this respect, trying to take over complex movements with your conscious thought is like trying to hack a computer by poking into its motherboard with a kitchen knife. In fact, just thinking of a complex movement like running while you're doing it reduces movement efficiency. This reduced efficiency is also what happens when we use internal cues like focusing on a specific muscle.

Internal vs. external cues

When we tell our brains what we want to achieve with a movement, it will optimize our muscle recruitment pattern to achieve this very efficiently, generally with the minimum energy expenditure necessary for the target outcome. For example, if you want to throw a dumbbell at someone doing curls in the squat rack, you don't have to think about which muscles you're going to use. You can just think 'this goes there' and your brain will automatically coordinate the movement for you. You can decide if you want to optimize for accuracy or power and your muscles will intuitively activate accordingly. These cues that you give yourself are called external cues: your attentional focus goes to something outside your own body. (Note: don't actually throw dumbbells at people in the gym. It's impolite.)

In contrast, focusing on the mind-muscle connection is a form of internal cueing: you focus on something inside your body, namely the target musculature. Internal cues result in worse performance than external cues across a wide variety of movement tasks, including maximal force production and repetition performance [2, 3, 4]. For example, Nadzalan et al. (2020) found that subjects can generally perform 1 to 2 more repetitions during squats or deadlifts with a 10RM load when thinking of lifting as much weight as possible (external focus) instead of when thinking about using their legs (internal focus). The external focus also increased average ground reaction forces, meaning the subjects put more force into the ground: this suggests that total force production and thereby muscle mechanical tension were higher.

An external focus is also best for long-term strength development. Nadzalan et al. (2019) in untrained men and Taylor et al. (2017) in strength-trained athletes both found significantly greater improvements in squat and deadlift strength in people training with an external focus than people training with an internal focus. Ghanati et al. (2022) also found greater improvements in hip strength, stability and athletic performance tests in athletes completing a training program with an external vs. internal attentional focus.

Internal cues, such as focusing on your quads during squats, are bad for performance, because they disrupt the optimized muscle recruitment pattern that your brain would otherwise have used. For the mathematics lovers, internal cues result in constrained optimization in the brain. Internal cues should also be unnecessary if your exercise selection is good. A good exercise for a muscle will strongly, often maximally, activate that muscle. That's the whole point of the exercise. For example, the bench press involves horizontal flexion against resistance. Since the pecs are a horizontal flexor, they contract to perform the movement. Lifting as much weight as possible thus requires maximum pec force production, tension and muscle activation. You don't have to focus on the pecs to achieve this. Your brain will do it automatically if the goal is maximum performance. In other words, internal cues result in inefficient movements.

This inefficiency can sometimes masquerade as greater muscle activity. Remember that Calatayud et al. (2016) found that trained men trying to isolate the triceps at 50-60% of 1RM during the bench press increased not just triceps but also pec activity equally? That's probably because the internal cue made the exercise as a whole more difficult, which effectively increases the training intensity. A weight that's 60% of your 1RM may become 65% of your 1RM when you use internal cues, as those can make you weaker. It wasn't so much the power of the mind-muscle connection but rather just inefficient movement. Similarly, a study by Snyder & Fry (2012) found that trying to isolate the pecs during 3 bench press reps at 80% of 1RM was in fact successful for the pecs, in contrast to all the other studies, but it also increased front delt activity. In fact, shoulder activity went up a bit more than chest activity (17% vs. 13%) when trying to isolate the chest. Triceps activity only went up with a mind-muscle focus at 50% of 1RM, not at 80% of 1RM, as in most research. So again, it wasn't so much that the mind-muscle connection really selectively enhanced the training stimulus for the target musculature but rather that a mind-muscle focus created an inefficient movement that made the exercise harder. Analogously, recall that Nadzalan et al. (2020) found that focusing on the legs during squats and deadlifts decreased how many reps they could do and how much force they produced, suggesting lower total muscle tension. They also found that the mind-muscle connection increased quad and hamstrings EMG activity. The higher muscle activity despite lower total force production was likely due to greater inefficiency of movement, as well as the shorter duration of the set due to being able to perform fewer reps. These findings may at first glance appear to support the effectiveness of a mind-muscle focus (although often for the wrong muscles), whereas they likely just represent inefficient movement, resulting in higher muscle activity levels by 'virtue' of making very submaximal exercise harder. As the research shows, these effects disappear when training with heavier weights, when training remotely close to failure or when lifting explosively.

We see a similar effect of making exercises artificially harder in blood flow restriction research, where occluding the triceps increases chest muscle activity and occluding the legs increases glute activity. Blood flow restriction training increases muscle activity levels and muscle growth just as much in the occluded as the non-occluded muscles [2]. It makes the overall exercise more difficult, raising the effective percentage of your 1RM that you're lifting and thereby increasing muscle activity levels when using light weights.

It's worth noting that inefficient movement can sometimes be useful when injured. In situations where you deliberately want to use lighter weights, a mind-muscle focus could help you maintain decent muscle stimulation with lighter weights. However, just lowering the weights or implementing blood flow restriction is arguably a more reliable method to achieve the same effect, likely with better strength development in the process.

Muscle activity aside, what about muscle growth? If a mind-muscle focus doesn't increase the activation of the muscle you're focusing on and it decreases total force production of the set, it logically can't increase muscle growth in that muscle. In fact, if your reps go down but muscle activity levels don't go up, as most research finds, this should reduce the total tension the muscle experiences. It would be nice to test this experimentally. Unfortunately, we have only one study that has tested the effect of internal cueing on muscle growth.

Schoenfeld et al. (2018) compared 2 groups training with either the instruction to "get the weight up" or the instruction to "squeeze the muscle" during barbell curls and leg extensions. The training consisted of 4 sets of 8-12 reps to failure twice a week. After the 10-week training program, the internal cue group did not gain more muscle in their quads, but they did gain more muscle in their biceps. Total body skeletal muscle mass and body composition did not differ across groups, nor did isometric strength gains. Why would 'squeezing the muscle' be effective for barbell curls but not leg extensions? If the mind-muscle focus significantly improved muscle growth, it should have affected both muscles, but the results were movement-specific. It's plausible that the 'muscle squeezing' group had better exercise technique. You can't mess up a leg extension, but instructing untrained, college-aged males to 'get the weight up' during barbell curls to failure often results in something that looks more like a supinated power clean than a strict biceps curl. The elbows come forward, they skimp on the range of motion and they lean back during the curl. Instead, the authors speculated that the participants couldn't establish a mind-muscle connection, whatever that actually means, with their quads because they were untrained. This explanation requires the hypotheses that the mind-muscle connection varies per muscle group, that trained individuals have a better mind-muscle connection than untrained individuals and that attentional focus increases muscle growth despite most research finding negative effects on force production and no effect on muscle activity. Given that multiple studies have failed to find any effect of training status on our ability to isolate muscle groups and that there is no evidence that these mechanisms differ per muscle group, this hypothesis is convoluted and questionable. Better exercise technique is a simpler explanation that aligns better with the mechanistic research and doesn't require multiple additional hypotheses (Occam's Razor). Unfortunately, the authors did not report dynamic strength development and training volumes, so we can't see if the internal focus negatively affected how much weight the participants could lift, as we would expect based on the other research. They did report isometric strength development, which did not significantly differ across groups.

Speaking of the difference between attentional focus per se and better technique, some people use the mind-muscle focus deliberately as a cue to improve exercise technique. This can work, at least during isolation movements. Focusing on the mind-muscle connection generally reduces ego lifting and makes people perform isolation movements stricter. However, it's probably more effective to directly think of the exercise technique that you want so that your motor cortex can optimize that exact movement. The more direct the technique cue, the better, research finds. For example, Beach et al. (2018) found that instructing people to 'not round their spine' during object lifting (deadlifting essentially) was significantly more effective to prevent spinal flexion than the cue to 'use your legs' or 'bend with your knees and hips'. The motor cortex is incredibly good at its job, so when you instruct it what its job is (lift the weight without rounding the spine), it will do it well. In that same vein, if you want to do something like keep your elbows at your sides during barbell curls, it's probably more effective to just think of exactly that: keep your elbows in place. This is likely more efficient than thinking of the biceps.

In conclusion, the limited body of evidence we have does not support the bodybuilding idea that focusing on a muscle makes it activate more and thereby grow more. Most evidence indicates that when you're training hard, we can't increase muscle activation further, because it's already maximal. Focusing on performance normally maximizes force output and muscle activity, which should thereby maximize muscle tension if you perform the right exercises with good technique. We also know that focusing on the mind-muscle connection, and internal cues in general, decrease how much weight we can lift and how many reps we can perform with a given weight. We have only 1 highly ambiguous study on how this affects muscle growth. The primary stimulus for muscle growth – mechanical tension – should follow force output, so how could muscle growth increase without making a muscle more active and while decreasing performance?

Summary

The mind-muscle connection is not total broscience, but there is also no convincing evidence to supports its use. It's questionable if humans are biologically equipped to accurately sense mechanical tension or muscle activity. The existing research suggests subjective and objective muscle activation don't consistently align and there are clearly many cases where how much we feel a muscle does not correspond with muscle activity or tension. We also don't appear capable of significantly isolating muscle groups by focusing on them during high-effort exercise, not even if we're very well-trained. The effects of attentional focus on muscle activity are limited to very submaximal exercise. During intensive training, our motor cortex will automatically optimize muscle activity levels to maximize performance, if we tell it that performance is the goal. Research finds that focusing on performance and exercise technique is more effective for both than focusing on the mind-muscle connection. For muscle growth, muscle tension should also be maximized by maximizing force output, although empirically we're limited to just a single highly ambiguous study.

Practical application

You're generally best off letting your motor cortex do its job when you're in the gym. Focus on performance and any constraints you have with regard to exercise technique, such as keeping your elbows in place or your back straight. You'll then automatically optimize muscle activity levels. Plus, performance will be higher than with internal cues. Lifting heavier weights or doing more reps with a given weight, given the same technique, should maximize the amount of tension you put on your muscles.

However, when you're injured, the inefficiency of internal cues actually becomes useful. With internal cues, you can reach relatively high muscle activity levels with relatively low loads, so the stress on your connective tissue for a given level of muscle activity is lower than with performance-oriented strength training.
Below are some tips to make full use of the mind-muscle connection for injured body parts. They rely on active feedback to the brain to enhance its ability to stimulate the target musculature.

- Touch the muscle group you're trying to emphasize, if possible. This provides tactile and kinesthetic feedback. Verbal feedback has been shown to be similarly effective as tactile feedback.
- Perform the exercise in front of the mirror. Visual feedback can enhance motor learning.

Repetition tempo

How fast should you lift your weights? Should you just lift intuitively, push yourself for maximal explosiveness or slow things down and keep control? These are questions related to your exercise repetition tempo. Let's discuss the effects of varying the speed at which you perform your reps.

Total rep tempo

Slowing down your reps reduces how much weight you can lift, or how many reps you can perform with a given weight [1, 2, 3, 4]. Intuitively, you may think that lifting a greater training tonnage equals more gains. However, as you learned in the module on training intensity, differences in external work output do not always correlate with differences in internal muscle stimulation: high and low training intensities typically stimulate equal muscle growth. Lifting with a slower tempo is much like training with a lower intensity in the sense that with a slow tempo, you typically start a set with a lower level of muscle activity than if you lifted explosively. However, as Henneman's size principle explains, throughout the set there is an increase in the recruitment of higher-threshold motor units to meet force production demands in the face of increasing neuromuscular fatigue. At the end of a set taken (close) to failure with a given weight, all motor units are normally recruited regardless of rep tempo. Moreover, the total degree of neuromuscular fatigue will be similar and the set will deplete a similar amount of glycogen in type I and II muscle fibers regardless of tempo, supporting that at the end of a hard set, the total amount of anaerobic work done by the muscle is the same no matter what tempo you train with. In the end it's still the same load taken to the same level of fatigue.

If the internal neuromuscular stress is probably similar with a slow and fast tempo, does it matter that you can perform more work with a faster tempo?

For strength, greater performance and muscle activity seems to translate into greater development. A meta-analysis by Davies et al. (2017) found slightly better strength gains with faster rep tempos, though only significantly when the training intensities were in the 60-79% range. In this analysis, repetition volumes (sets x reps) were equated. Thus, the faster tempo groups were restricted to increase their work output via heavier weights lifted and progressive overload. Since in practice you can train with a higher intensity or volume with faster tempos, and both of these factors can stimulate strength development, the benefits of a faster tempo for strength are likely greater than this meta-analysis shows. As we'll get to in the section on the concentric contraction, this is indeed the case.

For muscle growth, total repetition duration does not influence muscle growth in most studies, including a 2015 meta-analysis by Schoenfeld et al. [2, 3, 4, 5] and a 2021 review by Wilk et al. Unfortunately, most studies on repetition tempo have very low ecological validity for numerous reasons. Most studies are on untrained individuals, many did not implement progressive overload well and many artificially equated total work between groups. Many studies also did not equate training intensity between groups. Still, high-quality studies also generally find no effects of total repetition duration on muscle growth or even strength development.

- Carlson et al. (2018) found no difference in muscle growth or strength development between a 2-4-, a 10-10- and even a modified 30-60-second concentric-eccentric tempo during workouts performed to repetition failure with 10RM loads by trained lifters. This resulted in ~10 reps being performed for the 2-4 tempo, ~4 reps for the 10-10 tempo and only 1-2 reps for the 30-60 tempo. These results provide strong evidence that repetition tempo does not matter much, as long as your training intensity is high enough.
- Lacerda et al. (2021) had untrained men perform a strength training program with a different tempo for each leg. One leg performed leg extensions with a 1-1

concentric-eccentric tempo and the other leg performed the same program with the same loads, rest periods, etc. with a 3-3 tempo. Both legs trained to failure, resulting in the faster tempo performing double the median number of reps per set. After 14 weeks, there were no significant differences between legs in the development of muscle size (CSA) or 1RM strength.

- Martins-Costa et al. (2022) found no difference in muscle growth (pec and triceps CSA) or 1RM strength development between groups of untrained individuals bench pressing for 12 rep sets with a 1.5-1.5 tempo or 6 rep sets with a 3-3 tempo with the same intensity (50-55% of 1RM).

An exception to the irrelevance of rep tempo may be super slow tempos. Just like with training intensity, there seems to be a minimum threshold you need for maximum muscle growth and especially strength development. Morton et al. (2019) found that a fast repetition tempo (1/1/1 s eccentric/pause/concentric) led to greater acute anabolic signaling (phosphorylated/total S6 ribosomal protein) than a slow repetition tempo (3/1/3 s) with 30% of 1RM but not 80% of 1RM loads. These findings suggest it's fine to use a slow tempo with heavy loads, but the combination of low loads and a slow tempo may provide a suboptimal growth stimulus. With super slow tempos, you're forced to use very light weights. For example, Keogh et al. (1999) found that to complete a 5RM on the bench press with a 10-second repetition tempo, the load had to be as low as 55% of 1RM, in comparison to the normal ~85% with an intuitive tempo. Moreover, muscle activity in the pecs and triceps was 12-36% lower throughout the entire set compared to a traditional 6RM set. If you're not performing low rep sets, a super slow tempo may result in insufficient muscle activity for maximum gains.

Schuenke et al., later reanalyzed by Herman-Montemayor et al. (2015) support that super slow tempos are probably a bad idea. 34 Untrained women performed an

8-week strength training program for the lower body. They performed 3 sets of 6-10 repetitions to failure, either with a traditional tempo of 1-2 seconds per concentric/eccentric contraction (TS) or with a slow tempo of 10 second concentrics and 4 second eccentrics (SS). The traditional training group achieved a greater increase in satellite cell number and myonuclear domain size. They also achieved significant growth in the cross-sectional area of all muscle fibers, 26% and 34% in type 1 and 2, whereas the slow tempo group only increased 6% in type 1 and 16% in type 2. The mean total increase in muscle fiber area did not differ significantly between groups, but the increase in the traditional group was almost 4 times as great and significant at a lower *p*-level (see graph below).

As such, these findings strongly suggest that a traditional tempo is better for muscle growth than a very slow tempo.

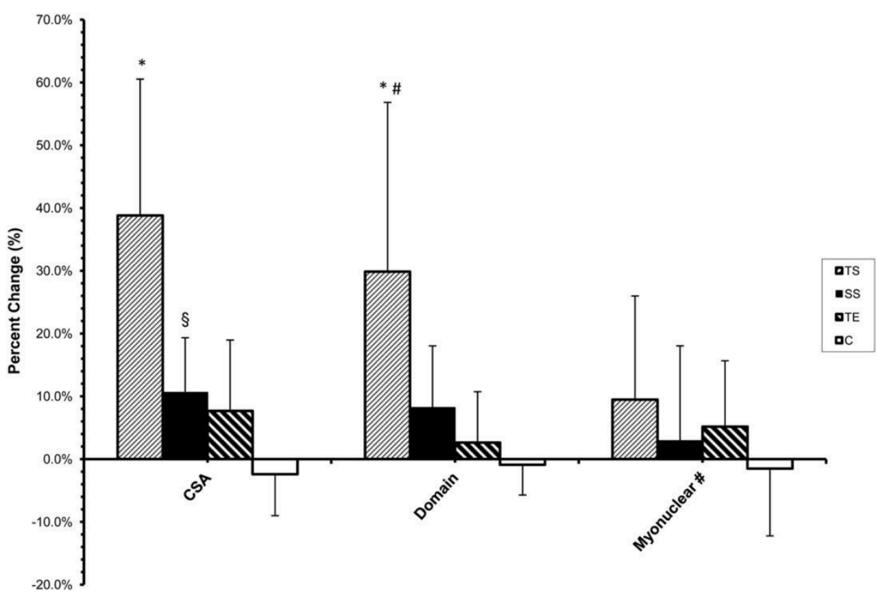


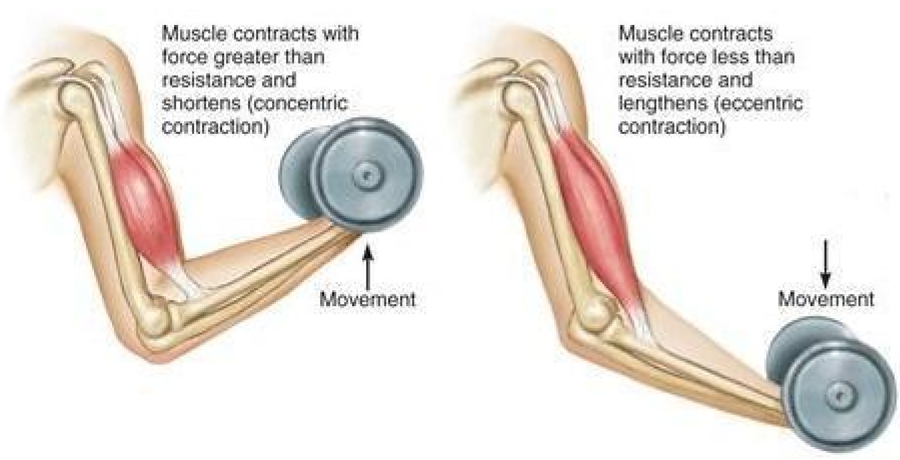
Figure 2. Percentage change (%) in mean fiber cross-sectional area, myonuclear domain size (domain), and number of myonuclei per fiber cross-section (myonuclear number) from pretraining to posttraining for each group (TS, SS, TE, and C). Absolute values were used for statistical analysis of data. Data presented as percent change (%) for the purpose of variable comparison. Values are mean ± SD. *Significant increase after training, $p < 0.001$. §Significant increase after training, $p \leq 0.05$. #Significantly greater increase after training compared with all other groups (SS, TE, C), $p < 0.01$. TS = traditional strength; SS = slow speed; TE = traditional muscular endurance; C = nontraining control.

➢ Research overview

Effect of repetition duration on muscle growth, strength development and muscle activity

All the studies discussed so far only looked at the total repetition duration. To get a better understanding of the effects of movement speed, rep tempo, also called cadence, can be broken down into 4 components.

1. The concentric contraction (muscle shortening): with free-weights this is normally the upward phase of movement.
2. The pause or lack thereof after the concentric (at the top/lock-out).
3. The eccentric contraction (muscle lengthening): with free-weights this is normally the downward phase of movement.
4. The pause or lack thereof after the eccentric (in the bottom/in the hole).



You'll sometimes see tempo being prescribed as a series of 4 numbers which represent the phases of a repetition. 'x' then often denotes 'as fast as possible'. Example: x/0/4/1 for the bench press, using the above order, means you push up the weight as fast as possible, you do not pause at the top, you then lower the weight slowly on a 4 second count and then pause for one second with the bar on your chest before starting the next rep. There is no consensus about the order in which the 4 numbers are presented, however, and some people only use 2-3 phases, often ignoring the pause(s). So when you see tempos dictated as a number sequence, be sure to verify which phase each number represents.

The above studies all manipulated the duration of the concentric and eccentric phases at the same time. But what if you only manipulate one phase's length?

The concentric contraction

A faster concentric is probably the reason why faster tempos tend to result in greater strength development. A 2023 meta-analysis of 24 studies compared strength gains in people lifting their weights in no more than 2 seconds (≤ 2 s concentric rep tempo) versus people lifting their weights in over 2 seconds or intentionally slowed down. The results were clear in both trained and untrained individuals: strength development was faster with faster training velocities.

Multiple studies convincingly illustrate the importance of explosive concentrics for maximum strength.

- Jones et al. (1999) studied the effect of self-selected vs. maximally explosive concentrics in the upper body training programs of an off-season NCAA Division 1AA football team. The groups performed the exact same programs. Even though the explosive group was not allowed to lift more weight or perform more reps, they still developed significantly more bench press strength and throwing distance. There was also a trend for greater power production.
- Pareja-Blanco et al. (2014) showed similar benefits for the full squat in trained men. Performing the same submaximal program with maximal concentric velocity instead of half-maximal velocity led to a strong trend for greater 1RM strength development as well as greater jump height performance. The effect on sprinting performance was unclear. The explosive training resulted in slightly more metabolic stress (lactate and ammonia) and neuromuscular fatigue (loss of jump height).
- An almost identical study in trained men by González-Badillo et al. (2014), comparing maximal vs. half-maximal concentric velocities during the bench press in an otherwise identical work-equated program, found significantly greater 1RM bench press strength development in the explosive group.

Both Pareja-Blanco et al. (2014) and González-Badillo et al. (2014) found that the more explosive concentric groups experienced approximately double the strength/velocity gains regardless of which movement velocity the strength was tested at: 1RM strength, low- and high-velocity training. The lack of apparent change in the force-velocity relationship indicates that the change in strength was not simply due to velocity-specificity but likely general neural improvements. Performing your concentrics explosively maximizes motor unit recruitment and thereby force production and velocity. Practicing this maximum neural drive for all muscle groups during an exercise is key to strength development. Strength on any specific movement is in large part neural in nature, the result of optimized coordination of all the active motor units.

We can dissociate the effect of repetition tempo and maximum neural drive by looking at isokinetic exercise. During isokinetic exercise, the velocity of movement does not affect total work output, because isokinetic machines automatically adjust the resistance to maintain a given velocity of movement, so regardless of velocity, you should be producing maximal force and achieving maximum muscle activity at any point of the movement. As it turns out, during isokinetic, concentric-only exercise, a faster concentric does not benefit strength development or muscle growth. The contrast between isokinetic machines and traditional constant resistance exercises shows that it's the increased effort and neural drive that maximizes strength development, not the velocity per se. It's the *intent* to move fast that matters, so it's fine if the reps aren't actually fast with heavy weights or near the end of a set.

For muscle growth, neural learning is not directly relevant. However, another benefit of faster concentrics is that they normally allow you to perform more reps or lift more weight by pushing through sticking points. The resultant higher total work volume may increase muscle growth and strength development in the long run.

Moreover, training for strength and power can increase your nervous system's ability to recruit motor units. This results in higher levels of muscle activity during training, along with greater loads lifted. As such, it is plausible that the greater strength and power development over the long run increases your potential for muscle growth. Then again, absolute load and muscle activity may not matter at all for muscle growth if sufficient mechanical tension is reached.

Unfortunately, there isn't a single study on trained individuals that measured muscle growth and manipulated only the concentric contraction duration with isoinertial resistance (like free-weights). The research in untrained individuals discussed earlier suggests muscle growth is unaffected by concentric movement velocity.

Conclusion

Training with explosive concentrics increases acceleration, force, training volume and muscle activity and is beneficial for strength and power development. There is no direct evidence showing faster concentrics improve muscle growth, presumably because at the end of a set taken close to failure you recruit all muscle fibers anyway under enough tension. However, it's plausible that increased strength and training volume can over the long term slightly improve muscle growth and it's highly unlikely there's any downside, so the practical advice is to perform your concentric muscle contractions explosively. For strength, move as explosively as possible. For muscle growth, move with the aim to maximize repetition volume.

The eccentric contraction

With traditional isoinertial (= constant resistance) exercise, like a barbell, you resist gravity's downward pull on the weight. You're only fighting gravity when you produce upward force. Thus, lowering the barbell faster during a bench press will decrease muscle activity, as you're resisting gravity's pull less and the muscles thus have to produce less force. Since your muscles are generally at least 20% stronger during the eccentric contraction than the concentric one, it's plausible that an excessively fast eccentric will not result in enough mechanical tension for maximal growth.

However, we've already seen that variations in total repetition tempo have little effect on muscle growth. As such, any benefits of slower eccentrics would have to be no larger than the benefits of faster concentrics for them to cancel out. The literature specifically comparing different eccentric contraction durations aligns with this, as most studies find no significant difference between groups in muscle growth resulting from different eccentric rep tempos. A 2025 meta-analysis also found no significant effect of eccentric repetition speed on muscle hypertrophy or strength development. Gains in power were greater with faster eccentrics. Mechanistically, as long as you train to or near failure, you're going to stimulate all muscle fibers, regardless of whether you get there with fewer slower reps or more faster reps. In both scenarios, your muscles are lifting the same load until the same level of fatigue, which is the inability to lift the given load.

- Sampson & Groeller (2015) compared untrained men performing biceps curls for 4 sets of 4 biceps curls at 85% of 1RM with explosive concentrics and either an as-fast-as-possible eccentric or a 2-second eccentric contraction. One set was taken to failure and used as a benchmark of progress to implement progressive overload. Despite the supposed use of progressive overload, there was no difference in training loads between groups. You would expect the faster-eccentric group to be able to perform more reps or lift more weight. Somewhat unsurprisingly then, there was no difference in muscle growth (CSA) or strength development (1RM and MVIC). There was also no difference in muscle activity during the maximal strength tests, supporting there were similar neural adaptations.

- Fisher et al. (2016) performed a study with actual progressive overload and trained individuals on a full-body training program. The traditional-tempo group performed all exercises with a 2-second concentric and a 4-second eccentric contraction. The 'eccentric-accentuated group' increased the duration of the eccentric to 10 seconds. Both groups trained to failure at ~75% of 1RM, which led to up to 6 reps per set for the slower-eccentric group and up to 12 reps per set for the traditional-tempo group. Unfortunately, they did only 2 workouts per week with only ~2 sets per muscle group. As a result, there were minimal changes in body composition (BodPod) in either group and unsurprisingly then, strength changes did not differ between the groups.
- Mike et al. (2017) had strength-trained men do 4 weeks of Smith machine squats with either a 2-, 4- or 6-second eccentric tempo. Volume and intensity were equated between groups, so the slower tempo groups trained harder, but this did not significantly increase 1RM strength gains, at least not over the mere 4-week study duration.
- Shibata et al. (2021) compared 2- vs. 4-second eccentric tempo squats to failure at 75% of 1RM in male soccer players. The speed of descent did not affect thigh muscle growth (CSA). The super slow descent group built significantly less 1RM squat strength, which is expected because strength is velocity-specific. A slow eccentric may also reduce the benefits of the stretch-shortening cycle. Eccentric muscle actions before concentric ones potentiate the concentric muscle contractions, allowing you to be more explosive and perform more reps, but this effect only occurs if the muscle is stretched somewhat rapidly [2, 3]. Being explosive is generally good for strength, as it helps you to push through sticking points.
- Pearson et al. (2022) had strength-trained men perform leg extensions with one leg doing 1-second and the other leg doing 3-second eccentric phases with the same weights and repetitions. Unsurprisingly, the 3-second condition resulted in

higher ratings of perceived exertion (RPE)s, as they were lifting the same loads for the same number of reps with more time under tension. However, the slower lowering phases did not increase 1RM strength gains or proximal quadriceps muscle thickness gains over their 8-week training programs. In fact, distal quad gains were slightly and even statistically significantly greater in the 1-second leg somehow.

Still, there is some evidence an excessively fast eccentric contraction – or rather lack of a contraction – is detrimental.

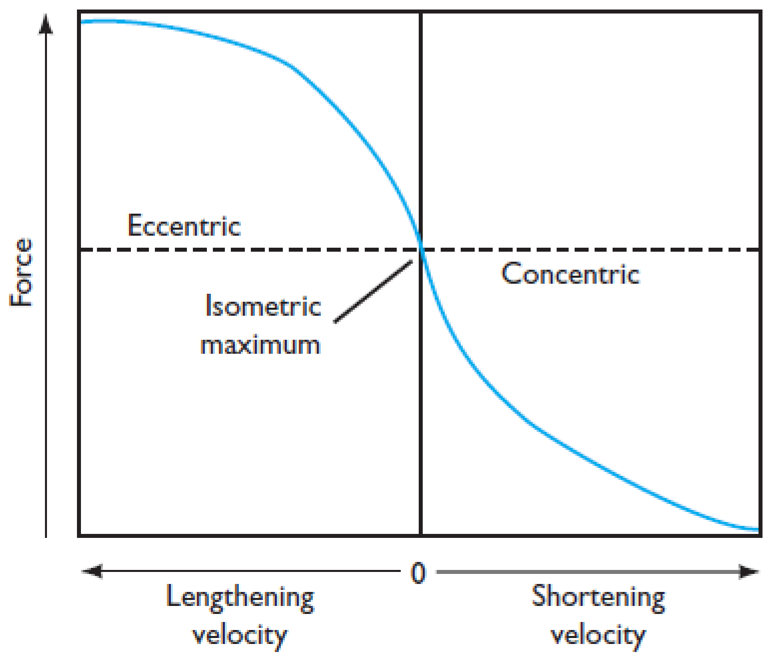
- In a study by Kojic et al. (2025), a group of endurance but not strength-trained individuals squatted with either 1 or 4 second lowering phases. Both groups did 3-4 sets to failure at 60-70% of 1RM 2x per week. After 7 weeks, there was no significant difference in total quadriceps growth between the groups. There was significantly greater growth in the vastus lateralis of the slower-tempo group though, supporting some previous research that tempo may influence regional hypertrophy. Also, a 1 second descent during a squat in an untrained individual may be a little too fast, too furious. If you dive bomb down, you neglect muscle tension during the eccentric contraction. However, since there was no difference in any of the other 4 regions or the total sum, the greater VL growth could easily have been a fluke. In contrast to the earlier studies, the 4-s descent group gained more squat 1RM strength than the 1-s descent group (p = 0.04).
- Pereira et al. (2016) compared a program of Scott biceps curls performed with either a 4- or 1-second eccentric duration by trained men. They found a trend for not only greater muscle growth but also greater strength development with the slower eccentrics. However, despite what the title and abstract of this grammar-error-loaded publication from Brazil suggest, neither difference was statistically significant. There was a trend in effect sizes, but with only 6 subjects per group and the use of ultrasound to measure muscle size, the chance of not

just a false negative (type II error) but also a false positive (type I error) is relatively high. Moreover, in private correspondence with Menno, Paulo Eduardo Pereira clarified that “The total work was equalized between the groups.” This would suggest that the faster tempo group was not allowed to train with heavier weights, rendering the study results irrelevant for practical purposes where heavier weights are the very goal of a faster tempo. He unfortunately stopped responding when asked to confirm whether total work or only repetition volume were equated.

Assuming there truly was a beneficial effect, it was probably because a 1-second eccentric contraction during a Scott curl is too short to stress the muscles. That’s a speed of almost 180°/s. If you let the weight free-fall, you effectively have no eccentric muscle contraction. We know dynamic contractions are superior to concentric-only contractions for muscle growth (see the course module on exercise selection), so at least this study suggests you should control your eccentric contractions.

- Azevedo et al. (2022) also found weak evidence in favor of longer eccentric muscle contractions. A group of untrained individuals performing leg extensions with 4-second eccentrics gained more vastus medialis size than a group doing 2-second eccentrics during an 8-week training program. However, growth in the rectus femoris, vastus lateralis and quadriceps as a whole did not differ between groups, nor did 1RM strength gains. Moreover, somehow there was no significant difference between groups in how many reps they could do while supposedly training to failure. This is highly suspect and renders the findings of questionable relevance, because the main downside of training with slower eccentrics is normally that you sacrifice repetition volume in favor of time under tension. If you do the same number of reps with a slower tempo, that increases the amount of work your muscles did and it makes sense that you gain more muscle, but slowing down your reps normally decreases how many reps you can do.

The benefits of controlling the descent during isoinertial resistance exercise are likely the result of the muscles being exposed to greater tension and producing more work, not an inherent positive effect of slow muscle lengthening, because faster isokinetic, eccentric contractions have been found to result in *greater* muscle growth and strength development [2]. As you learned, due to the force-velocity relation of muscle tissue, muscles can produce more force eccentrically when lengthening rapidly than when lengthening slowly. During conventional isoinertial training, you cannot take advantage of this, as while your muscles become stronger with a fast descent, the resistance from gravity decreases. During isokinetic training, the machine increases resistance in proportion to your force output, so you can always apply maximum force.



Source: Susan J. Hall: Basic Biomechanics, 7th Edition

As expected, when we control for total work during isokinetic training, faster eccentrics no longer stimulate more muscle growth than slower ones. Váczi et al. (2014) compared ~1.5 second vs. as-fast-as-possible eccentric leg extension training in elderly men in a work-equated program. Here the machine adjusted the torque to match work between groups while performing the same rep and set volumes. The eccentric contraction speed did not influence muscle growth (CSA) or strength development, though the faster-eccentric group still developed more explosive strength.

While there's a potential benefit to controlling your eccentric muscle contractions for muscle growth, eccentric muscle contractions longer than 2-4 seconds impair subsequent concentric maximal strength, movement velocity and power. Very slow eccentrics reduce the potentiating effect of the stretch-shortening cycle and of course simply sap more energy. Impaired performance may reduce strength development.

In practice, using a specific eccentric contraction speed is problematic for technique development and the measurement of progressive overload. If you time many trainees that supposedly use a 4-second eccentric with a timer, you'll find they rarely actually take a full 4 seconds to lower the weight. It is typically much less. Moreover, as the weights get heavier, people are strongly inclined to make the eccentrics progressively shorter in duration. This means it becomes impossible to see if someone's getting stronger or if they're just shortening their reps.

Conclusion

A free-fall fast descent of a free weight is likely detrimental for muscle growth and strength development, because it takes away a significant part of the eccentric muscle contraction. You should retain muscular control. Keeping the tension on your muscles should also reduce the stress on your connective tissues, as dive bombing down into a squat or chin-up can be hard on your tendons. Slowing down the descent of your reps even further than needed to retain control of the weight does not seem to provide any benefits. Whether you do more, faster reps or fewer, slower reps does not seem to influence total muscular work or your gains. Since very slow training is impractical and may interfere with maximal strength development due to velocity-specificity, without any benefits in return, healthy trainees should generally train with controlled but not deliberately slowed or timed eccentric muscle contractions.

Injured athletes may benefit from slow eccentrics, as they can achieve similar training adaptations with significantly lower weights or rep volumes and less stress on their connective tissues.

Pauses

Should you pause between the concentric and eccentric phases? Unfortunately, there is no direct research that has tested this.

Theoretically, many bodybuilders argue that a pause is needed after the eccentric contraction before you start the concentric contraction to ensure your muscles are actually doing the work and the weight isn't going up merely due to the elastic effect of your muscles. However, this concern is unwarranted. If the stretch-shortening cycle really was purely a process of elasticity, it would occur even without an active subsequent contraction. You can easily test this. Dive-bomb down during a squat and see how far you "effortlessly" bounce back up. (Okay, on second thought... just imagine dive-bombing down on a squat. Your patellar tendons will thank you.) It is true that during an eccentric contraction your muscles and tendons store elastic energy and this contributes passive force to the subsequent concentric contraction. This is part of the reason why you can bench press more weight with a touch-and-go technique than from a dead stop. However, there is also an active force improvement resulting from the so-called stretch-shortening cycle. A fast muscle stretch potentiates muscle activity during subsequent contractions via a stretch-reflex [2]. A stretch-reflex is a signal sent by your nervous system when it registers a muscle is rapidly lengthening to the muscle to activate it and prevent muscle tearing. The stretching-shortening cycle is why you're stronger and muscle activity is higher during a regular squat than during a box squat (even when the squat's 1RM was used to determine box squat intensities, which in fact made the box squats being performed at a higher intensity). The stretch-shortening cycle also explains why total force output in the bottom of a dynamic squat is higher than during an isometric squat. So you can move more weight by making use of the stretch-shortening cycle and this is accompanied by a greater amount of active work done by the muscle tissue. That can benefit muscle growth, strength and power.

If you happen to have access to isokinetic exercises, training at high velocities can further improve the efficiency of the stretch-shortening cycle, though it seems that during eccentric-only contractions the tempo does not affect how much the SSC efficiency improves.

After the concentric contraction, there is also probably no need to rest before starting the eccentric contraction. Resting excessively long with the muscles under tension may be detrimental if it decreases your how many reps you can do and thereby your training volume. However, if the active muscles relax at this point, which is the case for the quads and glutes during squats for example, resting at this point effectively turns the set into a cluster set. The pros and cons thereof will be discussed in the advanced training techniques module, but for now, suffice to say it is not needed to pause by default. If you do pause, make sure you pause for a consistent duration each rep so that you can reliably track your progression over time.

The elderly

Elderly individuals may benefit from an actively slowed down tempo. 2 Studies by Watanabe et al. (2013, 2014) find greater muscle growth from training with 3 second concentric and eccentric muscle contractions than 1 second ones. However, both studies are extremely limited, as the faster-tempo groups paused in between reps and both studies employed very low intensity training (30-50% of 1RM). Slow reps without pauses may be needed with such low intensities to accumulate metabolic stress to increase muscle activity levels sufficiently for muscle growth. Moreover, the studies equated repetition volume between groups, so the slower-tempo groups were simply training harder.

Still, these results are in line with the finding that elderly individuals have deteriorated motor functioning. Their nervous system is no longer as well suited for explosive lifting. Elderly trainees fatigue faster than younger trainees when performing explosive reps but not when performing moderate or slow reps [2].

So for fatigue management, safety and possibly greater muscle growth, elderly individuals are advised to train with a very controlled tempo.

Women

Similar to the elderly, women may benefit from a less explosive lifting tempo. While women's muscles 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. During explosive exercise at very high training intensities, like powerlifting, men can perform more reps than women. The superior work capacity of women also disappears when training with weights very close to their maximum strength (1RM). Men are only more powerful during explosive, dynamic contractions though, not during heavy negatives or isometric contractions, even at a high intensity.

Women also recover less well after explosive exercise like sprints. In contrast to women's generally greater recovery capacity, high volume sprint training can take over 72 hours to recover from in women. This results in worse training adaptations for explosive exercise in women. For example, women don't build as much muscle protein after high intensity sprints as men. This is striking, because after regular strength training women build just as much muscle protein as men.

Since women are less explosive than men, women can perform more reps with a more controlled, less explosive lifting tempo. Forcing women to use a fast, fixed tempo does not take advantage of their higher endurance. While there is no direct research on any gender-tempo interaction, it is very plausible that increased repetition volume translates into greater muscle growth. As such, for muscle growth, women should use a slightly more controlled tempo than men: aim for maximal repetition performance rather than maximal acceleration.

For strength and power, a maximally explosive concentric is still likely to be beneficial. Morrissey et al. (1998) studied the effect of a 1-up-1-down vs. a 3-up-3-down tempo during a serious squat program with 8RM loads and progressive overload in untrained women. Both tempos resulted in similar squat strength development, but the faster tempo group developed more power across various measures.

Time under tension

You may have heard of research about the time under tension (TUT), literally meaning the time the muscle was under tension. Some coaches put great stock in the importance of TUT. However, if you prescribe a certain number of repetitions and a certain tempo, you are indirectly also prescribing a TUT: it is the product of reps x tempo. Thus, there is no need to concern yourself with TUT separately.

Practical application

The literature on exercise repetition tempo's effects is poorer than Robin Hood. From what it can tell us, the direct effects of rep cadence are small. Comparable to the effects of your inter-set rest intervals, it is plausible that your rep tempo is practically only important for muscle growth indirectly via its effect on your training volume. The vast majority of literature is volume-equated and thus shows no effects of variations in repetition tempo with one exception: training with an explosive concentric movement allows you to reach higher levels of muscle activity, perform more work and develop more power and strength. The extra training volume might in turn benefit long-term muscle growth. Making use of the stretch-shortening cycle can further increase muscle activity and total work. The lengthening phases should be controlled to ensure there is actually a significant eccentric muscle contraction, but there is no need to deliberately slow down the movement beyond what is needed to control the movement, as any increased muscle activity seems to be offset by the decrease in work output.

Female and elderly trainees do not have to train with maximal acceleration during their concentric muscle contractions and should instead aim for maximal repetition performance. For men, maximal acceleration generally results in maximal repetition performance, so this recommendation corresponds with the general advice to choose your repetition tempo with the aim to maximize performance.

In short, for muscle growth, an intuitive rep speed that maximizes how many reps you can perform without losing control of the weight during the eccentric is likely optimal. For strength development, the concentric phases of each rep should be maximally accelerated. Making use of the stretch-shortening cycle may be particularly important for strength and power. However, note that strength gains are partly velocity-specific, so Powerlifters should train the bench press with a pause in the bottom position, just like in competition.

Injury management poses an exception to the above recommendations. During (p)rehabilitation of a connective tissue injury (i.e. joints, ligaments tendons or bone), training with a controlled tempo is an effective method to avoid aggravating the tissue while still stimulating the target musculature. Since the benefits of a more explosive tempo are small, a slower tempo is a highly efficient compromise to preserve muscle stimulation while reducing stress on the tissue. We'll discuss this further in the course module on injuries.

Training to failure

How close to failure should you train? Should you go all-out every set or should you leave some gas in the tank? Before we can discuss this, we have to define what 'failure' exactly means, because there are 3 definitions of failure.

- In exercise science, training to failure refers to momentary muscle failure, the inability to perform another complete repetition despite maximum effort. In other words, you literally fail to complete the last rep of the set, despite trying. Momentary muscle failure could be called 'true failure'. It's often implied that momentary muscle failure means you trained with maximum effort. True momentary muscle failure in that sense means that if somebody had put a gun to your head, you still wouldn't have been able to complete the repetition. However, since it's impossible to observe someone's level of effort or motivation, we usually reserve the term momentary muscle failure for any failed rep with self-reported maximum effort, even if they might have been able to complete the rep with greater motivation or encouragement.
- Volitional failure refers to stopping a set when it gets too difficult: you no longer have the volition to complete another rep, although physically you might have been able to and you didn't literally fail to complete any rep.
- Technical failure refers to the inability to maintain your intended exercise technique in the presence of fatigue during a set. This term is often used in practice but is virtually unused in exercise science, as it's difficult to objectively quantify. Moreover, trained lifters should generally be able to train to failure with good technique. In fact, you could argue that an important part of good technique is to optimize performance, so if you find your technique is limiting your performance, it may not be ideal technique in the first place.

Unfortunately, even scientists often confuse the types of failure, so it's important to read studies on training to failure with a keen eye and check if the training protocol made sense with the provided definition of failure. For example, if a study says the participants completed 4 sets of 10 reps to failure with the same load and a limited rest interval, the participants were evidently not training to momentary muscle failure, as that's virtually impossible. If 10 reps constituted failure in set 1, meaning they failed the 11th rep, it's highly unlikely they could do 10 reps in set 2 again, let alone in set 4. In this module, the phrase 'training to failure' refers to training to momentary muscle failure, unless explicitly noted otherwise.

The effects of momentary muscle failure

Training to momentary muscle failure increases muscle activity levels only slightly, as you learned in the module on training intensity. The effect of training intensity – relative load – on muscle activity is far greater than that of going to failure. If the load is not high enough, training to failure still does not achieve maximum muscle activity levels.

Neuromuscular fatigue increases substantially more when training to failure: it keeps linearly increasing every rep and some measures of fatigue, such as ammonia levels, even show an exponential increase. A 2021 meta-analysis confirms that training to failure significantly increases neuromuscular fatigue, metabolic disruption and muscle damage compared to not training to failure, *even when the same total number of repetitions are performed by both groups in the workout* [2]. This means training to failure has a poor stimulus-to-fatigue ratio. You induce a lot of extra fatigue for very little increase in muscle stimulation.

Training to failure is also an inefficient way to add training volume, because the neuromuscular fatigue you induce impairs your work capacity. After having taken a set to failure, you cannot perform as many reps in subsequent sets anymore as you would have if you had left even one rep in the tank. As a result, your total work output generally does not increase when training to failure; in fact, it often decreases across multiple sets compared to staying a few reps away from failure, despite higher training exertion [1, 2, 3, 4, 5, 6].

After the workout, you also need more time to recover if you trained to failure. For example, training to failure increases the recovery time of 3 sets to failure by about 24 hours compared to the same volume of submaximal training [2].

Over the course of weeks, excess fatigue may even result in overtraining symptoms. Training to failure for several weeks has been shown to suppress IGF-1 and testosterone levels while increasing cortisol levels without any benefit to strength or power development. Training to failure is thus hard to effectively combine with high training frequencies or volumes.

It's also worth noting your blood pressure also increases considerably when taking a set to failure, although this is normally not a medical concern, as it's very transient.

Training to failure thus impairs both the quality (stimulus-to-fatigue ratio) and the quantity (volume) of the rest of your training session. Is the relatively high fatigue induced by training to failure worth it for your gains?

Effect on muscle growth

We have a large literature on training to failure with a relatively clear big-picture consensus. For a given number of sets, training closer to failure generally improves muscle growth compared to training further away from failure [2], although the effect often doesn't reach statistical significance in individual studies. Leaving reps in reserve roughly linearly decreases muscle growth for a given number of sets. In studies that equate for the total number of repetitions instead of the number of sets, training proximity to failure ceases to have any benefit [2, 3]. Thus, the increase in muscle growth is driven by the additional repetitions performed, not by any inherent effect of momentary muscle failure. It's the total accumulated mechanical tension on the muscle that causes muscle growth, not fatigue. In these studies, the groups training further away from failure have to do additional sets to get the same number of total reps as the groups training closer to failure, so training closer to failure is more time-efficient.

These findings also align with our own in-house meta-analysis, conducted by Fredrik Tonstad Varvik, co-author of this course: training to failure improves muscle growth only in cases where it results in a greater total repetition volume. In other words, training to failure primarily or even exclusively affects muscle growth indirectly via its effect on training volume. You can see the analysis results and a full research overview of training to failure below.

➢ Research overview

[Effect of training to failure on muscle hypertrophy: in-house systematic review & meta-analysis]

To illustrate the effect of training volume mediated by training to failure, let's look at some individual studies. [Martorelli et al. (2017)] compared a group of young women performing 3 sets of biceps curls to failure at a 70% intensity compared to a group performing only 3 sets of 7 reps and a group performing 4 sets of 7 reps (roughly volume matched to the failure group). All groups gained a similar amount of strength and muscle endurance, though interestingly the group training to failure was the only one not achieving an increase in peak torque, a measure of strength. The group training to failure did achieve more muscle growth than the group performing the same amount of sets several reps away from failure but not more muscle than the group that also trained submaximally but added a set to equate total work. In other words, a higher repetition volume improved muscle growth and it didn't matter if this came from training closer to failure or from doing an additional set. A similar study by [Da Silva et al. (2018)] replicated these findings in elderly men. The researchers compared 3 groups: not training to failure, training to failure and not training to failure with total volume matched to the failure group. All groups gained a similar amount of strength and power. The 2 groups with higher volume gained more muscle. It didn't matter if the volume came from additional sets or from taking each set closer to failure. [Andersen et al. (2024)] yet again replicated the finding that training closer to failure is only beneficial in so far as it increases your training volume in well-trained lifters (~4.5 y experience training ~4x/wk). One leg trained reasonably close to failure, to a 30% velocity loss, doing up to 14 reps per set. The other leg trained very far away from failure, stopping the set after a mere 15% velocity loss, doing only up to 7 reps per set. Total work volumes were equated by making the 'are these warm-up sets?' group do twice as many sets. After 9 weeks, the gains in each leg were nearly identical. 1RM leg press strength increased by 40-42% and quad muscle thickness in both measurement sites increased by 5-7% in both legs. The lifters in this study trained with maximally explosive concentrics, which is probably necessary to make sets effective when you don't even get close to failure. The overall result in all these studies is that training harder per set or doing more, lighter sets is on average equally effective if you end up with the same total number of reps.

Mechanistically, muscle grows from mechanical tension and every rep performed with the same weight requires a similar force production and thereby mechanical tension. Thus, every rep contributes similarly to muscle growth. However, you do have to train with a reasonable level of effort for these findings to apply. If you don't train anywhere close to failure, all the work is done by your type I muscle fibers and you never stimulate the bigger, higher-threshold motor units. Based on motor unit recruitment data, we need to be at roughly 80% of 1RM to reach full motor unit recruitment, which conservatively translates into 8 reps to failure. (Remember Henneman's Size Principle of motor unit recruitment? If not, go back and revisit the modules on understanding muscle growth and optimal program design.) For example, Goto et al. (2005) found that taking a 30-second break in the middle of your sets hampers muscle growth compared to doing the same number of reps in one uninterrupted set. On the one hand, this result is extremely unsurprising. Shocker: you have to train with some effort. On the other hand, this study was the first proof of principle that total tonnage and repetition volume are not all that matter. Reps performed closer to failure more effectively stimulate muscle growth by virtue of achieving higher levels of motor unit recruitment, thereby stimulating more mechanical tension.

Even if you can theoretically achieve maximal gains without training hard, the number of sets you'd have to do becomes impractical. For example, Myrholt et al. (2023) compared the effects of training closer to failure (40% velocity loss) with around 3 sets of 8 reps vs. training further away from failure (20% velocity loss) with around 6 sets of 4 reps in advanced male strength trainees. Although the 20% VL group did about double the number of sets as the 40% VL group, they averaged only ~355 reps per exercise compared to ~430 reps in the 40% VL group. Accordingly, the group training closer to failure with half the sets experienced greater size gains on all 5 measurements, although only the difference in vastus lateralis muscle thickness reached statistical significance. This means someone leaving more than 5 reps in reserve every set may have to do more than double the number of sets to rival the gains of someone that pushes every set close to failure. That's very impractical.

Thus, in practice, for maximum muscle hypertrophy, it's advisable to perform as many reps as you can every set. This guideline is simple, time-efficient and enables you to accurately track your progression compared to staying further away from failure. Stop the set when you expect you'll fail your next rep. Reaching momentary muscle failure induces significantly more fatigue and reduces how many reps you can do in your next sets, which is generally not worth it for the marginal increase in growth stimulus that set.

Effect on strength development

For strength development, training to failure seems to be less beneficial than for muscle growth, sometimes even *detrimental*. The latest 2024 meta-analysis found no relationship between proximity to failure and strength development in studies. Both Vieira et al. (2021)'s and Grgic et al. (2021)'s meta-analyses on training to failure found that training to failure did not affect strength gains in volume-equated studies. In non-volume-equated studies, training to failure *reduced* strength development. Another meta-analysis by Gantois et al. (2021) also found a trend for greater strength development when not training close to failure, as measured by the maintenance of a high velocity during the set, but this was not statistically significant. A 2022 meta-analysis by Hickmott et al. on velocity-based training did find a statistically significant detrimental effect of training closer to failure (> 25% velocity loss) on strength development, even though it was beneficial for muscle growth. Another 2022 meta-analysis on velocity-based training by Jukic et al. found that strength and power development were not significantly affected by proximity to failure (as assessed by velocity loss), in contrast to muscle hypertrophy, although there was some trend for greater strength gains when staying a bit further away from failure. This negative effect of training to failure was not found by an earlier meta-analysis by Davies et al. (2015): they found no statistically significant difference in strength development between training to failure vs. not to failure, regardless of whether training volume was equated (note the erratum in 2016). Lastly, a 2023 meta-analysis on velocity-based training found strength gains were optimal when training to a velocity loss of 20-30%, with worse gains below or above that. However, this analysis had several important limitations. The researchers did not factor in the effect of training volume (!) and they only included men and studies that measured 1RM strength in the powerlifts.

In conclusion, it's clear that training to failure does not benefit strength development. Reaching complete momentary muscle failure has a very poor stimulus to fatigue ratio and probably even an outright detrimental effect.

Why does more effort not equal more strength gains? There are several reasons why training to failure may not benefit strength development and could even harm it.

1. Once full motor unit recruitment is reached and muscle activity levels are near-maximal, additional reps may not contribute an additional stimulus to increase neural efficiency.
2. Neuromuscular fatigue can reduce motor unit firing rates and muscle activity levels, as you've learned. For strength, high muscle activity can be more important than total training tonnage.
3. Failed reps inherently have poor technique, which may interfere with consolidating the optimal motor pattern in the brain.

To illustrate a relevant study finding detrimental effects on strength development of training to failure, Carroll et al. (2018, 2019) performed a 10-week study in advanced lifters. Taking the last set of each exercise to failure led to worse overall strength development compared to training at 65% to 92.5% of maximal effort, despite obviously greater RPEs in the group training to failure.

However, the negative effects of training closer to failure on strength gains are certainly not consistent in individual studies. Most studies find no significant effects, *some* research found *positive* effects of hitting failure on the last set and multiple studies found we should at least get somewhere close to failure, just like for muscle growth. Most of the negative effects of training closer to failure thus seem to come from the very last reps, especially hitting true momentary muscle failure, and in particular on earlier sets when the acute fatigue reduces the quality of the next sets.

Moreover, all studies measured short-term strength development, which is largely neural in nature: the strength comes from improved coordination of the trained movement. Long-term strength development is much more strongly correlated with muscle size (see course module on understanding muscle growth) and we know training closer to failure improves muscle growth on a set-by-set basis, so the research likely understates the long-term benefits of training closer to failure for strength development. Combined with the poor time-efficiency of staying further away from failure, you probably don't want to leave more than 5 reps in reserve during your sets.

Also, make sure you're training explosively if strength is your primary goal. Performing your concentric contractions with maximum power ensures you reach high muscle activity levels even when you're not close to failure. If you train neither explosively nor close to failure, you won't maximize muscle activity and therefore likely won't maximize strength development. Many of the studies on training to failure for strength development involved athletes and velocity-based training with maximal concentric velocities, so the lack of need to get close to failure may be conditional upon explosive concentrics.

Conclusions on training to failure

For muscle growth, training to failure is only beneficial in so far as it increases total repetition volume. Reaching momentary muscle failure itself is not a growth stimulus per se and induces a disproportionate amount of neuromuscular fatigue. Any small benefits of training to complete failure are generally not worth the significantly greater neuromuscular fatigue, loss of subsequent work capacity, prolonged recovery time, potential suppression of anabolic hormone levels and increase in cortisol and blood pressure. Thus, it's most efficient to do as many reps as you can every set but not intentionally fail any reps. Still, it's better to perform as many reps as possible and occasionally accidentally fail a rep than to stay 3+ reps away from failure and never fail any reps. If you're not coming within 8 reps of failure, the set can hardly be called an effective work set at all for trained individuals looking to maximize muscle growth. It would take an impractical number of extra sets to make up for training so far away from failure and there's a limit to how much you can compensate for low effort with extra sets.

For strength development, training to failure seems to offer no direct benefits and may even be harmful, because it lowers the quality of the work you do, in particular the muscle activity, performance and technique of subsequent sets. It's best to stay 1-5 reps away from failure. Training 1 rep to failure is a good default strategy for combined size and strength, but if strength is more important to you than muscle growth, you can stay up to 5 reps away from failure. Leaving 2-3 reps in reserve works well in practice for strength-focused trainees.

Practically the only scenario in which training to complete failure is advisable is when learning how to estimate your proximity to failure, which brings us to the next question.

How do you judge proximity to failure?

Not going to failure begs the question of how you determine how close you are to momentary muscle failure in the first place. There are several methods to measure this.

Velocity-based training

One way to determine how close you are to reaching muscular failure is by assessing your movement speed, like the upward velocity of the barbell during a squat. As you come closer to failing a repetition in a set of any exercise, your movement speed will decrease. As you reach failure, the movement speed becomes zero. The slowing down of your movement is a pretty accurate measure of how fatigued you are. Therefore, movement velocity can serve as a measure of proximity to muscle failure. When you know your movement velocity at a certain training intensity for an exercise when training to failure, your velocity loss across a submaximal set can reasonably accurately estimate how many reps you could still perform if you went to failure. Velocity loss is generally a more accurate and objective way to determine your proximity to repetition failure than subjectively estimating how many reps you have left in reserve.

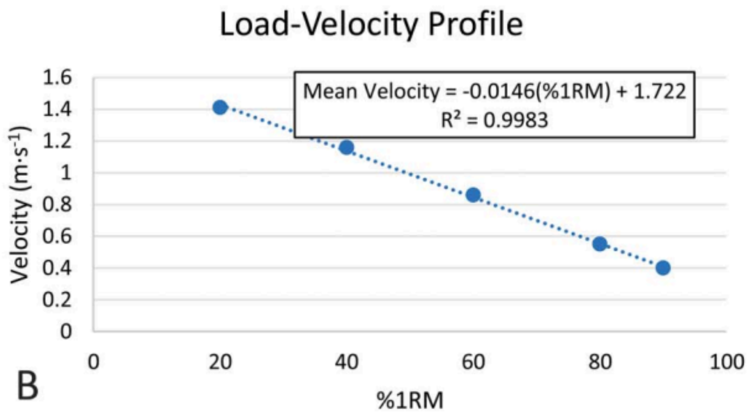
Shattock & Tee (2022) found that rugby players training until a prescribed velocity loss achieved considerably greater strength and power development after 6 weeks than a group training until a subjectively estimated level of fatigue (RPE/RIR, discussed below). Both groups achieved the same total training work volume and trained with the same intended intensities (%1RM), so objectively, the stimulus should have been similar, yet the velocity-based group achieved better performance gains. How? Velocity-based training has the major advantage that it's objective, so it probably aligns our training stimulus more closely with our true level of neuromuscular fatigue. Maybe you thought you could do more, but you were pushing too close to failure. Alternatively, maybe you told yourself you were close enough to failure, but the objective data showed you could push harder.

Moreover, acute feedback on your movement velocity may be motivational and educational to train as explosively as possible. As discussed in the section on rep tempo, training with explosive concentrics can improve force and rate of force development.

While velocity-based training is great in theory, the relation between number of possible repetitions left and velocity varies significantly per individual, load, set and exercise [2, 3], so you can't accurately determine how many repetitions someone could still do if you don't have prior data about their movement velocity specifically for that exercise at that percentage of 1RM at that level of fatigue. Essentially, you can only make accurate predictions during a very fixed training program. Generalized algorithms aren't very useful.

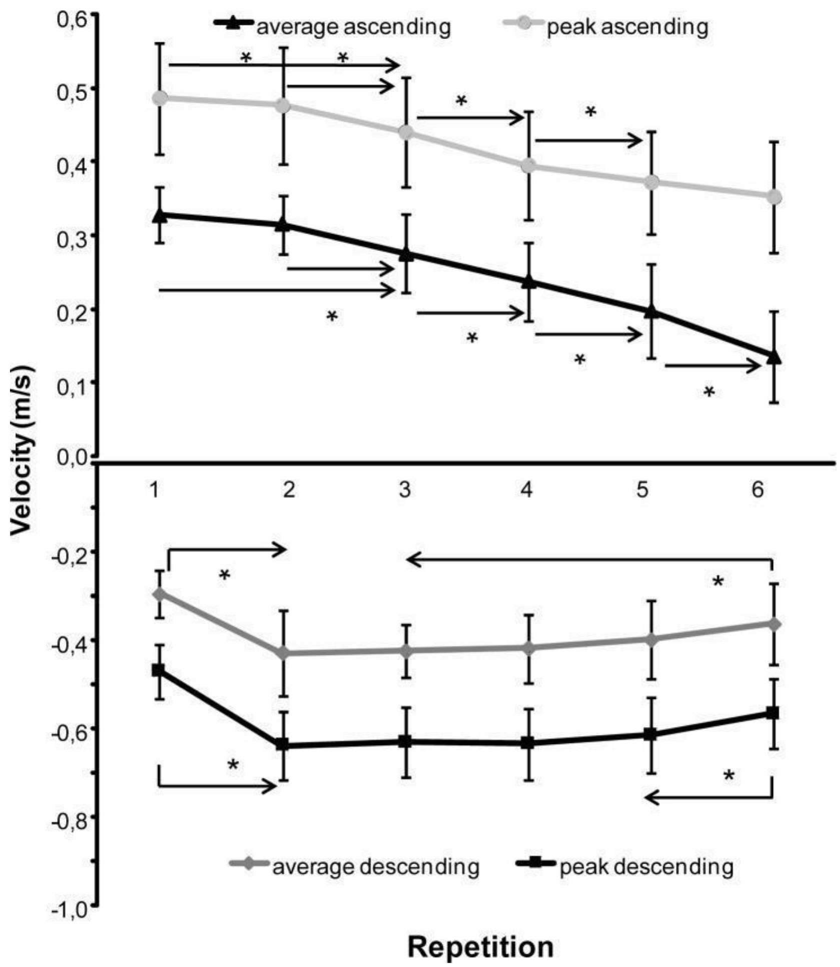
Thus, to implement velocity-guided training optimally, you need to personally monitor your movement velocity for each exercise. This is much easier to do in a laboratory than in a commercial gym. While there are some commercially available and practical apps and sensors that claim to function as reliable accelerometers, few have been validated in research and even if you have a good kit, it's a lot of work to set up. The table below summarizes the steps you'd need to take for each exercise to determine its load-velocity profile, along with a sample load-velocity profile. These data could then be used to estimate 1RM and training intensities based on current training velocity, although 1RM predictions based on movement velocity don't seem to be very accurate.

Steps for developing an L-V profile for an athlete in the back squat	
Session 1	**Session 2**
1. Warm-up with dynamic movements and stretches	1. After 48-h rest, the athlete returns and completes repetitions with 20, 40, 60, 80, and 90% of 1RM
2. Complete 3 repetitions at 20, 40, and 60%.	2. Three repetitions should be used for loads 20–60% and 1 repetition for 80–90%.
3. Complete 1 repetition at 80 and 90%.	3. For sets that involved multiple repetitions (i.e., loads 20–60%), the repetition with the fastest MV should be recorded.
4. Then 5 maximal attempts at achieving a 1RM are permitted	4. With this information, individualized L-V profiles can be constructed within Microsoft Excel using the MV plotted against relative load and by applying a line of best fit.
5. After successful attempts, barbell load can be increased in consultation with the athlete with loads between 0.5 and 2.5 kg.	5. A linear regression equation can then be used to modify training loads within and between sessions
6. The last successful attempt with a full depth squat with correct technique can be established as the 1RM.	
48 hours have been provided between testing occasions.	
1RM = one repetition maximum.	



How to construct an exercise's load velocity-profile. [Source](): this is a great and freely available paper on how to implement velocity-based training if you're up for the work.

If you don't have a validated sensor and app, the common implementation of velocity-based training is something along the lines of: "You stop the set when your explosiveness decreases/movement speed decreases/your reps start grinding." Such instructions are barely more objective than directly estimating reps to failure. Some people have the idea that your movement velocity suddenly drops at some level of fatigue; in reality, movement speed already starts decreasing very far away from muscular failure and continues to decrease gradually. At which point do you determine the decrease is significant or notable? You may think you can do this, but look at the actual velocity measurements during a 6RM bench press in the graph below. There is no clear cut-off point in either average or peak speed of movement, not in the upward phase of the movement nor in the downward phase.



Source

Based on objective data, you should consider a decrease in movement velocity more like a minimum level of training intensiveness than a maximum, at least for muscle growth. Using subjectively perceived movement velocity as a measure of closeness to momentary muscle failure in a set is at best a very rough measure that requires an arbitrarily determined cut-off point of how much speed reduction is acceptable.

So is it worth implement velocity-based training and getting the required equipment for it? Probably not. Despite some promising findings, a 2022 meta-analysis of the literature by Orange et al. found that velocity-based training did not result in better strength development than other methods to estimate proximity to failure. A 2023 meta-analysis did find greater improvements in jumping and sprinting performance, but these improvements primarily seem to result from performance feedback rather than velocity-based autoregulation per se. Some research on velocity-based training did not equate the total work volume, training intensity and proximity to failure between groups, such as Rossi et al. (2024), so that begs the question if the velocity-based training group simply didn't train harder or at least more explosively.

Even if you don't implement velocity-based training, it's very useful conceptually to think of velocity loss during a set as a measure of proximity to failure. True momentary muscle failure is preceded by significant velocity loss, until the movement comes to a complete halt in the biomechanical sticking point. If someone fails a rep at any other point during the exercise, the failure was either due to suboptimal exercise technique or lack of effort, not true momentary muscle failure. Similarly, if somebody stops a set before there's any measurable velocity loss, they most likely weren't close to momentary muscle failure and the failure was thus psychological: this is often called 'volitional failure'. Unfortunately, even many researchers do not properly distinguish between momentary muscle failure ('true muscle failure') and volitional failure ('mental failure').

RPE, RIR & RTF

Ratings of perceived exertion (RPE) are, as the name implies, a rating on a scale (say 1-10) of how difficult something is. A 10/10 RPE is training to failure by definition, so the RPE score can serve as a measure of how close you are to that.

There are various definitions and scales of RPE, but there's no need to go into them individually, because you probably shouldn't use any of them. The validity of RPE as a measure of training intensiveness is fundamentally flawed, because it is based on the incorrect underlying belief that your subjective perception and judgement of your effort are a reliable indication of your objective performance potential. Any subjective measure is by definition specific to the individual. For example, what level of pain is cause for concern? If you just ask "Does it hurt?" some people may whine it's intolerable at the earliest signs of discomfort, whereas another person may be walking around with bone protruding through the skin and reassure you "It's just a flesh wound." In that same vein, albeit less extreme, bodybuilders report lower levels of RPE at the exact same intensiveness of intensity × reps than recreationally active individuals. Several other variables can influence our performance and RPE differentially.

- The presence of a spotter can decrease RPE while increasing the number of bench press reps performed by increasing your self-efficacy ('confidence').
- Men report lower RPEs during exercise when being watched by a woman and higher RPEs when being watched by a guy.
- Oxygen shortage can increase RPE without affecting performance.
- Music can considerably affect the perception of effort while having minimal impact on objective performance [2].
- Transcranial magnetic stimulation – buzzing our brain with a targeted electrical current – can increase repetition performance without affecting our RPE.

Most proponents of the use of RPEs have come to the same conclusion: over time, most coaches' definition of RPE has shifted further away from subjective effort and closer to being a needlessly complex version of repetitions to failure (RTF). RPE is now often defined as the inverse of RTF and given the new name of Repetitions in Reserve, which is essentially the same as RTF.

Reps to failure

The simplest and most practical way to determine proximity to failure is by stating it in terms of the amount of repetitions you're away from reaching momentary muscle failure: reps to failure (RTF). Many researchers use a similar scale called Reps in Reserve (RIR), but the disadvantage of this scale is that it doesn't include muscular failure, as 0 RIR could mean either failure or that you think your next rep would fail.

With RTF, the scale logically goes from failure upward:
0 RTF means your last rep of the set fails despite maximum effort: you hit momentary concentric muscle failure.
1 RTF means you perform every rep you can except the one that you think would fail.
2 RTF means you leave 1 rep in the tank.
3 RTF means you leave 2 reps in the tank.
Etc.

Estimated reps to failure more accurately predict actual reps to failure than RPE scores do [2]. Trained individuals are typically reasonably accurate at estimating how many reps away from failure they are. A very motivated individual's estimated RTF when training close to failure is typically within 1 rep of actual reps to failure [2]. However, most people, especially lesser motivated individuals, still underestimate how many reps they can do by up to a few reps and the more tired people get, the more prone they are to underestimate how many reps they still had left to failure. Very few people accidentally hit momentary muscle failure. During particularly effortful exercises like squats, many people, probably most people, never accidentally hit failure in their entire life. People generally become less accurate in their predictions during higher-rep sets and when they stay further away from failure [2], which is logical, because a given error percentage constitutes a higher number of reps for higher estimates. If you generally underestimate how many reps you could still do by a quarter, that's not even a full rep for your 3RM, but it's 5 reps for your 20RM.

Counterintuitively, a 2021 meta-analysis found trained individuals are no more accurate than untrained individuals at estimating reps to failure. The lack of effect of training experience on judging closeness to failure was confirmed in subsequent RCTs [2, 3, 4]. Stronger individuals also don't seem to be better at estimating their RTF. It may feel like we get better at estimating how many reps we have left in a set, but in practice this is likely knowledge rather than improved introspection. Our *feeling* of how close to failure we are doesn't improve; rather, we just *know* that, say, 100 kg is our 10 RM and therefore we can deduce that after 8 reps we only have 2 more reps in reserve.

Conclusion

To induce maximal muscle growth, training one rep to failure (1 RTF) is often advisable. Every rep contributes to muscle growth, so it's most efficient to do all the reps you can. However, try not to regularly fail any reps, as it has a poor stimulus-to-fatigue ratio and it limits your subsequent work capacity.

1-5 RTF is all you need for maximum strength development in the short term, but the advantage of doing every rep you can is that you can more accurately track your progression. The accuracy of the reps-to-failure estimation decreases the more submaximal you train. What seems like strength progression may just be training closer to failure. Plus, in the long term, muscle growth should increase strength, so training 1

RTF is an effective and practical rule of thumb for most lifters. However, powerlifters and athletes that care more about strength than muscle growth – especially those restricted by weight classes – probably achieve an optimal stimulus-to-fatigue ratio around 2-3 RTF. This roughly means you do as many high-quality reps as you can, but you don't squeeze out the last few reps that would require you to grind with potentially shaky technique.

While you ideally shouldn't regularly train to failure regardless of goal, accidentally hitting failure occasionally can be fine, especially when training for muscle growth. It's a sign you're training hard enough. If you never accidentally hit muscle failure when trying to stay 1 rep to failure, your training efforts are questionable and it's advisable to occasionally take the last set of an exercise to failure, provided this is safely possible. Many trainees do not go nearly 1 rep to failure unless pushed by someone else. In fact, a 2022 meta-analysis found that the average gym goer leaves **6-7** reps in reserve during their workouts.

Breathing

How should you breathe during exercise? A study by [Blazek et al. (2021)] compared how multiple breathing techniques affected the 1RM bench press of strength-trained athletes.

- The Valsalva maneuver (VM): breathing in deeply while lowering the weight and then exhaling against a closed glottis while pushing. In other words, you keep the air tight inside you until you're past the hardest part of the lift.
- Holding your breath: similar to the VM but without inhaling extra air before you stop exhaling. It's essentially a less tight version of the VM.
- Lung packing (PAC): this is like an ultra-VM during which you gulp in extra air multiple times to really stuff your lungs before the lift.
- Reverse breathing (REVB): breathing in when pushing up the weight and out when lowering the weight.

The general trend was that reverse breathing decreased performance, while all the techniques that involved holding your breath during the push were effective. This means we intuitively tend to breathe properly.

The Valsalva maneuver and lung packing showed a trend to make the lift the most effortless: they decreased the time spent in the sticking region. These techniques increase intra-abdominal pressure by making us hold extra air in our lungs and keeping that pressure inside us until we're past the hardest part of the lift.

A 2024 study compared 3 other breathing techniques while lifting weights.

1) Pure nose breathing
2) Pure mouth breathing
3) Inhaling through the nose, exhaling through the mouth

107 Trained lifters did as many reps as they could with the same weight on the bench press with each breathing method. The researchers taped the lifters' mouths and clipped their noses to enforce the desired breathing method. After each trial, the researchers asked: "Did you experience the feeling of dried oral cavity?" Slovakian scientists don't mess around...

While the majority of lifters preferred the nose-mouth breathing, there were no significant differences in repetition performance, blood oxygen saturation or subjective training effort (RPE).

In conclusion, most people breathe well in the gym the same way they breathe well outside of the gym: by not thinking about it. You'll do it right intuitively. However, for extra hard reps, especially during squats and deadlifts, you should breathe in some extra air to brace your core extra tight before the rep and keep the air inside you're past the sticking point.