Exercise Selection

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Proper exercise selection can be tough. There are countless lifts to choose from and most of them have several similar-but-different variations. Most people don't have a systematic method to select their exercises. They just do what feels best, what looks best in the mirror or what others do. In this module of the course, you'll learn what makes an exercise effective based on systematic, scientific criteria. You'll find that the most popular ways to classify exercises are largely irrelevant, yet the factors that do strongly influence our gains are often neglected by non-evidence based lifters.

➢ Lecture [optional]

Exercise selection

Compound vs. isolation exercises

A never-ending debate in the fitness community is that of compound vs isolation exercises. Bodybuilders tend to prefer isolation exercises to specifically target 1 muscle group, whereas 'functional' and old-school type crowds tend to prefer compound exercises involving as many muscle groups as possible. Compound exercises tend to put much higher neurological, hormonal, and cardiorespiratory demands on your body than simple isolation exercises. However, as you learned earlier in the course, the contribution of systemic factors to muscle growth is highly overrated. Muscle growth is almost exclusively a local process. Muscles respond to tension without any care for or knowledge of what's going on in other muscles in the body. A 2023 meta-analysis of 7 studies by Rosa et al. found that single-joint and multi-joint exercises, which usually corresponds with isolation and compound exercises, result in similar muscle growth on average in the literature.

Many studies have found that compound and isolation exercises can be equally effective to stimulate muscle growth. Multi-joint exercises do tend to be better for strength development in the sense that their strength gains transfer over better to isolation exercises than the other way around in some studies. The better strength transferability could be explained by the greater neuromuscular coordination that's required from multi-joint exercises than single-joint exercises.

- Paoli et al. (2017) compared a training program consisting entirely of single-joint exercises to a program consisting entirely of multi-joint exercises with the same total volume load. There was no statistically significant difference in body composition change between the groups, again suggesting it doesn't matter if you use isolation or compound exercises, as long as the muscle fibers produce enough mechanical tension. VO_2max, a measure of cardiorespiratory endurance, improved more in the multi-joint group though, which isn't surprising considering compound exercises put far greater demands on your cardiorespiratory system. Interestingly, the multi-joint group gained more strength in not just the squat and the bench press but also the leg extension, which the participants only trained in the single-joint group. The multi-joint group trained with heavier weights (%1RM) and rested longer between sets. We know both of those factors are good for strength development and this study would suggest they're even more important for strength than specificity of movement pattern.
- Goncalves et al. (2019) found further evidence that multi-joint exercises are better than single-joint exercises for strength development even with the same program parameters (70% of 1RM to failure). The participants trained one leg with 3 sets of leg presses per workout. The single-joint leg group did 3 sets of leg extensions and 3 sets of leg curls. The leg doing leg presses gained significantly more strength not just in the leg press but also in the leg extension and the leg curl. The greater leg curl strength development from leg presses is particularly striking considering leg presses don't activate the hamstrings nearly

as much as leg curls. The superior strength development of multi-joint exercises thus seems to overshadow any benefits of exercise specificity.

- Bezerra et al. (2018) again found no difference in body composition changes or strength development between a group training exclusively with multi-joint exercises (cable chest presses and seated rows) and a group performing the same volume split over those multi-joint exercises in addition to single-joint exercises (biceps curls and triceps extensions). However, the participants were untrained elderly and neither group achieved significant body recomposition during the program, meaning they were probably just slacking too much and fine-tuning with exercise selection was irrelevant.
- Marchiori et al. (2021) found no difference in hamstring growth or isokinetic torque (strength) in elite rugby players doing either only stiff-legged deadlifts or Nordic hamstring curls. This study had a few notable limitations though. Training intensity was far higher in the Nordic hamstring curl group while completing the same repetition volume, the study was only 5 weeks long and hamstring muscle thickness was only measured in the long head and only in the middle of the femur.
- Earp et al. (2023) also found that leg extensions and squats are equally effective for quadriceps muscle growth.
- Gentil et al. (2015) compared pronated grip, wide lat pulldowns to supinated grip barbell curls. Both exercises resulted in 6% biceps growth and 10-12% strength gains (isokinetic peak elbow flexor torque). While the study didn't have major statistical power with only 10 subjects training twice per week for 10 weeks, these results suggest any exercise that achieves enough mechanical tension on the muscle fibers can achieve major muscle growth. Correspondingly, a well-controlled study by Pompermayer et al. (2021) found that supinated, shoulder-width pulldowns and biceps EZ-bar preacher curls stimulate a similar level of muscle damage in the biceps.

Overall, the weight of the evidence supports compound and isolation exercises are inherently equally effective for muscle growth, all else being equal. Muscles respond to tension and it doesn't inherently matter if there's also tension in other muscles at the same time. Even if there's no inherent difference between compound and isolation work in terms of muscle stimulation, with compound exercises you'll generally burn a few extra calories, you save time, you improve your cardiorespiratory endurance and health more, and your strength gains should have more carry-over to other movements. So in practice, compound exercises are often more efficient to have in a program and isolation exercises are generally reserved to 'fill in the gaps' and reach the desired training volume for each muscle group.

However, in practice it's not nearly always the case that all else is equal between a given isolation exercise and a given compound exercise. Different exercises can stimulate different levels of muscle growth because they differ in how much tension they stimulate. For example, in contrast to pulldowns, rows don't seem to be very effective for the biceps. Handa et al. (2005) found that lat pulldowns stimulate considerably greater biceps muscle activity (EMG) than barbell bent-over rows and seated cable rows, all performed with a double pronated grip at 70% of 1RM. Mannarino et al. (2021) found that supinated dumbbell curls stimulate approximately double the biceps growth as supinated dumbbell rows over an 8-week training program. Soares et al. (2015) correspondingly found that unilateral seated rows don't induce as much muscle damage or neuromuscular fatigue as dumbbell preacher curls and Leitao et al. (2024) found dumbbell curls stimulate more acute muscle swelling in the biceps than rows, although Marchetti et al. (2020) found similar neuromuscular fatigue and muscle swelling after rows and biceps curls when both were performed with full range of motion (ROM) and a supinated grip. Rows are likely suboptimal to target the biceps due to a combination of generally limited range of motion, lack of high tension at long muscle lengths and submaximal demands for elbow flexion.

In conclusion, the effectiveness of an exercise to stimulate muscle hypertrophy depends on how much tension it generates in the target musculature, not on whether it's a compound/multi-joint or isolation/single-joint exercise.

Bodyweight exercises

Just like the compound/isolation categorization is irrelevant, so is the bodyweight exercise categorization. It doesn't matter whether an exercise is a 'bodyweight exercise'. Kotarsky et al. (2018) and Calatayud et al. (2015) found push-ups and bench presses performed at the same intensity improve pec muscle size and even bench press strength equally well. Wei et al. (2023) found that bodyweight single leg squats and barbell back squats resulted in similar strength and size gains. They measured body composition change, muscle growth in the calves, quads (RF) and glutes and strength gains throughout the body (peak torque). The study had multiple design limitations in how the programs were constructed, but overall, the literature is clear that bodyweight exercises are neither inherently better or worse than weight training.

The only major problem with bodyweight exercises in practice is that it's hard to implement progressive overload with them. We'll discuss this problem later in more detail along with the microloadability principle.

Machines vs. free weights

Another irrelevant way to classify exercises is machine vs. free weight exercises. A 2021 meta-analysis found that strength, power and muscle size gains are the same with free weights and machines. Strength gains were significantly modality-specific: free weight training generally improved free weight strength more, whereas machine training improved machine-tested strength more.

When strength was measured on exercises done by neither group, there was no significant difference in strength gains. However, there is a trend in the literature for free weight exercises to have better strength transfer to other exercises. 9 out of 12 effect sizes and the average at least slightly favored free weights. Some research clearly favored free weights. For example, Rossi et al. (2018) found that squatting builds leg press strength significantly more effectively than leg pressing builds squat strength. The average effectiveness of free weights in the meta-analysis was drawn down considerably by 1 effect size by Fisher et al. (2013) that was over 10x different from the average and this study was arguably wrongly categorized. It measured machine back extension strength after RDLs vs machine back extensions. Of course, machine back extensions did much better, as this was what they trained for, not a neutral exercise. Without Fisher et al., 10 out of 12 effect sizes at least slightly favor free weights.

If we look at studies not included in the meta-analysis, most support the general conclusion that machines and free weights are equally effective for muscle growth and modality-specific strength development. However, some studies favor free weights for strength development and transfer.

- Blazevich et al. (2003) found hack squats are just as good as free-weight squats at increasing quad muscle size and strength and sprinting and jumping performance, although it was only a 5-week study.
- Aerenhouts & D'Hondt (2020) found similar muscle growth, strength development and improvements in functional movement screen scores in untrained men after a 10-week full-body strength training program using either exclusively free weights (barbell squat, dumbbell presses/pulls), exclusively machines (leg press, machine presses/pulls) or starting with machines and transitioning midway to free weights.

- [Earp et al. (2023)] found that leg extensions and squats are equally effective for quadriceps muscle growth in somewhat-trained men during an 8-week training program.
- [Spennewyn (2008)] found performing a training program in a free-movement machine compared to a fixed-movement machine resulted in significantly greater strength development and better improvements in balance.
- [Schott et al. (2019)] found that free-weight training resulted in greater strength development during the program than machine-based training during 2 out of 5 exercises, along with a non-significant trend for greater handgrip strength, in a functional elderly population.
- [Hernández-Belmonte et al. (2023)] found that an otherwise identical full-body program performed with either a barbell or machines with similar movement trajectories resulted in equal muscle growth and exercise-specific strength in trained men.

For muscle growth, it makes perfect sense that the modality of exercise is irrelevant. Our muscles grow in response to tension and it doesn't matter what causes the tension. For strength, neural adaptations like increased muscle activity and rate coding likely also aren't influenced by the modality of exercise. However, neural adaptations like intermuscular coordination and antagonist co-activation are likely the reason strength is still movement-specific. So theoretically speaking, machines and free weights may be equally effective for strength development. However, in practice when people talk about 'strength' in general, they tend to have free weight strength tasks in mind and as we discussed in the module on understanding muscle growth, there's some research that finds free-weight training is better at improving 'functional' outcomes like jumping, as well as the 2 aforementioned studies showing greater strength development with free weights compared to machines. As such, when people have 'general strength development' as a goal, they should probably favor free-weight training.

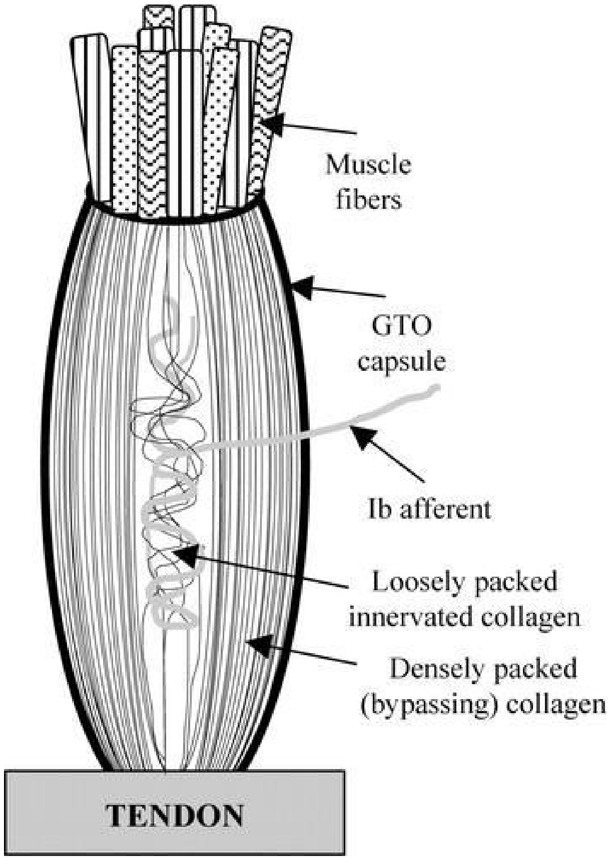
Ultimately though, what matters is an exercise's biomechanics, not with which equipment you perform it. As a general principle, no training modality is inherently superior to any other: kettlebells, dumbbells, bodyweight exercises, machines, ultimately all that matters are the biomechanics of the exercise. That's all your neuromuscular system registers. While many machines in commercial gyms offer virtually no advantage over free weights, some machines are excellent and provide options that are hard to rival with free-weights, such as a good leg extension. It all depends on the design. Examples of highly useful machines include reverse hyperextensions, glute pendulum kickbacks, convergent chest presses, pull-over machines, leg extensions, leg curls, (seated) calf raises and practically all cable pulleys. If abdominal hypertrophy is desired, ab training machines are also often the only way to use heavy loads. Crunches won't be heavy enough for advanced trainees.

Now that we've discussed the popular ways to classify exercises that don't inherently matter, let's discuss how to best select our exercises. The most intuitive approach for many people is to select the exercises for a muscle that they feel well in that muscle.

Feeling the muscle

Most psychologists agree that the majority of our decision making happens in the subconscious, emotional part of our brain (system 1). It's effortful to involve the more rational part of our brain on top of it (system 2). We intuitively make most decisions based on what feels best. For exercise selection, this tends to result in lifters selecting exercises based on how well they feel the target musculature during that exercise. But is feeling a muscle a good proxy for an exercise's effectiveness? Do you need to have a good 'mind-muscle connection' to train a muscle well?

Let's start with our ability to sense mechanical tension, the primary stimulus for muscle growth. This is not broscience. On the contrary, our ability to sense muscle tension been well-studied and it 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

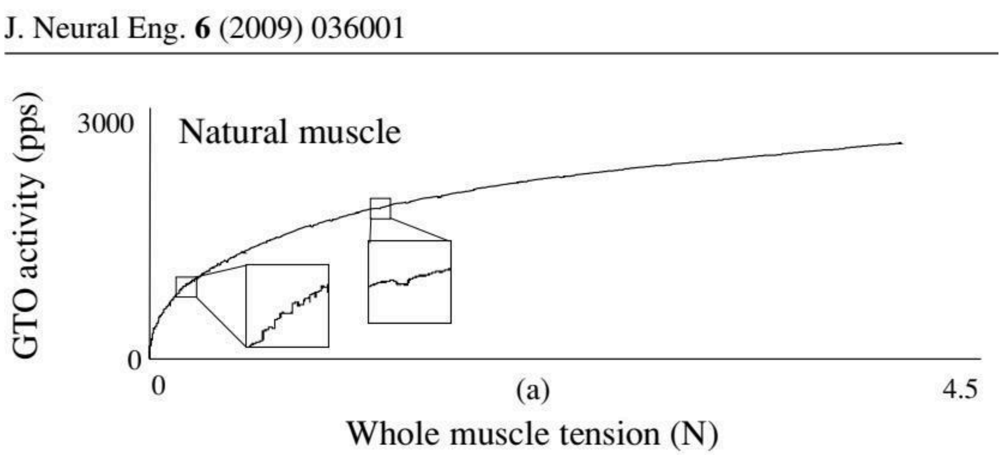
While GTOs can sense active mechanical tension in our muscles very accurately, the signals that they send to the brain do not linearly correspond with the total tension the muscle experienced for multiple reasons [2]. It's worth noting that most of our understanding of GTOs comes from mathematical modeling, *in vitro* research and animal research, but for basic physiology like this, these models are generally quite representative of living humans.

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 (discussed later), although muscle

stretching 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 higher and very high tension.



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: Arguably 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 sense from external sources (exafferent signals). 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.

Mechanistically, we can thus conclude that our bodies are biologically equipped to sense muscle tension, but the system is very imperfect for bodybuilding purposes. 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. One of the first questions new trainees ask is: "What 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 register the internal muscle tension or are you feeling something there because you expect to feel something there? We also like to think we get better at estimating how close to failure we're training, but most people don't. A 2021 meta-analysis found trained individuals are actually no more accurate on average than untrained individuals at estimating reps to failure. (We discuss this in more detail in the course section on training to failure.)

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 subjective 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.

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 (see exercise selection module).
- Using short rest intervals similarly increases the pump and burn you get from training, but it actually generally reduces the stimulus for muscle growth (see workout structure module).
- 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 levels are in fact significantly higher during high-intensity than low-intensity exercise (see module on optimal program design).

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.

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, yet glute activation drills do not increase actual glute activity, force production or strength development over time (see course module on warming up for more details).

In conclusion, there is no evidence that humans can accurately sense mechanical muscle tension and thereby select optimal exercises by feel. In fact, there are clearly many cases where our feelings of subjective muscle activity do not correspond with objective muscle activity and tension. Subjective sensations during an exercise should thus at best be a secondary consideration. Let's discuss the objective principles of exercise selection that do allow us to optimize our exercise selection.

Principle 1: The Limit Factor

The target musculature of an exercise should be a limiting factor in its execution.

This principle is a simple extension of the facts that muscle fibers grow in response to stimulation and that not all exercises stimulate all involved musculature equally. The Limit Factor Principle is particularly important in several situations.

1.1 Grip strength

If your grip always gives out first on deadlifts, then your posterior chain will remain understimulated and deadlifts end up being a poor choice for training your lower body. Thick bars and Fat Gripz can induce the same effect for other exercises. The thicker the barbell, the less weight most people can row or deadlift. Upright rows and curls also suffer from very thick bars and Fat Gripz. The worse someone's grip strength is and the smaller their hands are, the worse the effect is. While most people can press the same weight with thicker bars, a thick bar can reduce muscle activation during the bench press.

Fat Gripz: theoretically a great way to add low-effort grip work to any exercise but practically limited to some presses.

Intentional grip training will be discussed in the module on training gear.

1.2 Bi-articulate muscle contributions

Whether a muscle is a limiting factor during an exercise becomes more complex in the case of bi-articulate muscles, muscles that cross 2 joints and therefore can produce movement at different joints. When a bi-articulate muscle contracts, it cannot choose which joint it applies torque at. It will necessarily apply torque at both joints. If all the resulting joint movements are desirable, muscle activation is unhindered. If some are but others are not, however, the muscle may be limited in how much tension it can productively generate.

The hamstrings

As you've learned in the anatomy module – a module you should be intimately familiar with before proceeding with this module – the hamstrings are a bi-articulate muscle, because it crosses the knee and the hip joint. All 4 heads of the hamstrings can flex the knee and extend the hip, except the short head of the biceps femoris, which is only active at the knee. During a squatting movement, hip extension is desirable to erect your torso, but knee flexion would pull down your thighs. The hamstrings thus directly antagonize the quadriceps during the squat. As such, the hamstrings are not a limiting factor during the squat. The quads are the limiting factor. Indeed, EMG research confirms that hamstring activation during squatting movements is low and the hamstrings grow barely 20% as fast as the quads and the glutes after squatting [2, 3].

In conclusion, squats are a good exercise for the quads and glutes but a poor hamstring exercise.

The rectus femoris

The rectus femoris (RF) of the quads is in a similar position as the hamstrings during squats. The RF helps extend to the knee and straighten your leg, which is crucial to get up from a squat. However, the RF also flexes the hip, which would pull you back down during a squat. Since the RF cannot help straighten your legs without simultaneously pulling you back down into hip flexion, the rectus femoris barely activates during squats based on biomechanical analyses, electromyography (EMG) data and correlations between muscle size and squat strength [2, 3, 4]. Accordingly, the RF doesn't grow much from squatting according to most high-quality research [2, 3, 4, 5, 6], though some research found the RF grows just as well as the other heads of the quads from squatting [2, 3]. Theoretically, squats can be made more effective for the RF by staying as upright as possible to minimize hip extension demands, but the increase in EMG activity of the RF during high-bar vs. low-bar squats is negligible even during submaximal training. Other research finds the RF does not increase in activity during squatting with higher training intensities, unlike the other heads of the quads, so when you train close to failure, the RF are unlikely to be stimulated as much as the rest of the quads even during high-bar squats.

In contrast, leg extensions are very effective to grow the rectus femoris. To optimally engage the RF during leg extensions, lean back about 45°. Leaning back during leg extensions results in significantly more growth in the RF without reducing growth in the vastus lateralis of the quads. You often have to push the back seat all the way back to be able to recline enough. Performing your leg extensions sitting fully upright at 90° hip flexion is very suboptimal. The RF are too short to effectively produce tension in that position.

Other lower body compound movements aren't much better for the rectus femoris. Fonseca et al. (2014) compared the same volume of either just barbell back squats or a combination of squats, leg presses, deadlifts and lunges for the rectus femoris. The combination group trended to achieve more robust growth of the rectus femoris, but the growth rate was still below that of the vastus lateralis and vastus medialis.

Thus, for maximum quad growth, you likely need a leg extension type movement that isolates the quads. Alternatively, you could add a hip flexion exercise, such as hanging knee raises, to squat-type exercises, but hip flexion exercises are often impractical to load and cannot easily target the RF at long lengths.

The gastrocnemius

The 2-headed main muscle of the calves, the gastrocnemius, is another bi-articulate muscle with sometimes conflicting functions. Contracting the gastrocs produces an ankle joint moment that causes plantar flexion (pushing your feet down, like during a calf raise) as well as a knee joint moment that causes flexion (bending, like during a leg curl).

The gastrocnemius is particularly bad at doing both at the same time: it enters passive insufficiency when lengthening considerably at the knee and ankle at the same time and active insufficiency when it shortens considerably at both joints. In a state of insufficiency, the gastrocs can produce virtually no tension because its actin and myosin filaments are either too close together (active insufficiency) or too far apart (passive insufficiency) to produce effective cross-bridges. A seated calf raise with the knees bent at 90° must be carried out mostly by the soleus, as the gastrocs are in active insufficiency. Seated, bent-leg calf raises effectively grow the soleus but not the gastrocnemii, whereas standing and straight-leg calf raises grow both the soleus and the gastrocnemii [2]. During a leg curl, the gastrocs can contribute force effectively only when you curl up your toes (dorsiflexion). Plantar flexing the ankle during a leg curl often causes cramping in the gastrocs, as they're too shortened to produce much tension.

During a squat, plantar flexion force is needed, especially if the knee travels forward in the bottom. Contracting the gastrocs, however, will cause a knee flexion joint moment, which is the opposite of what you want: straightening your legs. As a result, the gastrocs are barely trained by squats [2, 3, 4, 5, 6]. Muscle activity in the gastrocs is only a fraction of what you achieve during a standing calf raise. Leg presses perform similarly poorly to squats in terms of activating the gastrocs.

In contrast to lower body presses, deadlifts result in significant gastrocnemius muscle activity, presumably because knee flexion joint moments do not interfere as much with a deadlift as with a squat. Conventional and sumo deadlifts from the floor result in higher average gastrocnemius muscle activity levels than stiff-legged deadlifts, though peak activity may be higher during SLDLs. McAllister et al. (2014) even found that Romanian deadlifts and Goodmornings resulted in similar medial gastrocnemius muscle activity as prone leg curls and glute-ham raises: RDLs even outperformed prone leg curls. However, only a single repetition was performed in this study with 85% of 1RM. Considering the gastrocs lengthen during the ascent of RDLs and Goodmornings, they can only act as stabilizers, so it's questionable if RDLs and goodmornings very effectively train the gastrocs.

A useful rule of thumb is not to count lower body presses as effective gastrocnemius training volume and to count only half of deadlift volume.

During leg curls, the gastrocnemius aids in knee flexion. However, it cannot do so when the ankle is plantarflexed, as it will be excessively shortened. As such, you should keep your ankles in maximal dorsiflexion during leg curls to maximize muscle activation, force production, training volume and thereby strength gains, assuming you want to train the gastrocs. It's worth noting that one study found that ankle dorsiflexion during leg curls increased repetition volume but not long-term strength gains, but strength was only measured as isometric torque, so the increase in actual leg curl volume is probably more practically relevant. Muscle growth was not measured in either long-term study, but greater active force production and training volume by the calves, plus potentially some stretch-mediated hypertrophy, should result in greater hypertrophy.

The triceps

The same bi-articulate conflict applies to the long head of the triceps during pulling and pushing movements. Activating the long head of the triceps will cause both an elbow extension moment and a shoulder extension moment. Importantly, the long head's much stronger at the elbow, where it's also the sole prime mover, than at the shoulder, where it's one of the weaker shoulder extensors. The shoulder extension moment of the long head of the triceps is relatively small and largely passive.

As a result, the triceps is generally not very active during pulling exercises like chin-ups and pull-downs. The long head is too weak at the shoulder to make its contraction worthwhile for shoulder extension during something like a pulldown: its elbow extension moment would only sabotage the biceps' efforts to try to bend the arm. As a result, pulldowns achieve minimal triceps activation, unless you use a very wide grip so that the long head of the triceps can aid in shoulder extension without limiting the biceps at the elbow. In practice, pulling exercises don't comprise effective training volume for the long head of the triceps unless you keep your arm straight, such as during a straight-arm pull-over. Then the long head can contribute fully without interfering with elbow flexion.

During pushing exercises, the triceps is commonly thought to be highly active. However, you may not maximally stimulate the long head of the triceps with pressing exercises, because of its conflicting role at the shoulder: contracting the long head produces a shoulder extension moment, which is the opposite of the desired shoulder flexion needed during a pressing movement. Whether activating the long head aids pushing strength depends on whether the press is mostly limited by elbow extension or shoulder flexion strength. If elbow extension strength is the limiting factor, activating the long head will be very beneficial. If shoulder flexion strength is the limiting factor, activating the long head will likely be net detrimental. Since theoretically both are possible, we need to look at empirical data to see how much pressing exercises stimulate the triceps.

If we look at electromyography (EMG) data to see how much the triceps activates during presses vs. triceps isolation exercises, there's a trend for isolation exercises to more consistently reach maximum activation.

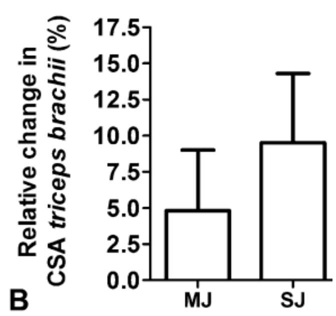
- Borges et al. (2018) found that lying triceps extensions achieved higher activity of the long head of the triceps than bench presses.
- Campos et al. (2014) found that straight-arm pull-overs achieve significantly higher activity in the long head of the triceps than bench presses.
- Soncin et al. (2014) found that lying triceps extensions activate the long head more than bench presses done with a wider but not with a closer grip.

However, multiple other studies found triceps activation in the long and lateral heads is comparable across a variety of triceps exercises, including compound presses as well as isolation work with the arm overhead and at the side [2, 3] and bench presses are just as effective at activating the long head of the triceps as lying triceps extensions and triceps pushdowns.

If we look at studies that measured muscle growth in the triceps and the pecs during a bench press training program, we see bench presses stimulate significantly more muscle growth in the pecs than in the triceps. We've compiled them in a research overview here. On average, the pecs grow about **twice** as fast as the triceps.

In contrast to where muscle growth occurs, neuromuscular fatigue seems to occur to a similar extent in the triceps and pecs during barbell presses. The triceps need almost as much recovery time as the pecs after 6 sets of barbell bench pressing to failure in trained men, suggesting similar recruitment and thus stimulus for muscle growth.

We only have one study that directly compared muscle growth in the long head of the triceps from bench presses vs. triceps isolation exercises, in this case barbell skull-crushers: Brandao et al. (2020). Total triceps muscle growth did not statistically significantly differ between the exercises, but as you can see in the graph below, the triceps grew approximately twice as fast from the skull-crushers (SJ) than the bench presses (MJ), supporting the overall trend in the literature that bench presses only stimulate 50% of maximal triceps growth. When zooming in on the individual heads of the triceps, the difference in growth was clearly attributable to the long head: the skull-crushers were significantly more effective than bench presses at growing the long head of the triceps.



The researchers also looked at groups doing both the bench press and the skull-crushers. Adding skull-crushers to the bench press brought the growth in the long head up to a similar level as that of just the skull-crushers. For the other heads, adding skull-crushers to bench presses also stimulated marginally more growth. Thus, it seems like triceps isolation work is essential to maximize triceps growth, but you don't need that much of it in your program if you're already doing a fair amount of barbell bench pressing.

In conclusion, for maximal triceps growth, specifically in the long head, you most likely need triceps isolation work in your program. Then for simplicity's sake, you can probably count barbell presses as if they fully stimulate the triceps. The long head receives a little compensatory volume from pulling exercises and a high volume of triceps work is very harsh on the elbow joint for many people, frequently resulting in medial elbow tendinopathy. If you want to be precise and aren't worried of elbow injuries though, you should count barbell presses as achieving only a 50% triceps stimulus compared to 100% for triceps isolation exercises. Exercises like lat prayers, a variant of straight-arm pulldowns, can effectively stimulate the long head of the triceps in relative isolation to compensate for its lack of activation during pushing exercises.

The biceps

The biceps is a tri-articulate muscle: it's active at the shoulder (chiefly as a weak flexor), the elbow (flexion) and the forearm (supination).

Due to conflicting roles as a shoulder flexor and elbow flexor, pulling exercises might not maximally stimulate the biceps: contractions produce a shoulder flexion moment, which is the opposite of the shoulder extension that occurs during a pulling movement. However, the biceps is very weak at the shoulder [2]: its potential for shoulder flexion moment is much weaker than its potential for elbow flexion moment. The biceps can also only contribute to shoulder flexion up until 60°. As soon as your elbow reaches shoulder height, the biceps stops being a relevant shoulder flexor. As a result, the short and long head of the biceps have very similar activity profiles during a variety of movements.

Activity during shoulder flexion is generally minor [2] though not zero. As a result, the biceps generally does not contribute much during pushing movements. The elbow flexion moment would sabotage the efforts of the triceps to extend the elbow with only a minor shoulder flexion moment to help with the movement. For example, bench presses achieve minimal biceps activation.

While the biceps is a very weak shoulder flexor, shoulder flexion does shorten the biceps, which generally makes it weaker. The biceps is strongest at relatively long muscle lengths (see functional anatomy module). Keeping your elbows at your sides or even behind your body is therefore generally ideal when targeting the biceps, such as with biceps curls.

The biceps is also active at the forearm as a supinator. Common bodybuilding wisdom is that you should therefore train the biceps in a position of supination. However, this doesn't logically follow. The biceps may not maximally contract during pronation, as it would cause a supination moment, but when the forearm is kept in a fixed position or when it's going from a pronated to a supinated grip, such as during a ring chin-up, the biceps can contract just fine. It may not have an optimal moment arm, but it can produce plenty of tension. Several lines of research support that forearm position doesn't majorly influence biceps tension.

- Gentil et al. (2015) compared pronated-grip, wide lat pulldowns to supinated-grip barbell curls and found that they resulted in equal biceps growth and strength gains (isokinetic peak elbow flexor torque). Paulo Gentil's credibility as a researcher has been questioned though after his unapologetic involvement with Matheus Barbalho, who has had multiple publications retracted for 'improbable data' (read: fraud).

- Correspondingly, Lusk et al. (2010) and Lehman et al. (2004) both found no significant difference in biceps muscle activity (EMG) between pronated and supinated pulldowns. Lusk et al. did the experiment with both wide and narrow grips, which did not influence the results. However, both studies used the same load for all pulldowns. To the extent that a pronated grip makes you weaker, this biases the results in favor of the pronated grip due to the higher relative load. Lusk et al. justified their decision to use the same weight for all pulldown variations by citing that a previous study with a similar design found no significant difference in 1RMs between the different variants. This may have been true for weaker individuals, but Lusk et al. studied strength trainees and for these we cannot assume equal strength levels for the different exercises.
- Dickie et al. (2016) found no significant differences in mean or peak biceps activity between wide, pronated pull-ups and shoulder-width chin-ups with a supinated, neutral or rope grip. Since most people are approximately equally strong with a supinated and a neutral grip, the intensity should be similar and these results strongly suggest a neutral/hammer grip and a supinated grip are equally effective to stimulate the biceps. Similarly, Ricci et al. (1988) found no significant difference in biceps activity between chin-ups (supinated) and pull-ups (pronated). Snarr et al. (2017) also found no significant difference in biceps activity between bodyweight pull-ups with a pronated grip, towel pull-ups and suspended pull-ups.
- Youdas et al. (2010) did find that chin-ups with bodyweight caused higher biceps activity than pull-ups. Chin-ups with a rotating grip were on par with regular, fixed-bar chin-ups. However, grip width and range of motion (ROM) weren't standardized, resulting in significantly greater elbow flexion ROM during

the 2 chin-up movements, which suggests the pull-ups were performed in a more back-dominant manner by pulling from the elbows.

- Marcolin et al. (2018) found no significant differences in biceps brachii or brachioradialis muscle activity between supinated barbell curls and EZ-bar curls with a semi-supinated grip. The subjects were strength-trained men and they performed each curl with the same training intensity. The researchers described the EZ-barbell grip as “almost semi-pronated”, so it’s actually unclear if the grip was semi-supinated, as is traditional, or semi-pronated, which would be an overhand/reverse grip. The barbell curls even tended to result in higher activities than alternating, standing dumbbell curls with active supination, although this comparison may have been confounded by greater ROM during the dumbbell curls and the alternating execution. Biceps activity can decrease in the bottom position of a dumbbell curl when the biceps relaxes in between reps, bring the average down.
- In 2019, Bagchi & Raizada again found no significant differences in muscle activity of the biceps or brachioradialis between EZ-bar and regular barbell curls. They tested the difference at 3 grip widths. This study wasn't great though. Only 1 rep was performed and it seems they used the same weight for all exercises.
- Coratella et al. (2023) also found arguably trivial differences in muscle activity between barbell and EZ-barbell curls performed at the same intensity either with or without simultaneous 30° shoulder flexion (letting the elbows come up a bit during the curl) by a group of bodybuilders. The straight BB resulted in 1.8% higher muscle activity, which was somehow statistically significant, compared to the EZ BB during the concentric phase but not the eccentric phase. With simultaneous shoulder flexion, the difference disappeared during the concentric phase but became significant during the eccentric phase at +3.8%.
- Another study by Coratella et al. (2023), using the same ten bodybuilding subjects as the last study, compared a supinated bar, pronated bar and neutral

rope grip during cable curls. The choice of cable curls as opposed to dumbbell or barbell curls is arguably unfortunate, especially considering they didn't standardize the distance to the cable tower or the ROM, both of which can make a substantial difference to how difficult the exercise is. Moreover, it's unclear if 8RMs were conducted for each exercise, as they talk about a single 8RM yet say it was done with 'the technique described above', which referred to the 3 different exercise techniques. They also trained submaximally, performing 6 reps and discarding the first and last reps. For what they're worth, the results were quite odd. The main result seemed to vindicate the supinated grip for the biceps. Biceps activity was highest in order of supinated > neutral > pronated. However, this was only true for the ascending phases: there were no significant differences for the descending phase. In contrast to the idea that recruitment follows leverage, brachioradialis activity was also greatest with a supinated grip yet equal between neutral and pronated grips. Again, there were no differences in brachioradialis activity during the descending phase, only during the ascending phase. Weirdest of all, front delt activity was significantly higher with the pronated and neutral grips than the supinated grip. The trend was pronated > neutral > supinated for both the ascending and descending parts of the lift, although during the descent only the pronated grip significantly differed from the other 2 grips. The difference in shoulder activity suggests the trainees moved their elbows forward with the neutral and pronated grips, which may explain their lower biceps recruitment. All in all, it's unclear exactly how the exercises were performed, the results don't make biomechanical sense and they conflict with the research on pulldowns and pull-ups.

In conclusion, analogous to the story of the long head of the triceps during presses, you can generally treat full ROM, overhead pulling exercises as if they stimulate the entire biceps fully. Just make sure you have at least 1 biceps isolation exercise with your arm at your side in your program. Pulling exercises like rows that don't achieve full range of motion for the biceps and operate in the shoulder flexion range under 90° may only count half. Pushing exercises don't count as effective biceps training volume. Forearm rotation probably doesn't affect biceps recruitment much, as long as no active pronation occurs during the exercise.

1.3 Instability during exercises

Unstable surface training has a mixed reputation. Some 'functional trainers' still regard it as an almost pure improvement over stable surface training. That's where we see basically any exercise imaginable being performed on wobble boards, Bosu balls, Swiss balls and foam rollers, including the infamous Bosu ball squats. In most hardcore strength training circles, unstable surface training is regarded as an outright dumb, potentially injurious and ineffective way to train.

The evidence falls somewhere in the middle. There are pros and cons of unstable surface training. The most obvious con is that you generally cannot lift as much weight on an unstable surface as you can on a stable surface, because your balance can be a limiting factor. Try squatting your 1RM on a Bosu ball and you'll see – that's sarcasm: do not actually try this unless you want to be evidence of natural selection. The lower external force production can be accompanied with lower muscle activation, indicating the muscles are producing less mechanical tension and will therefore likely not grow as much from this type of training.

The reduction in muscle activation and external force production on unstable surfaces isn't nearly as large as you may expect though. For example, Goodman et al. (2008) found that bench press 1RM strength, muscle activity and range of motion (ROM) were all similar on a Swiss ball compared to the standard flat bench. However, these were all novice lifters and they most likely weren't implementing a tight set-up with arching in the thoracic spine or leg drive. You'd be hard pressed to find any competitive powerlifters who will agree you can bench as much on a Swiss ball as on a flat bench. Indeed, Anderson & Behm (2004) confirmed that while muscle activation levels were similar when performing chest presses on a bench or a fitness ball, force output was reduced by 60% on the unstable ball.

Yongming et al. (2013) also found similar muscle activation levels for traditional back squats and squats on a Core Board at 30% and 60% of 1RM. Hammer et al. (2018) found that heavy squats on a vibration platform build just as much strength as squats on the floor and Saeterbakken et al. (2019) found that wobble board squats build just as much strength and muscle as squats on the floor.

Split squats are also commonly thought to be ineffective to stimulate the lower body because of their seemingly high demand for balance.

Split squats, also called pitcher squats or Bulgarian split squats when the rear leg is elevated. You can perform split squats with dumbbells or a barbell or in the Smith machine.

Research finds split squats are a great exercise (and a brutal one). Split squats and back squats result in similar muscle activation in the vastus lateralis, biceps femoris, gluteus maximus and even the erector spinae. Testosterone production post-workout is also similar. Some research finds that split squats result in higher hamstring and gluteus medius activation but possibly lower quadriceps or at least rectus femoris activation [2, 3]. This probably depends on the exact execution of the 2 exercises.

It thus takes a large amount of instability to make an exercise less effective to stimulate its target musculature, such as standing on an unstable surface. The overall trend of the effect of unstable surface training on muscle activation and especially external force production and performance in general is clearly negative [2, 3, 4], with several studies finding detrimental effects of unstable surfaces and only studies using very light weights finding positive effects on muscle activation (because an unstable surface is needed in that case to make the weight somewhat challenging). Importantly, the negative effect of unstable surface training on muscle stimulation is proportional to the degree by which the unstable surface and your balance limit your prime movers from producing maximal force. For example, the more unstable the surface you're lying on during the bench press, the less you can bench and the less your triceps and chest will be stimulated and the more you stimulate your abs. Similarly, the more unstable the surface you're squatting on, the less weight you can lift (in this study muscle activation of the leg musculature was largely unaffected, but that was likely because this study employed isometric (static) rather than regular, dynamic squats).

As a result, unstable surface training is generally inferior or at best equal to stable surface training for improving athletic performance that is performed on the ground, such as sprinting and jumping [2].

In terms of practical application, unstable surface training, practiced within reason (i.e. safety) can be an effective tool for core training and certain rehabilitative exercises due to its potential for relatively high muscle activation with low training loads. However, as a main strength training modality, it offers only limitations compared to traditional strength training.

Terminal instability during exercises seems to be less disadvantageous. Li et al. (2024) found that adding instability to pulldowns by holding on to elastic bands improved strength carry-over to pull-ups. There was also reduced antagonist coactivation without any effect on prime mover muscle activity. Muscle growth, as crudely measured by arm circumference, did not differ between groups but was insignificant in both groups to begin with. Changes in maximal voluntary force production also did not differ between groups, suggesting the greater pull-up strength gains with instability were entirely mediated by improved coordination.

In short, The Limit Factor criterion removes almost all unstable surface exercises from the strength trainee's core exercise menu. Standing on an unstable surface tends to make the stabilizing muscles or neuromuscular coordination the limiting factor in the exercise instead of the target muscular tissue. It takes a considerable amount of instability to make an exercise less effective for muscular development though. Split squats, dumbbells and rotating grips do not result in excess instability.

1.4 Dumbbells vs. barbells

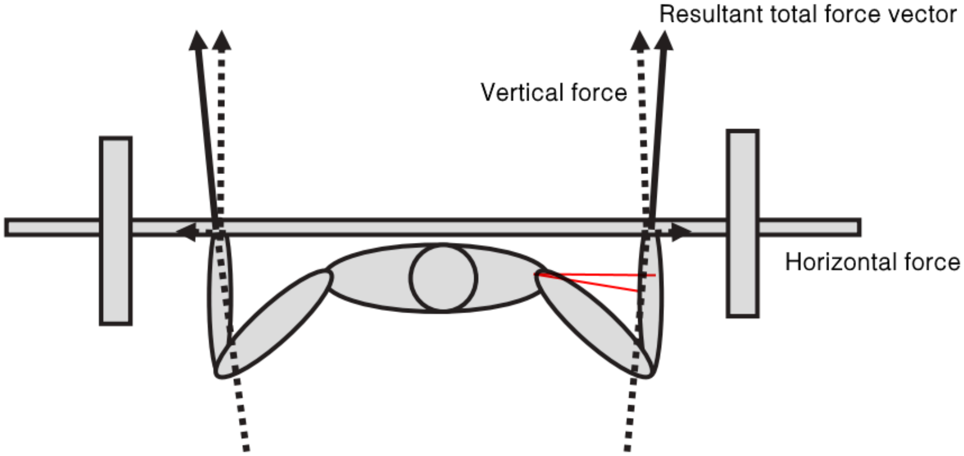
A classic competition: the dumbbell vs. the barbell. Which is better? Dumbbells provide more freedom of movement, whereas barbells provide more stability. For many exercises, these differences are not major. Both are weights and the muscle doesn't care in which shape the weight comes. Same for kettlebells vs. dumbbells. However, there are a few considerations you should be aware of.

First, the greater freedom of movement of dumbbells might be slightly advantageous for the pecs and delts during pushing movements. Faris et al. (2017) found dumbbell bench presses result in higher pec activity than the barbell bench press. However, other research finds no difference in the effectiveness of barbell vs. dumbbells for pec activation. Dumbbell bench presses also allow you to get a greater range of motion in the bottom, which is generally an advantage (more on ROM later). Saeterbakken et al. (2013) found that dumbbell overhead presses stimulate slightly greater activity in all the delts than barbell overhead presses (but lower triceps activity: more on this later). Performing the exercises standing also increased muscle activity compared to sitting. Standing allows for greater freedom of movement, especially in the hips, and it allows you to focus on the side delts better than sitting, which often turns into a super high incline press rather than a full overhead press.

Second, for rows and presses, a barbell normally allows for greater contribution of the arms because horizontal movement is constrained: your hands are fixed in position on the bar. Unless you'd be so strong you could break the bar, your arms can put as much horizontal force on the bar as they can produce, so they can contract forcefully. With a dumbbell, lateral force production moves the dumbbell and this would make you perform a very different movement.

Specifically, the triceps extends the arm, which means it moves the hand outwards, away from the body, during a press movement. With a barbell your hand position is fixed in relation to the barbell: your hands cannot move outwards or inwards during the exercise. If your elbow is flexed enough so that your forearm isn't perpendicular to the barbell yet (i.e. your hands are inside your elbows), the outward force production from the triceps to generate elbow extension helps you lift the weight up. So in general, when you use a grip wide enough to have your hands outside your elbows, triceps activity will decrease compared to a more narrow grip [2, 3].

The difference in triceps activation isn't as consistent or large as you'd expect purely from the elbow flexion demand, however, because even when your hands are outside of your elbows, the lateral force production from the triceps can still help you lift the weight up. Intuitively, since you can't spread the bar apart, the outward force helps you generate upward movement. The physics involved are quite complicated. Technically, the barbell's reaction force from your triceps' outward force production reduces the total resultant's force's moment arm for horizontal shoulder flexion, as illustrated in the 2 graphics below.



Horizontal shoulder flexion moment arm of the barbell
without (top: horizontal distance between shoulder joint and hand)
vs. with (bottom: line from shoulder perpendicular to barbell's total force vector)
horizontal forces taken into account.

Adapted from source.

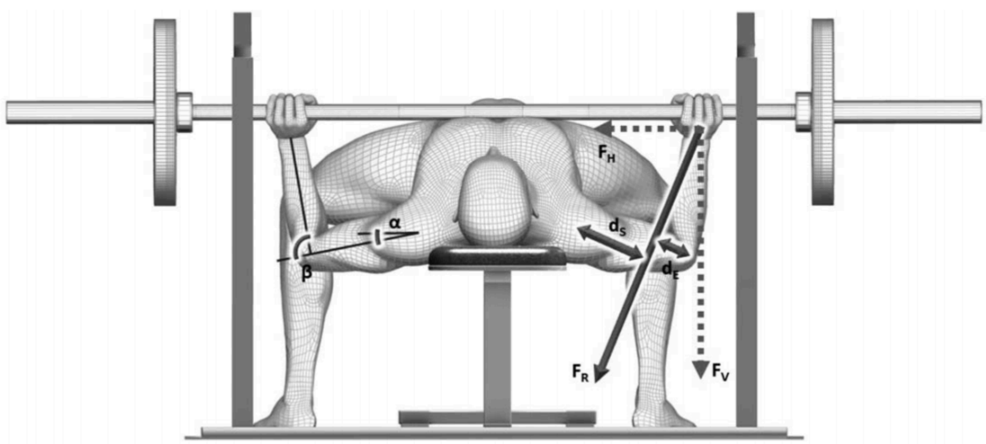


Figure 1. Animated bench press figure of one representative subject at the bottom position of the bench press. The left side illustrates the three-dimensional joint and segment angles: a = shoulder horizontal adduction angle; β = elbow flexion angle. The right side illustrates the force vectors and moment arms: F_V = vertical force component; F_H = horizontal force component; F_R = resultant force vector; d_S = shoulder moment arm; d_E = elbow moment arm. Produced by MuscleAnimations.

Because your triceps try to press the bar apart, creating outward horizontal (lateral) forces, you're effectively pressing the bar up and out rather than straight up. The bar in turn thus effectively press down and inward on you (the resultant force vector) and this explains why the triceps is still involved even though the hands are often directly above the elbows. Source

The result of this is that during a barbell bench press, your grip width does not majorly affect muscle recruitment patterns. Only when your grip is so wide that your hands are outside your elbows, does triceps activity seem to decrease and specifically in the lateral head, not the long head (as the long head isn't well-trained by a barbell bench press in the first place). Anterior delt activity does not meaningfully change. Pec activity is also not majorly affected by grip width, except that narrow grips reduce lower pec activity due to the lower reliance on horizontal shoulder flexion. The upper pecs can still contribute via shoulder flexion.

In contrast to the barbell press, during a dumbbell press your hands can move outwards. Excess outward hand movement effectively turns the movement into a fly movement, rendering the triceps unable to contribute as an active mover of the weight, as the dumbbell will exert an elbow extension moment. As such, the contribution of the triceps during dumbbell presses is significantly reduced compared to barbell presses [2, 3, 4]. The resulting muscle damage and muscle growth in the triceps are also low with dumbbell presses.

In short, dumbbell presses are mediocre triceps exercises. In contrast, barbell presses, even overhead ones, achieve high triceps activation in the lateral head [2], comparable to pec activation. If you change a barbell press to a dumbbell press in a program, you should thus increase the volume of triceps isolation work to compensate. A practical rule of thumb is to count dumbbell presses as only 50% as effective for the triceps as barbell exercises, so if you switch 4 sets of barbell bench presses to 4 sets of dumbbell bench presses, add 2 sets of triceps isolation work.

The biceps faces a similar situation during pulling movements. Dumbbell rows only stimulate the biceps roughly half as well as biceps isolation movements or fixed-bar pulls like pulldowns, as you saw in the section on compound vs. isolation exercises.

However, grip width during straight-bar exercises like pulldowns does not seem to affect biceps muscle activity considerably [2]. Unless perhaps if your grip is extremely wide, horizontal force production seems to compensate for the lower inherent elbow flexion demands.

Principle 2: Eccentric contractions

Exercises must include eccentric muscle actions to maximize the growth stimulus per set.

When you lift a dumbbell, your muscles contract while shortening during the upward phase of the movement. This type of shortening contraction is called a concentric muscle action. When you lower the dumbbell, the muscle is contracting while lengthening: this type of lengthening muscle contraction is called an eccentric muscle action. The eccentric and the concentric phases result in somewhat different morphological [2] and neural adaptations. Concentric and eccentric actions also differently activate anabolic cell signaling patterns [2] and satellite cell activity.

The eccentric muscle contractions are most important for muscle growth, as muscles can produce more mechanical tension during this phase, both actively and passively. During eccentric contractions, the actin-myosin cross-bridges are cleaved mechanically rather than biochemically, enabling higher active force production. Moreover, during eccentric contractions the myofilament titin also produces passive elastic force by virtue of its stiffness. This passive tension contributes to the total biomechanical tension on the muscle fibers and therefore contributes to muscle growth.

Concentric-eccentric contractions also allow for higher muscle activity and force production during the concentric phase due to the stretch-shortening cycle. (See course module on repetition tempo for more details.) You're strongest on the concentric when it's immediately preceded by the eccentric phase of a movement. That's how you naturally jump, kick in doors and throw heavy objects at people doing curls in the squat rack.

Oh, and it's the most effective way to do most exercises, too. Exercises with both a muscle shortening (concentric) and lengthening (eccentric) phase outperform purely concentric exercise for muscle growth; for strength development, they outperform both concentric- and eccentric-only exercise [1, 2, 3, 4, 5, 6, 7]. Purely eccentric exercises have been found to rival concentric-eccentric exercise for muscle growth and strength development during any contraction type (concentric, eccentric and combined), at least in untrained individuals, confirming that the eccentric muscle contractions provide the greatest muscular stimulus. While the eccentric phases are most important for muscle growth, to maximize concentric strength and long-term muscle growth, you may need both concentric and eccentric muscle actions, given their different adaptations. In practice it's impossible to perform multi-repetition eccentric-only exercises anyway with conventional training equipment.

Rather than omit the concentric phase altogether, it's probably even better to overload the eccentric during dynamic contractions. Accommodating resistance training with eccentric overloading, outperforms regular constant resistance training in many studies for strength development and sometimes muscle growth [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. Muscles are generally over 20% stronger when lengthening than when shortening. So increasing the resistance during the lengthening phase allows you to produce more force, perform more work and achieve greater levels of muscle activity. Emphasized eccentric training can also enhance the stretch-shortening cycle. The same result can be achieved by increasing your strength biomechanically during the concentric movement phase. Importantly, many studies equate total work, which largely defeats the purpose of eccentric overloading: allowing you to perform more eccentric work. Because of the higher amount of work you perform in practice with eccentric overloading, accommodating resistance training correspondingly increases neuromuscular fatigue. While eccentric overloading is great in theory, it's not so easy to implement in practice. If you happen to have access to isokinetic machines or other machines that allow for eccentric overloading, that's great. If not, you're limited to being creative with your biomechanics, such as with calf jumps or Zottman curls. Eccentric overloading will be discussed in greater detail in the topic on advanced training techniques.

Isometric contractions

There is very limited research, both in terms of quantity and quality, on dynamic vs. isometric contractions. Isometric muscle contractions are a form of static exercise: they're contractions during which the muscle does not change length, such as holding a half-squat position. The research leans in favor of dynamic muscle actions with either significantly greater muscle growth, non-significantly greater muscle growth or equal gains [2]. Most studies unfortunately did not have the participants train with maximal effort in all groups. The effectiveness of isometric muscle actions greatly depends on at which muscle length they are performed. At long lengths, isometric contractions stimulate significantly more muscle growth than at short lengths, as is explained later in this module's section on ROM.

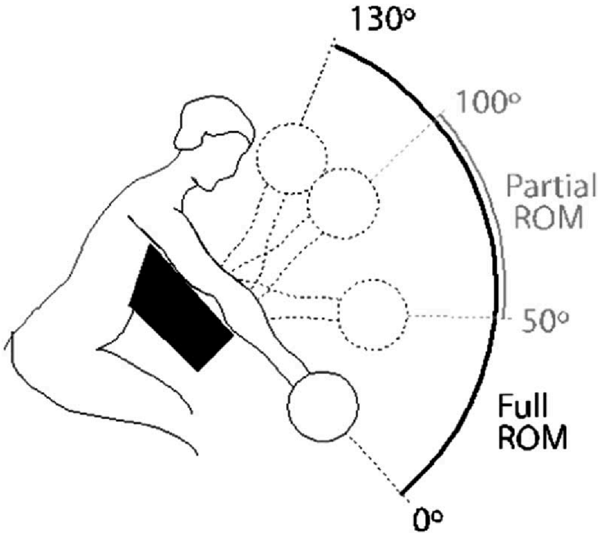
Most exercises inherently produce dynamic muscle contractions with both concentric and eccentric muscle actions, but we can rule out the following exercises as ideal muscle builders: the Olympic lifts (e.g. cleans, snatches and jerks), sled pushing or pulling, bicycling and, last but not least, traditional deadlifts from the floor without a controlled lowering (eccentric) phase. You can compensate for their ineffectiveness to produce high mechanical tension by performing additional sets, as you learned in the module on understanding muscle growth, but it's questionable if long-term muscle growth can be maximized without eccentric muscle actions.

In conclusion, exercises involving concentric-eccentric muscle actions are generally the most efficient method of imposing maximum mechanical tension per set on our muscles, thereby making them grow and get stronger.

Principle 3: Long lengths

Exercises should expose their target musculature to high mechanical tension at long lengths.

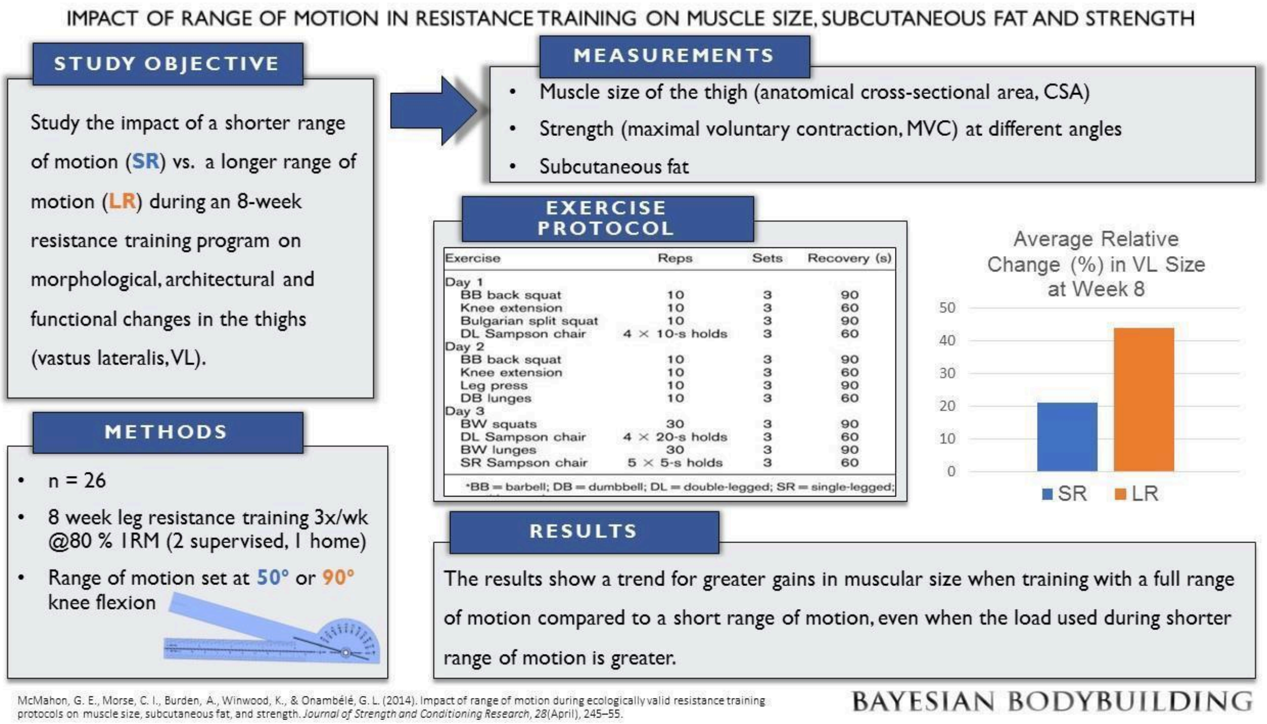
Most strength trainees are taught that the bar should touch the chest when we bench press and shallow quarter squats are only done by frat kids in between sets of curls. Full range of motion (ROM) training is a good general guideline for many exercises, but what does that mean exactly? Many people intuitively think ROM is equal to the distance a weight or body part travels. It's not. ROM is equal to the number of degrees a joint flexes, the range of *angular* motion. **ROM is measured in degrees, not distance**. Look at the illustration of elbow flexion ROM below.



Multiple studies and meta-analyses support that full ROM training is generally optimal for muscle growth and strength development [2, 3].

- Research comparing full to partial squats, including unpublished work by exercise scientist Truls Raastad in Norway, shows that full squats lead to more muscle growth of the quadriceps than partials ('half squats') and more isometric [maximum voluntary isometric strength (MVIC) gains](), which is significantly correlated with muscle growth.

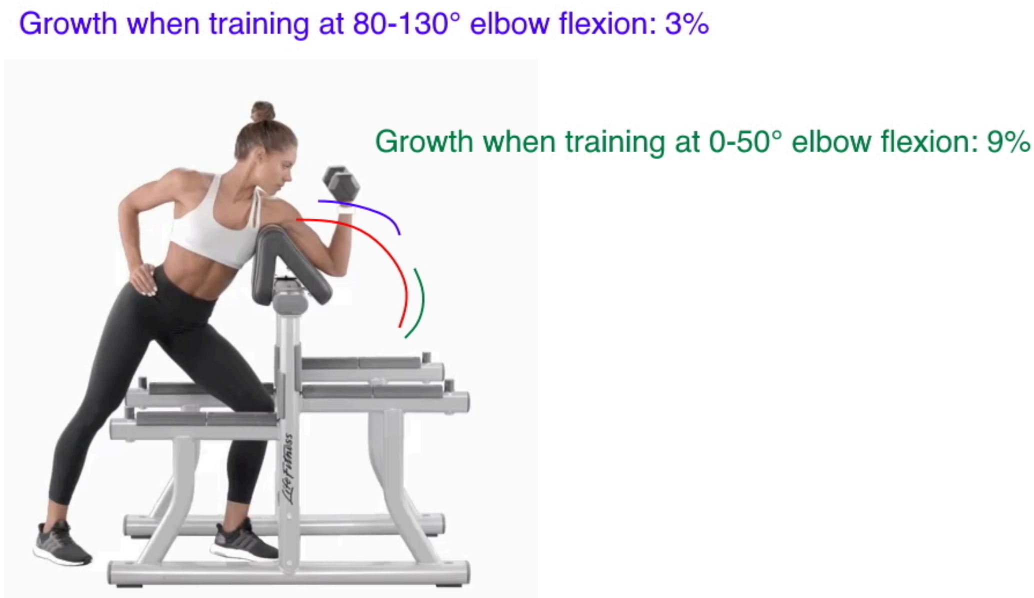
- [Kubo et al. (2019)]() found that full squats lead to more growth in the glutes and adductors than half squats, though the difference for the quads was minor and did not reach statistical significance.
- [McMahon et al. (2014)]() found that a full leg training program including squats resulted in more thigh muscle growth when performed with full reps than with partial reps.



- In [a study by Pinto et al. (2012)]() comparing Scott curls with a full compared to a partial ROM, there was a strong trend ($p = 0.07$) for greater biceps growth in the full ROM group.
- [Larsen et al. (2024)](), however, did not find greater quad muscle growth with full ROM leg pressing than from partial ROM leg pressing (to a 100° knee angle) in trained lifters.

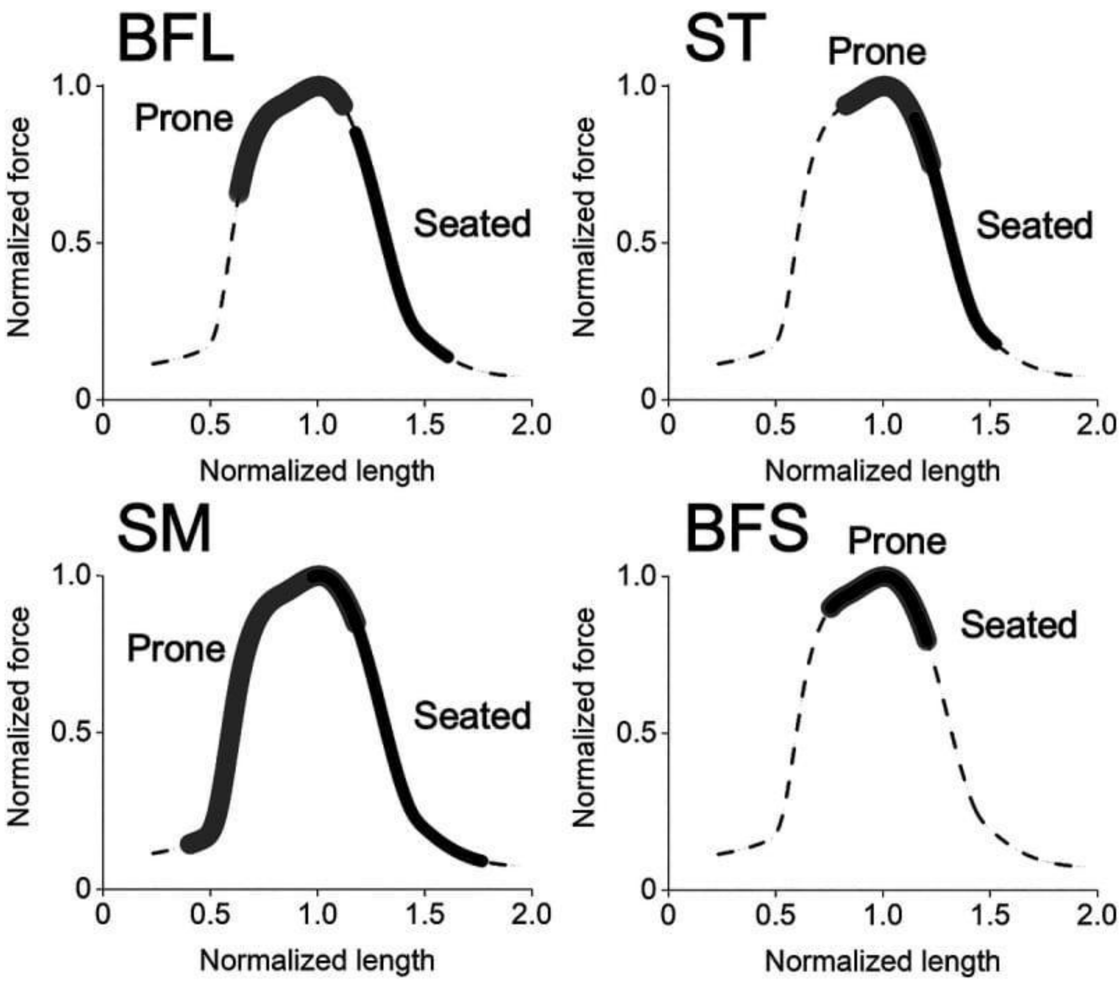
In sum, greater ROMs generally lead to greater gains in research. However, we theoretically shouldn't care about joint range of motion per se for muscle growth. We care about the muscle's length change. A muscle's maximal shortening distance – the distance it can shorten when going from a full stretch to full contraction – is called its functional excursion. A muscle's length influences which muscle fibers produce the most tension due to the length-tension relationship. Every muscle fiber has certain lengths at which it can more effectively produce force than at other lengths.

Full ROM training primarily augments muscle growth by training muscles at long lengths. Putting muscles under high tension in a stretched position can stimulate what is often called stretch-mediated hypertrophy, although some argue that term should be reserved purely for the hypertrophy resulting from extreme stretching protocols. A 2018 systematic review found that isometric contractions stimulate more muscle growth at long than at short muscle lengths. For example, Sato et al. (2021), found that training the biceps with preacher curls at long muscle lengths (0-50° of elbow flexion) majorly increased strength development and muscle growth compared to training the biceps at short muscle lengths (80-130° elbow flexion): see the image below. These findings were replicated by Pedrosa et al. (2021) and Pedrosa et al. (2023), adding that the greater growth at long lengths was primarily in the distal portion of the biceps, near the elbow.



Preacher curls.

Moreover, a [study by Maeo et al. (2021)]() compared seated and lying leg curls. A group of subjects performed the same training program with each leg for 12 weeks, except that one leg did seated leg curls, while the other leg did lying leg curls. While both exercises achieve full knee flexion ROM, the seated leg curls caused considerably more muscle growth in the hamstrings. This growth occurred specifically in the bi-articulate heads of the hamstrings. The simpler short head of the biceps femoris, which only performs knee flexion, grew similarly in response to both leg curls. Why did the hamstring heads that span across the hip grew more from seated leg curls? Because sitting stretches those heads at the hip. As a result, you train those heads of the hamstrings at longer muscle lengths with seated than with lying leg curls. This stimulates stretch-mediated hypertrophy.



For the more mathematically inclined: the length-tension relation of the hamstrings and which part of this is trained by each head of the hamstrings. Source: Maeo et al. (2021)

The same research group led by Maeo et al. (2024) replicated the superiority of seated leg curls over other leg curls, this time Nordic ham curls, a bodyweight leg curl. After 12 weeks, the seated leg curls stimulated substantially more muscle growth in the hamstrings, specifically in the heads that were stretched at the hip, as measured by MRI scans. Interestingly, not all heads of the hamstrings grew more from the seated leg curls. The short head of the hamstrings, which doesn't cross the hip, grew more from the Nordic hams. Nordic hams place maximum tension on the hamstrings in the bottom position when the short head is most stretched, unlike seated leg curls, which are typically hardest in the bottom position when the knees are flexed and the hamstrings are more shortened. So the greater growth from Nordic hams in the short head could be due to the greater tension at long lengths.

Maeo et al. (2022) also showed that overhead triceps extensions, which stretch the long head of the triceps, result in 40% more triceps growth than triceps pushdowns. Interestingly, all heads grew more, not just the long head. The other heads may have grown more from the greater tension at longer lengths with the overhead triceps extensions due to the longer external moment arm in that position. Pushdowns have very little tension on the triceps in the top position when the triceps is stretched.
A similar earlier study by Stasinaki et al. (2018) also found greater growth in the triceps after training at long vs. short muscle lengths, although in this study the difference did not reach statistical significance. Statistical power was lower due to having fewer participants (9), a shorter duration (6 weeks) and a less controlled design with partial ROM training. While we shouldn't read too much into non-significant between-group differences, it's interesting that the triceps grew 49% more in the distal portion but barely in the proximal portion when trained at longer lengths, causing total area growth to be similar. The highest-quality measurements around the middle of upper arm found 25-28% greater gains in muscle thickness after long-length training. There was no increase in muscle length. Stretch-mediated hypertrophy may thus be regional.

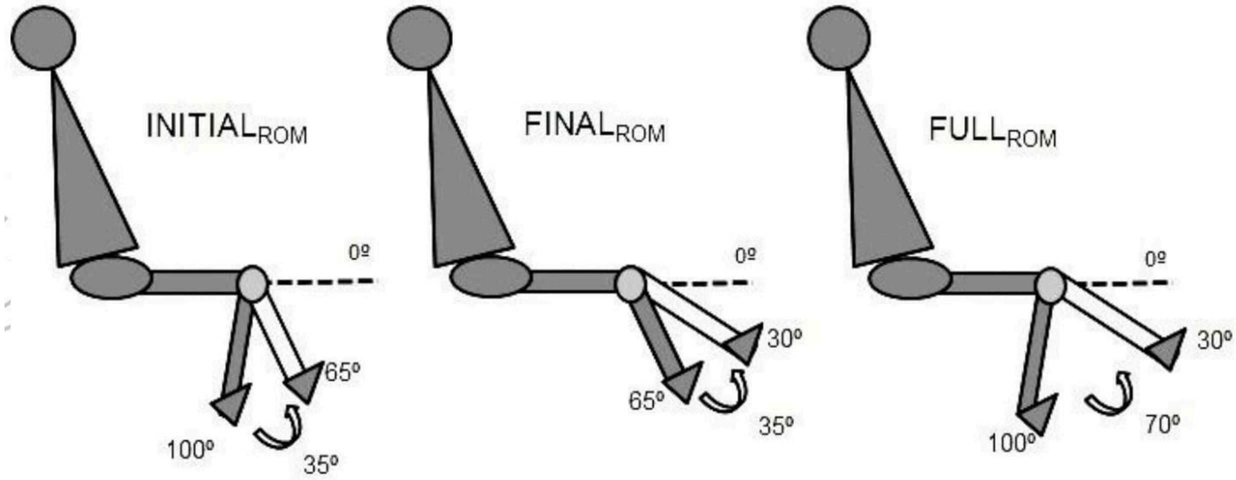
One mechanism for stretch-mediated hypertrophy may be passive mechanical tension. When muscles are stretched under load, they experience not just active muscle tension but also passive tension. Purely passively-stretch-mediated hypertrophy and corresponding strength increases of similar magnitude to strength training, even at short lengths, have been documented in strength-trained individuals, at least in the calves and pecs. Gains in muscle cross-sectional area (CSA) and muscle strength at short length strongly suggest muscle hypertrophy via the addition of sarcomeres in parallel, similar to traditional strength training. Sarcomerogenesis in parallel from passive mechanical tension via stretching has also been directly observed in animals, amounting to massive increases in fiber cross-sectional area. Animal research also shows passive mechanical tension stimulates muscle anabolic signaling just like active tension. In *in vitro* muscle cells, animals and bio-artificial muscles, the combination of muscle activation and stretching has been shown to strongly increase protein balance, anabolic gene expression, anabolic hormone signaling – particularly insulin-like growth factor-1 and mechano growth factor – and muscle growth [2, 3, 4, 5, 6, 7]. The titin muscle filament in particular experiences high passive tension during eccentric muscle contractions to a full stretch, as it's effectively spring-loaded. Titin is not just a force producing myofilament but also a mechanosensor: titin kinase can initiate anabolic signaling. Titin may play a key role in stimulating stretch-mediated hypertrophy via passive tension, because the passive tension from the muscle stretching during most exercises alone is unlikely to cause much muscle growth. High-tension (eccentric) muscle contractions at relatively long muscle lengths seem to be required.

Stretch-mediated hypertrophy can also occur via the addition of muscle sarcomeres in series or sarcomere lengthening: the muscle fascicles become longer [2]. However, this type of muscle growth is finite, as muscles can only get so long. Muscles are stuck between their origin and insertion, so there's a distinct limit to how much muscle growth can occur via the lengthening of muscle fascicles. For well-trained individuals, fascicle lengthening is likely not a very long-term growth driver, although muscle fascicle lengthening has still been observed in advanced strength athletes.

Some people have hypothesized that **all** stretch-mediated hypertrophy is due to fascicle lengthening. However, this does not fit with the aforementioned increases in muscle strength, the direct observation of sarcomerogenesis in parallel in animals and the increases in muscle thickness and cross-sectional area in human studies. Increases in muscle fascicle length can theoretically increase a muscle's anatomical cross-sectional area, but multiple human studies have found that even very large increases in muscle fascicle length do not translate into increased physiological cross-sectional area or muscle thickness [2, 3] (which strongly correlates with anatomical cross-sectional area). Moreover, a 2025 case study on an elite natural bodybuilder found that a torturous 12-week static stretching intervention on top of his habitual calf training resulted in significant gains in muscle size, strength and obviously range of motion without a meaningful increase in muscle fascicle length.

High tension at long muscle lengths is likely more important than training with a full ROM per se. A study by Pedrosa et al. (2021) had a group of untrained women perform leg extensions in 4 different ways.

1. The end range ROM group performed only the top 30° of movement near full knee extension.
2. The stretch ROM group performed only 35° of movement in the bottom ('lengthened partials').
3. The 'full' ROM group performed both of the above ROMs, reaching 100° of movement. Technically, this isn't full ROM, as most people have 120 or more degrees of knee extension ROM, but many leg extension machines don't allow for more ROM than 100°.
4. The varied ROM group alternated between the initial stretch ROM and the final end range ROM workouts.

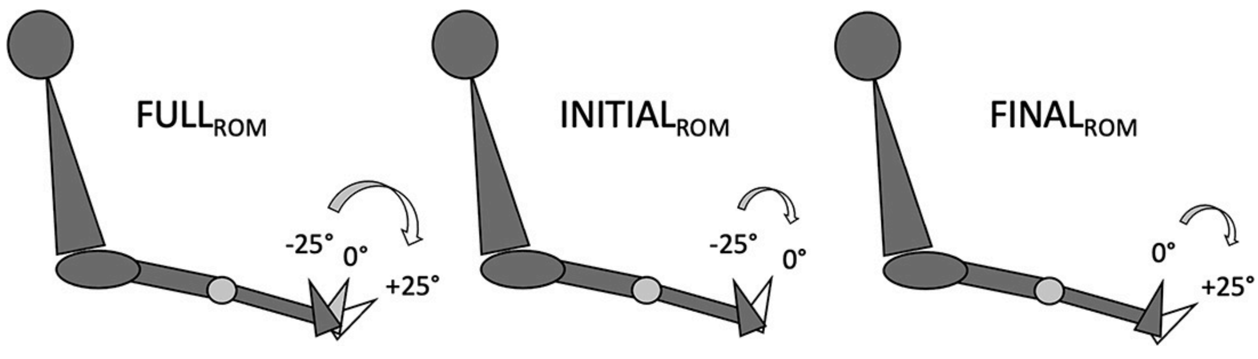


The 3 ranges of motion used by Pedrosa et al. (2021).

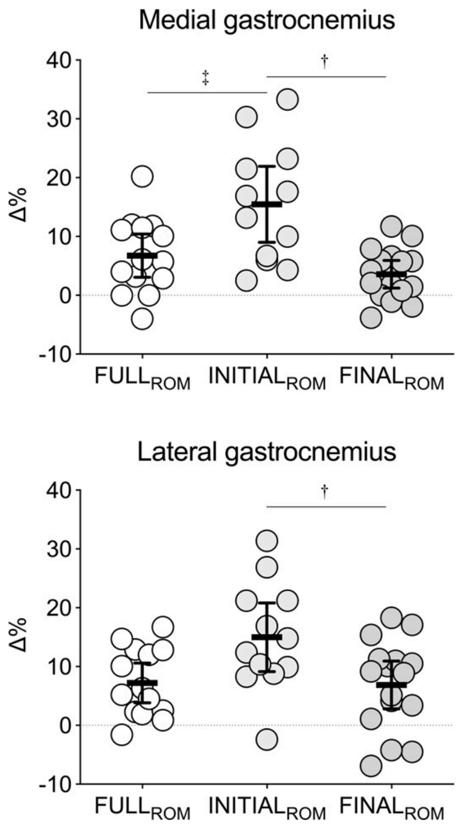
In contrast to the many studies cited above, the lengthened partials group gained more muscle than the full ROM group, as you can see below.

Muscle growth per group in Pedroso et al. (2021). The researchers didn't report total quad growth, so we estimated the percentage gain per measured site from their graphs. Since this is no longer an intelligible measurement unit and we had to estimate the numbers, we didn't include the y-axis with the exact numbers.

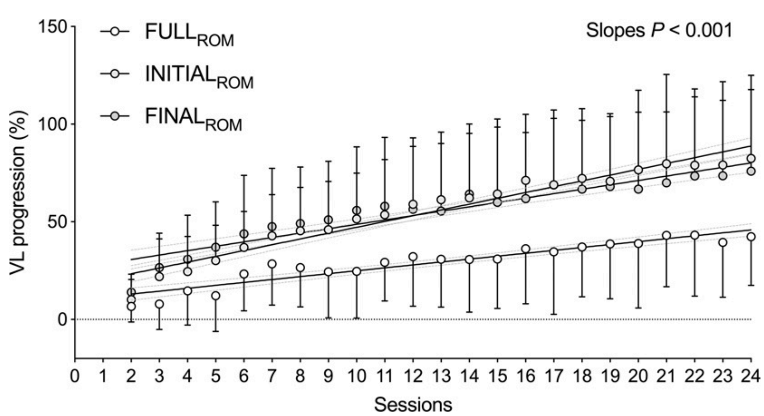
In 2023, Kassiano et al. replicated the finding that high tension at long muscle lengths is likely more important than training with a full ROM. The researchers had 42 untrained women train their calves with calf raises in a leg press in one of 3 ways: with full ROM, with only the initial ROM from a full stretch (25° dorsiflexion) to a neutral ankle position or with only the final ROM from a neutral ankle to ankle lock-out (or close to it: 25° plantarflexion).



All 3 groups trained their calves 3x per week for 3 sets to failure at 15-20RM. After the 8-week training program, calf gastrocnemius muscle growth was greatest for the initial (stretched) ROM group, followed by the full ROM group, followed by the final ROM group. Not all comparisons were statistically significant, but the trend was pretty clear, as you can see below.



The initial ROM group also gained strength faster than the full ROM group based on their volume load progression. Interestingly though, the final ROM group also gained strength faster than the full ROM group.



Should we only train the stretched position?

Both Kassiano et al.’s and Pedrosa et al.’s studies support that high mechanical tension at long muscle lengths is a potent stimulus for muscle growth. So potent that long-length partials beat full ROM training for muscle growth. However, subsequent research has not supported the superiority of lengthened partials over full ROM training.

A 2024 study by Wolf et al. supports that lengthened partials are not better for our gains than training with a full ROM in a practical training context. A group of strength-trained lifters trained one of their arms with a full range of motion (ROM) and the other with a partial ROM focused on the stretched part of the movement (lengthened partials). The programs for each arm were otherwise identical and performed to true rep failure.

After 8 weeks, there were no significant differences between the arms for gains in muscle thickness or 10RM lat pulldown strength. Interestingly, the triceps grew a bit more from full ROM, yet the biceps grew marginally more from the partials, exactly as you'd expect based on their length-tension profiles. However, neither difference was statistically meaningful. Importantly, muscle growth was measured only in the middle of the muscle belly. The lengthened position has been found to stimulate more distal growth in some research, which this study may not have picked up on.

A study by Gschneidner et al. (2024) also didn’t support the superiority of lengthened partials over full ROM training. The researchers had a group of 297 trained lifters perform a training program with either full range of motion (ROM) or lengthened partials (performing only the bottom half of the movement) for their arm and thigh exercises. The main exercises were leg extensions, leg curls, French presses and incline curls. After 12 weeks, muscle growth and strength development were statistically equivalent.

Thigh gains were virtually identical and the effect size differences for the arms and estimated 1RMs were trivial. Basically, they got equal gains. A major study limitation was that arm and thigh muscle growth was estimated with circumference and skinfold measurements performed at 15 different gyms and thus by at least 15 different people. This is particularly problematic given that very little muscle growth was observed in either group to begin with, likely because they only trained 2x per week with only 1 set per exercise. Another consideration is that the arm exercises were already inherently biased towards longer muscle lengths. For the legs, it depends on what machines they used.

There are 5 major reasons why it's not always ideal to only focus on training at long muscle lengths.

First, both Kassiano et al.'s and Pedrosa et al.'s studies involved untrained women. Untrained individuals may still experience significant hypertrophy via muscle lengthening, especially in their calves (see module on advanced training techniques, weighted stretching). However, this type of muscle growth is finite: muscles can only get so long. Thus, well-trained individuals may not benefit as much from emphasizing the stretch.

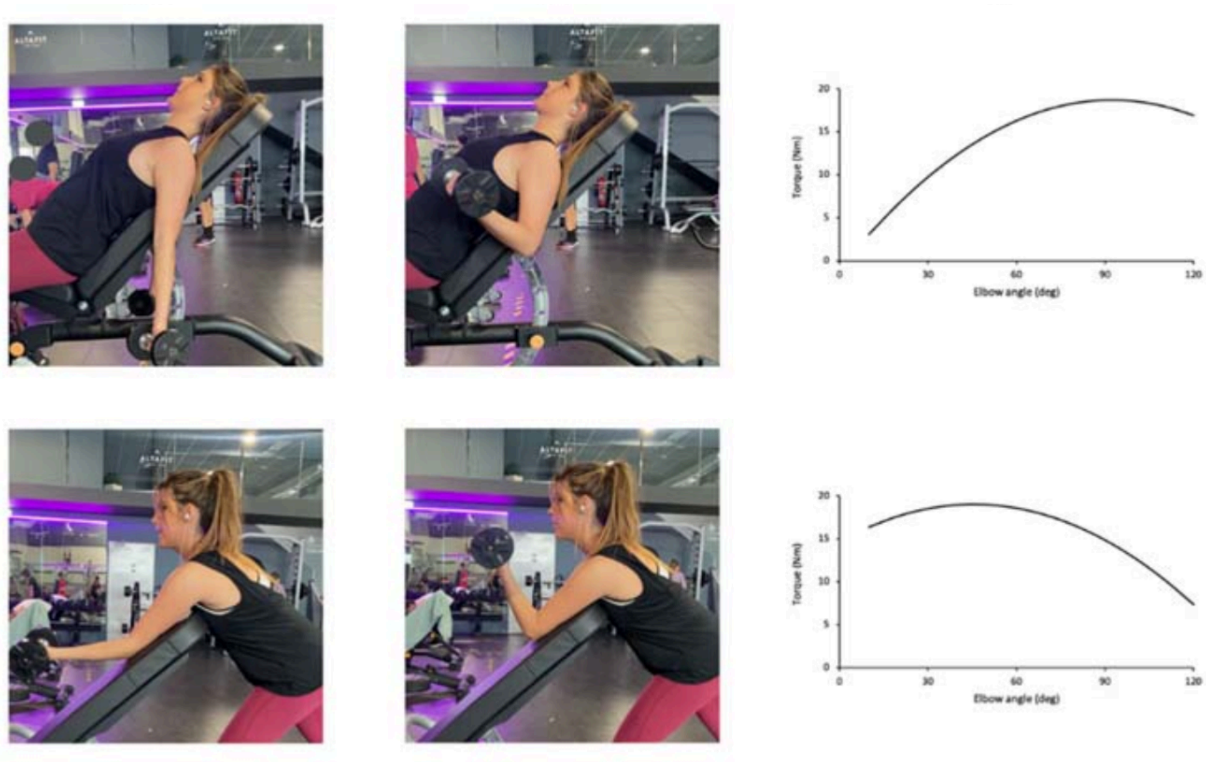
Second, leg extensions and calf raises typically have a major sticking point at the very top of the movement. You can then not lift nearly as much weight over a full ROM as when doing only the bottom ROM. Indeed, in both studies the stretch-only group trained with higher weights than the full ROM group. Other exercises, such as squats or bench presses, do not have this problem: if you can get the weight halfway up, you can likely lock it out. Stretch-mediated hypertrophy seems to result from the total accumulated tension – intensity and duration – on the lengthened muscle fibers. Thus, if you can't use more weight in the stretched position with partial ROM training, there's likely no point to omitting the top part of the movement. You should only be able to stimulate greater tension at long lengths if you can actually use more weight. (More on this in the exercise selection principle of constant tension.)

Third, maximum muscle growth doesn't seem to require *maximum* muscle lengths or *maximum* tension at those lengths. A study by [Nunes et al. (2020)] found no significant difference in muscle growth between barbell preacher curls and cable preacher curls. A barbell greatly increases the resistance in the stretched position, whereas a cable provides a much more even resistance curve with peak resistance roughly in the middle of the movement. These results suggest it's not necessary to always maximally emphasize the stretched position.

Cable and barbell preacher curl execution in Nunes et al. (2020).

Multiple studies have also compared preacher curls to incline or Bayesian curls. Incline and Bayesian curls train the biceps at longer lengths than preacher curls due to the slight shoulder flexion during preacher curls. However, preacher curls can put more tension on the elbow flexors near full elbow extension, depending on the exact set-up used. So which is more important: high tension at (relatively) long lengths or long lengths? The exercises seem to be similarly effective for the elbow flexors, but preacher curls seem to be slightly more effective for the brachialis, whereas incline and Bayesian curls seem to be slightly more effective for the biceps.

- Zabaleta-Korta et al. (2023) compared 2 types of supinated dumbbell curls: preacher curls vs. 45° incline curls up to 90-110° elbow flexion (so not completely full ROM to the top; see demonstrations below). The biceps is a (weak) shoulder flexor, so it reaches its longest lengths in the incline curls with the elbow behind the body. However, there's no tension on the biceps in the bottom position, as the external moment arm is zero. In contrast, preacher curls don't lengthen the biceps as much, but they put it under maximal tension, including maximal active tension, in its most lengthened position. So which is more important: maximal length or tension at high lengths? Strength-trained women performed either exercise for 4 sets at 12RM to volitional failure 3x per week for 9 weeks. There were no significant between-group differences, strictly speaking, in elbow flexor muscle growth (brachialis + biceps ultrasound muscle thickness). However, the preacher curls resulted in a higher percentage of muscle growth at all 3 measurement sites with a trend towards significance for the between-group comparison ($p = 0.10$). Near the elbow, the preacher curls stimulated significant growth in the distal elbow flexors (near the elbow), whereas the incline curls did not. This growth may have come from the brachialis. In conclusion, tension seems to be at least as important as muscle length per se.

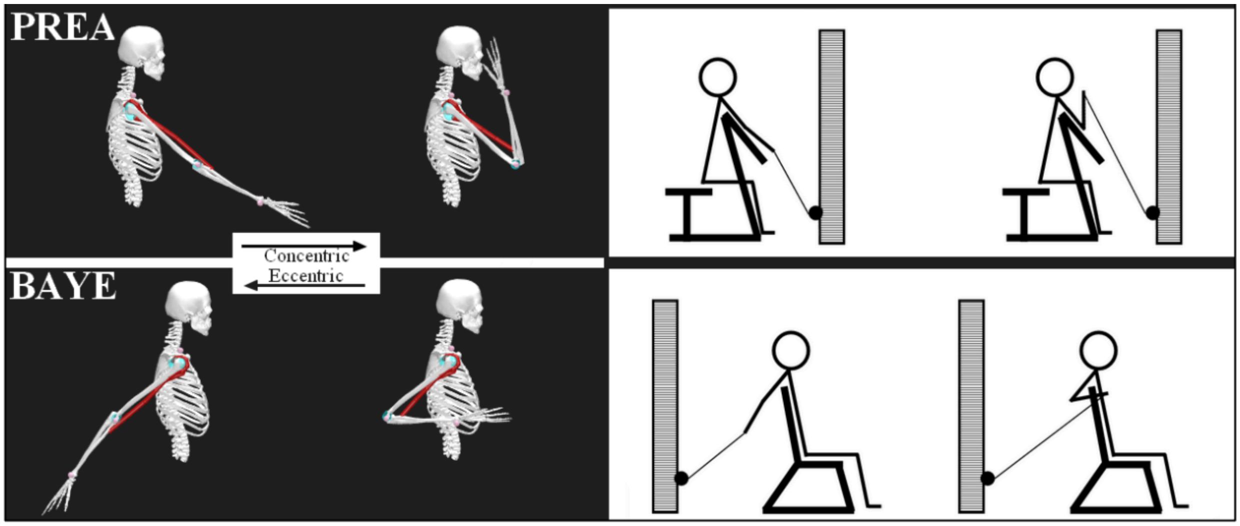


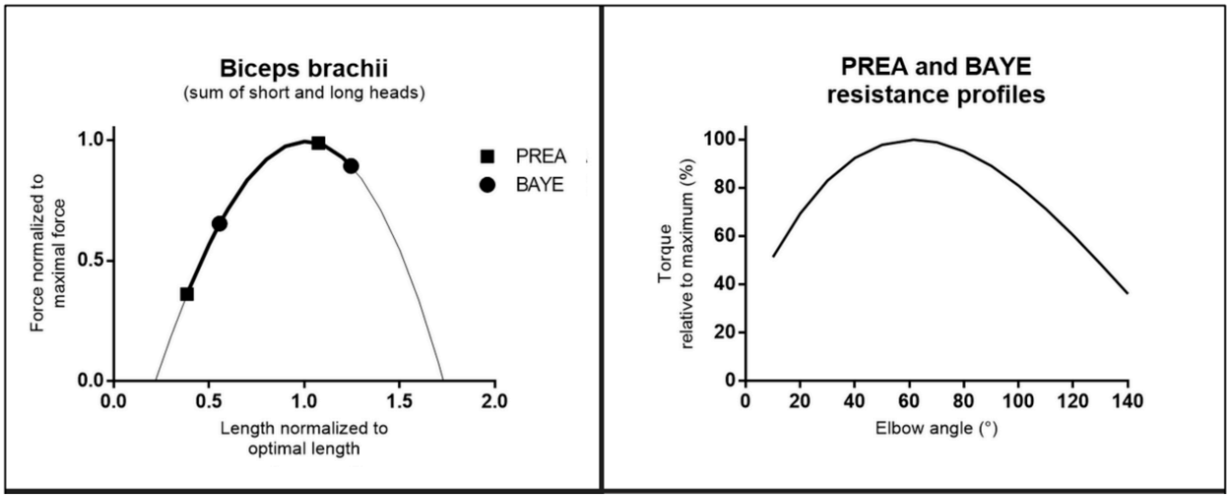
Incline dumbbell curls (top) vs. dumbbell preacher curls (bottom) and their resistance curves. [Source]

- A similar study by [Vendruscolo et al. (2024)] had strength-trained men train each arm with either preacher curls or incline curls and found no significant difference in elbow flexor growth. However, the study was severely limited by a mere 3-week duration and using blood flow restriction for some reason, even though statistical power was boosted somewhat by the within-subject design, training 4x per week and measuring muscle growth via magnetic resonance imaging (MRI) at 3 sites.
- [Kassiano et al. (2025)] again compared dumbbell preacher and incline curls, this time in untrained young women. After 8 weeks, incline curls this time did result in significantly more growth specifically in the upper biceps, whereas preacher curls resulted in significantly more growth in the lower elbow flexors. The upper biceps may have benefitted from being stretched at the shoulder during incline curls, whereas the lower elbow flexors – the brachialis and maybe even the

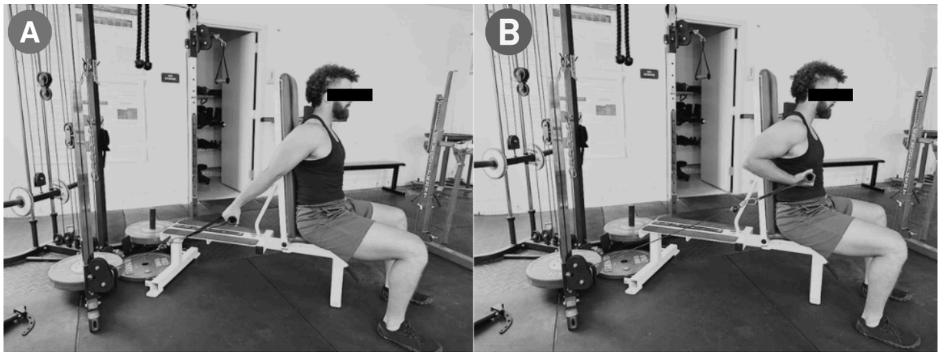
brachioradialis – likely benefitted from the high tension near full elbow extension during the preacher curls without any reduced stretch from the shoulder flexion. Ultrasound cannot distinguish well between the different elbow flexors. Therefore, it's plausible that incline curls are best for the (upper) biceps, whereas preacher curls are best for the brachialis and maybe brachioradialis.

- Attarieh et al. (2025) had a group of young men perform seated Bayesian curls with one arm and cable preacher curls with the other arm. Average reps, loads and load progressions were similar across arms. After 10 weeks, there were no significant differences between groups in elbow flexor muscle growth. However, in absolute terms the Bayesian curls resulted in more biceps growth at all sites. Post-hoc comparisons showed a small effect size (0.38) in favor of Bayesian curls for the biceps. With only 15 participants, the study had a less than 80% probability of finding this effect to be statistically significant. In contrast, the distal brachialis grew a bit more from the preacher curls.





It may also simply not be necessary to perform *all* training at long lengths to reap its benefits. A randomized cross-over study on biceps curls by [Hinson et al. (2025)]() found that only doing long-length training was not reliably superior to spending half your volume at short lengths and half at long lengths. A group of trained lifters trained their arms with 12 sets of incline cable curls per week for 8 weeks and another 8 weeks with 6 sets of incline curls and 6 sets of 'Scott curls' with the elbows very high up to shorten the biceps (illustrated below), all to failure. The rest of their upper body programs was identical. The overall conclusion from the researchers was that the differences in gains were not meaningful due to not reliably exceeding measurement error. However, the results slightly leaned in favor of long-length maxing, especially considering they didn't benefit from any exercise variety. While muscle thickness changes were virtually identical after the 2 programs, muscle area (CSA) increased 89% more after the long-length program with an 81% probability of being superior. Moreover, arm circumference increased reliably more after the long-length program, especially near the elbow, in line with prior research, though circumference is a crude measure of size. Isometric biceps strength, which tends to correlate well with size because it's a measure of raw strength, also increased marginally more with long-length training. Muscle soreness and workout effort ratings didn't differ meaningfully between the programs.



Some research doesn’t find any compelling support for the superiority of lengthened-biased training. In a study by Larsen et al. (2024), a group of 24 trained lifters performed dumbbell lateral raises with one arm and cable lateral raises with the other arm with all other program variables equated between conditions. After 8 weeks, muscle growth in the lateral deltoids was nearly identical in the upper muscle region and statistically indistinguishable in the lower (distal) region. However, it's worth noting that the percentage increase was 4.6% with cables vs 3.9% with DBs in the distal site. While statistically within the realm of chance, it fits with the research that most extra growth from emphasizing long muscle lengths occurs in the distal region. Moreover, range of motion (ROM) was equated in this study to fairly isolate the effect of the resistance curve. In practice, you can get more ROM with cables in the bottom position, which might help to stretch the side delts beyond anatomical position.

Fourth, by only training muscles at long lengths, we may neglect active muscle tension. A study by Plotkin et al. (2023), co-authored by Menno, found that parallel-depth barbell back squats and hip thrusts were equally effective booty builders for the upper, middle and lower gluteus maximus, as well as total glute size. Similar results were obtained in a study by Barolomei et al. (2024) comparing squats & step-ups to hip thrusts & reverse hyperextensions in strength-trained men and women. Squats should stimulate more stretch-mediated hypertrophy by virtue of training the glutes at longer lengths, but hip thrusts likely outperformed squats in terms of active muscle tension. Hip thrusts outperformed squats in terms of muscle activity recorded by electromyography (EMG) as well as subjective muscle sensation. Hip thrusts are most difficult at the very top when the glutes are shortest. In this position, the glutes can produce more muscle tension than at long lengths due to their length-tension relationship.

In support of the importance of both active and passive tension, Nakao et al. (2023) found no stretch-mediated hypertrophy in a study design equating the sum of active and passive muscle torque. Isometric 'seated' leg curls at longer lengths (30° knee flexion) did not stimulate more muscle growth or strength development at any muscle site or position than leg curls at shorter lengths (90° knee flexion). Importantly, the exercises were not performed to failure and the longer-length group produced lower active forces. The hamstrings are theoretically a great candidate for stretch-mediated hypertrophy due to how much we can stretch them, but for maximum muscle growth, we want not just high passive but also very high active tension.

The optimal muscle length for muscle growth may vary per muscle fiber, because not all muscle fibers run along the entire length of the muscle fascicle. Different muscle fibers are activated to different degrees at different muscle lengths, in part because different fibers have different length-tension relations. Therefore, muscles can experience regional hypertrophy (more on this later). Specifically, a 2024 meta-analysis by Varovic et al. found that training muscles at longer lengths tends to stimulate the most extra growth in the distal part of the muscle, which is generally the part closer to the moving joint, with essentially no increase in growth in the proximal part, which is generally the part further away from the moving joint. For example, training the quadriceps at longer lengths with deep squats and lengthened partial leg extensions seems to result in extra growth closer to the knee but not near the hip. The data were not clear though and while all effect sizes of muscle growth favored longer over shorter lengths, the effect sizes were very small, even at distal muscle sites.

The fifth reason not to do just lengthened partials is that training over a full ROM is generally an efficient way to achieve a high area under the curve for mechanical tension. For example, during the bench press, performing the top part of the movement should not considerably reduce how much you can lift. If you can get the bar halfway up, you should be able to lock it out. As such, the top part of the ROM may not be terribly effective to stimulate growth, but it's 'free volume'.

A good application of lengthened partials is on the last set(s) of exercises that don't achieve high muscle tension in the stretched position for the target musculature, such as leg extensions and calf raises (depending on the machine used). The first set with full ROM can then be used to benchmark performance and implement progressive overload (discussed in the periodization module). With partial reps, it's hard to know if you got stronger or you just used a bit less ROM. Lack of standardized performance makes it hard to implement progressive overload.

➢ Research overview [optional]

Studies on ROM that we didn't discuss because they had major limitations

Strength

For strength development as well, full ROM training is a good default training strategy. In multiple studies, full ROM training led to greater strength development than partials for leg extensions, Scott curls, squats and bench presses [2, 3, 4, 5, 6, 7, 8]. In one study, full ROM bench pressing did not build more strength than partial reps, but in this study 'partial' reps just meant avoiding the last 2-5 inches to lock-out. However, 3 subsequent studies showed that full ROM bench presses did in fact lead to greater strength development than avoiding lock-out and keeping 'tension on the muscles' or other combinations of partial ROM training [3].

While full ROM training is best to get stronger throughout a full ROM, strength gains are joint angle specific. You become stronger the most in the range of motion you exercise. Partial reps build strength specifically in the part of the movement you train with limited transfer to the rest of the movement [2, 3, 4, 5, 6]. In fact, over the course of one partial rep leg training study, quadriceps muscle activation decreased in the part of the ROM that wasn't exercised. The joint angle specificity of strength gains generally speaks in favor of full ROM training for maximum transfer to other movements. If you for some reason want to specifically improve a partial ROM, you may want to perform partial ROM exercise for that.

However, whether partials are better than full reps at improving the exercised portion of a lift varies. Some research finds full squats build not only more full squat strength but also more partial squat strength than partial squats. Full ROM bench pressing also seems to build the most bench press strength with any ROM and other research supports that full ROM training is best for strength development throughout the entire ROM, though in other research there's no difference in partial squat strength development or leg extensions strength at any part of the movement and in one study partial squats were better at building the partial squat than full squats.

In contrast to the specificity principle, full squats are better at developing power and jumping performance than partial squats [2]. This is a strong finding in favor of full squats. Partial squats have visibly greater movement specificity to jumping and result in higher power output than full squats. Still, full squats are better to increase power than partial squats.

More advanced lifters and more complex exercises probably benefit more from partial reps due to the principle of training specificity. Beginners and simple exercises do not require ROM-specific training to induce maximum muscle growth and build strength across the entire movement.

Full ROM training is often also easier on your joints. Partial squats tend to result in more pain and stiffness than full squats, presumably because you're subjecting your connective tissues to higher loads and you're overloading a limited movement pattern.

Combining full and partial ROM training

Even if partial ROM training is generally inferior to full ROM training, some powerlifters advocate for the use of both ROMs together to get optimal results. Theoretically, it's possible that incorporating partials in your training may improve maximum strength development via neural mechanisms, such as improved motor learning from a variation of motor patterns [2] or greater explosiveness. Partial squats allow for far greater power production than full squats, for example, and improving explosiveness could theoretically help you push through the sticking point of a lift. However, it's questionable if partial ROM training helps power *development*. Partial squats generally do not improve jumping performance, a measure of explosiveness, compared to full squats, as you learned in the Understanding Muscle Growth module. In a study on athletes, variable ROM training for the bench press improved measures of explosiveness, but it did not increase strength gains compared to regular full ROM training, so it's also unclear if greater power benefits strength development. Theory aside, does combining full and partial ROM training result in even greater gains than exclusively training over a full ROM?

Multiple studies have investigated this and none found any synergistic benefit for strength development from combining different ROMs. While some research founds trends in favor of the incorporation of partials, the only study reporting a significant between-group difference favored the full ROM group rather than the combined ROM group.

- Massey et al. (2004) compared groups bench pressing with an equal number of sets of either full reps or a combination of full and partial rep sets. Although the difference in strength gains were not statistically significant, the full rep group gained 25 pounds on their bench press compared to just 16.5 pounds for the full + partial group.
- The same research group replicated this study in 2005 and found the almost

exact same strength increases in both groups. This time, the strength difference was statistically significant: the full ROM group gained more strength than the full + partial ROM group.

- Bazyler et al. (2014) compared 6 sets of full ROM squats to 3 sets of full squats and 3 sets of partial squats in well-trained subjects. There were no significant differences in strength development. In this study there was actually a trend for greater strength and explosiveness gains in the combination group for some of the measures, yet the full ROM group seemed to gain the most muscle based on their body composition data. Body fat percent in the full squat group dropped by a whopping 10.3%, while body weight did not change in either group and body fat percentage did not change significantly (-5.3%) in the full + partial group. The only way body weight can remain stable while fat percentage decreases is by gaining fat-free mass, so the full squat group must have gained more muscle than the full + partial group. Thus, this study could be interpreted as weak evidence that incorporating partials may improve strength development at the expense of muscle growth.
- Whaley et al. (2020) found no significant difference in gains in squat strength, power or jump height between a group always doing full squats and a group starting with shallow squats and progressively increasing the ROM.
- Pedrosa et al. (2021) found that a combination of bottom ROM leg extensions and full ROM leg extensions did not improve strength development compared to doing all sets through only the bottom ROM. (Remember that this was the unique study in which partial reps in the stretched position outperformed full ROM training.)
- Gillingham & DeBeliso (2022) found no significant difference in 1RM deadlift strength development between a group doing 2 sets of heavy deadlifts from the floor and a group doing 1 set of heavy deadlifts from the floor plus 3 extra heavy singles from above the knees (rack pulls). In fact, neither group of competitive

male wrestlers gained a significant amount of deadlift strength from the floor during the 6-week study.

Conclusion

Most research finds it is best to train with a full ROM for muscle growth, strength development, explosiveness and joint health. The benefits of full ROM training seem to be primarily attributable to stretch-mediated hypertrophy that occurs when muscles are trained at long lengths. From a bodybuilding point of view, exercises with a good resistance curve probably offer all the benefits of partial reps and then some, although partials at long muscle may be useful alongside full ROM training for exercises that otherwise don't stimulate the target muscles well at long lengths. For muscle growth, full ROM training is a good default. Cutting down the ROM on an exercise demands a good reason. And for the record, "*a shorter ROM lets me go heavier and feeds my ego*" is not a good reason.

And yes, that means many pro bodybuilders are training in a suboptimal way, as many do midrange partials. If you can't fathom the idea that a largely poorly educated and underground subculture's intuitive way of manipulating the human physiology is not perfect, you have much to learn about this world. Most uneducated trainees have a hard time setting their ego aside in the gym and many bodybuilders are no different. It takes discipline to train with a full ROM. Your ego will often tempt you to cut the ROM short to lift more weight, do more reps, invest less effort and fake progress.

As much as we may love these guys, we should not consider them the foremost authority on exercise science.

Principle 4: Tissue stress distribution

Exercises should stimulate your muscles without overly stressing your connective tissues.

Targeted exercises should stimulate your *muscles* maximally and target other tissues, like tendons, only as far as their adaptations are required for maximum muscle growth. This ensures you are achieving maximal muscle stimulation with minimal injury risk. Which exercises achieve this is highly individual based on someone's body structure and we have limited direct research on injury rates, but we can make some general observations based on theory and the common experience of coaches.

4.1 Pushing and pulling behind the body is risky

For example, consider the pull-down to the chest or to the back of the neck. Pulling to the back of the neck is problematic for many people's shoulders, as the combination of shoulder abduction and forced external rotation increases friction in many of the subdeltoid tissues, such as the supraspinatus tendon and the subacromial bursa [2]. In fact, many people aren't even flexible enough to perform a behind-the-neck pulldown in the first place. To make the risk of that position worthwhile, there must be a clear advantage in terms of muscle activity for the behind-the-neck pull-down. Yet pull-downs to the neck do not result in greater lat activity than pulling to the chest. So regular pull-downs have a better tissue stress distribution than behind-the-neck pull-downs, assuming at least you're doing pull-downs primarily to train the lats.

Behind-the-body presses are similarly risky. Exercises such as dips and behind-the-neck presses anecdotally result in many aches and injuries with little unique advantage. Behind-the-neck presses place the shoulder in the same precarious position as behind-the-neck pulldowns [2] while also requiring high forces from the shoulder muscles. Dips put maximal stress on the shoulder in full hyperextension with protracted scapulae, putting high pressure on the rotator cuff tendons to keep the shoulder ball in its socket, while being relatively ineffective to train the long head of the triceps (see section on bi-articulate muscle contributions) and not having an ideal pushing angle to train the full pecs. While the evidence against behind the body pushing and pulling is mostly anecdotal and theoretical, there's often no reward for these potential risks. Unless you have a very specific reason to perform these exercises, you're generally better off choosing joint-friendlier variants that fulfill the same role, such as push-ups and military presses.

4.2 Freedom of movement is generally good

Your motor cortex, the part of your brain that governs movement, is very good at its job. It can make your joints move in precisely such a movement to efficiently achieve the desired movement. When we restrict this freedom, movement tends to become less efficient, which can increase the stress on our connective tissues without increasing the stress on our muscles, resulting in a worse tissue stress distribution. This principle is illustrated well by Spennewyn (2008): performing a training program in a free-movement machine compared to a fixed-movement machine resulted in less pain during exercise. Machines are not inherently bad for our joints though. A study by Hernández-Belmonte et al. (2023) found that a free-weight and an otherwise identical machine-based program were equally effective to *reduce* joint discomfort. The reduction in joint discomfort indicates the total training stress was low enough to be sustainable. However, it's plausible that a fixed-movement machine-based program limits how much total volume you can do without developing joint discomfort.

Rotating handles are often a great way to reduce elbow or forearm pain without impairing an exercise's effectiveness. Using gymnastic rings, cables, suspenders like a

TRX or gadgets like Angles90 rather than a straight bar for pulling exercises makes the exercise much easier on the elbows and wrists without reducing muscle activity of the target musculature [2, 3, 4].

In addition, people generally find training with free weights more pleasurable and enjoyable than training with machines [2]. Greater enjoyment of exercise may reduce psychosomatic pain, as we'll discuss in more detail in the course module on injury management.

While freedom of movement is generally good, sometimes restricting movement can be beneficial. Some machines perfectly suit somebody's structure, making them more tolerable on the joints than certain free weights. Certain types of injuries can also benefit from constrained movement patterns. Listening to pain signals is generally far more important than the freedom of movement an exercise offers.

4.3 Closed kinetic chain exercises may be preferable over open ones

Kinetic what? The definition of a closed kinetic chain is complicated. It refers to the freedom of movement in the terminal segment of the exercise. Fortunately, there's a much more practical guideline to see if an exercise has an open or closed kinetic chain. When you apply force to an object, either you move or that object will move. If *you* move, the exercise's kinetic chain is closed. If the *object* moves, the exercise's kinetic chain is open. Think of a push-up compared to a flat dumbbell press. During the push-up, you're moving, so it's a closed chain exercise. During a dumbbell press, the object is moving, so it's an open chain exercise.

Many physiotherapists have long favored closed chain exercises for rehabilitative purposes, because closed chain exercises generally allow you to move in a natural/intuitive manner, which stimulates your muscles well while being relatively easy on your joints based on some research. Closed-chain exercise results in more synchronized quadriceps activation than open-chain exercise, which may benefit knee health. Indeed, closed-chain exercises seem to be slightly more effective than open-chain exercises at increasing functional performance during knee rehabilitation. Anecdotally, push-ups are also much better tolerated by people with shoulder pain than bench presses, although this may be more related to the freedom of movement in the scapulae than in the terminal segment of the kinetic chain.

Overall, it may be beneficial to slightly favor closed chain exercises over open ones for injury prevention and rehabilitation. The research support for this theory is weak though, so again, pain signals and individual exercise considerations are much more important than an exercise's kinetic chain.

Principle 5: Unilateral > bilateral

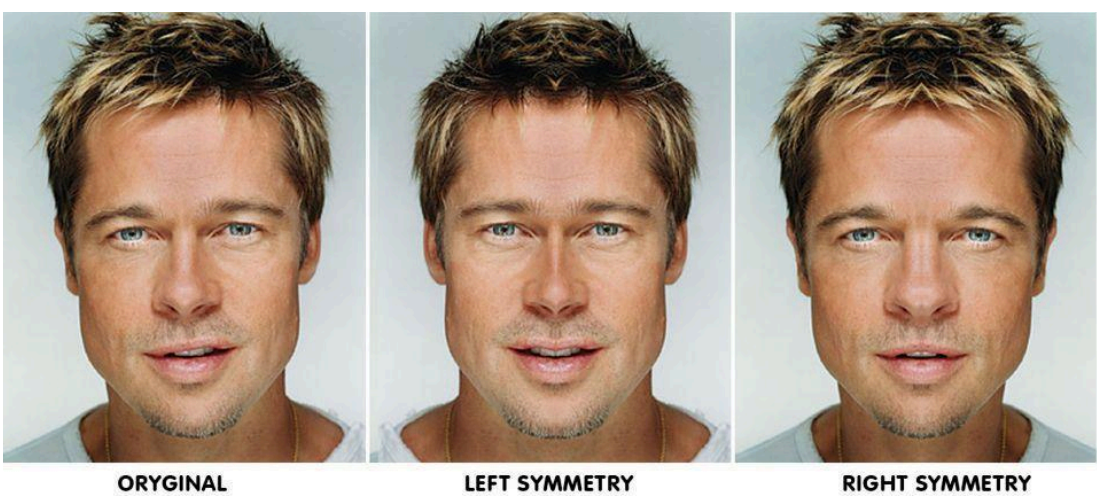
All else equal, exercises involving only one limb are slightly superior to those involving both limbs.

Many lifters tend to think of barbell compound exercises as ‘natural’ and ‘functional’, but humans did not evolve for bilateral movement. Virtually every natural activity is unilateral or at least asymmetrical: running, throwing, picking things up, striking, climbing, etc. Try writing your signature with your non-dominant hand.

Even the squat is not a fully symmetrical exercise outside the textbook. If you’ve ever watched many strong squatters on video from multiple angles, you’ll see that many of them show marked asymmetry. Common asymmetries are that the hips shift a little from side to side during the drive out of the hole and that people lean more on one leg than the other.

These are not just technique errors. Humans are simply not perfectly symmetrical in anatomy. Even our faces are not that symmetrical. While facial symmetry is generally found to be attractive, *perfect* facial symmetry can look downright weird. To show how asymmetrical even seemingly symmetrical faces are, here are some celebrities who have been photoshopped to have perfect left or right facial symmetry.

Middle: actual face. Left: perfect left facial symmetry. Right: perfect right facial symmetry.



**Spelling error courtesy of the unknown author.*

As a result of our asymmetries, the motor cortex is not as good at recruiting 2 limbs simultaneously as it as at controlling 1 limb at a time. Unilateral exercises generally have higher levels of muscle activity and force output per limb than bilateral exercises, all else being equal [1, 2]. Researchers call this the 'bilateral deficit'. It also occurs during jumping.

Some people question whether the bilateral deficit really exists, citing the lone deviant research paper with poor statistical power. Even setting aside the science here, the only proper response to this is: "Do you even lift?" The bilateral deficit is so evident that you should observe it in your own training. If you find your 5RM on the bilateral leg extension and then take off 50% of that, you can almost certainly perform more than 5 reps unilaterally with that weight, even when you do it as the next set and you're already fatigued. For example, if you can do 100x5 bilaterally, you can likely perform something like 50x8 unilaterally a few minutes later. Similarly, when you've repped out on biceps curls or lateral raises with a dumbbell in each hand, you can most likely still perform some reps with 1 dumbbell, even with your weaker side. That's how noticeable the bilateral deficit often is. The bilateral deficit tends to be even greater for compound exercises due to their more complex movement requirements.

The bilateral deficit will decrease with experience with bilateral exercises and you may even fully bridge the gap, but if you always do unilateral exercise, you will generally still end up with greater muscle activity and force output during unilateral than bilateral exercise [2].

Greater force output means more mechanical tension, so we would expect slightly more muscle growth per set with unilateral exercises. However, we have too few data to say if this is indeed the case. A 2025 meta-analysis found no significant difference in muscle growth between unilateral and bilateral training, but this was based on just 2 studies, both of which were on untrained women [1, 2]. Strength gains were movement-specific: unilateral strength gains were highest with unilateral training and bilateral strength gains were highest with bilateral training. Other research also clearly shows this trend of movement-specificity in strength [2, 3, 4, 5].

Unilateral exercises also allow you to correct strength asymmetries very well. Bilateral exercises performed with good, symmetrical technique will generally correct strength asymmetries reasonably well. However, how symmetrical strength develops between limbs varies significantly per person. Bilateral exercises do not guarantee perfectly symmetrical muscular development, because even in well-trained individuals bench pressing at 90% of 1RM to failure, there is considerable asymmetry in muscle activity between sides: people generally experience greater muscle activity in their dominant sides. Unilateral exercises allow you to determine exactly how hard each side trains. (See the module on customized program design for more details on how to correct muscular asymmetries.)

Unilateral exercises also seem to carry over a little bit better to bilateral exercises than the other way around, at least for compound exercises. For example, step-ups carry over quite well to bilateral squats, whereas squat strength doesn't carry over as well to step-up strength. Many strength coaches advocate for unilateral training in athletes, as it's more 'functional' than bilateral training. A 2021 meta-analysis by Liao et al. found partial support for the superiority of unilateral exercises over bilateral exercises to improve athletic performance. Unilateral training was significantly more effective to improve unilateral jumping performance, yet bilateral training was not significantly more effective to improve bilateral jumping performance. There were no significant differences in speed and change of direction ability though. A study by Ji et al. (2022) on athletes also found that unilateral training improved sprint cycling performance more than bilateral training, even with matched training loads.

Overall, we have a solid theoretical rationale to select unilateral exercises over bilateral exercises, all else equal, for symmetrical development with a slight theoretical advantage for muscle growth. Unilateral exercises are equal or possibly better in every regard compared to bilateral exercises, except of course the fact you have to do double the number of sets. Many trainees dislike unilateral training for this reason. A good compromise is often to try to have at least 1 unilateral exercise for most muscle groups in most of your programs. Many simple isolation exercises are good candidates for unilateral training, because there are no problems with balance and it's not that effortful to do another set when you'd otherwise just be resting anyway. Great candidates for unilateral training include cable lateral raises, Bayesian curls, leg curls and leg extensions.

Note that many unilateral exercises are not identical to their bilateral counterparts. Split squats, for example, are not identical to a back squat performed on one leg. They train the rectus femoris more and the erector spinae less than barbell back squats. Other exercises have major stability problems, such as unilateral dumbbell bench presses: you can't have your elbow out to the side with a heavy dumbbell, otherwise you'd topple over.

In addition to the above 6 principles of exercise selection to effectively stimulate your muscles, there's 1 more practical principle of exercise selection: microloadability.

Principle 6: Microloadability

The more precisely an exercise's resistance can be adjusted, the more practical the exercise, overlooking the other criteria.

The best mass-building exercises lend themselves both to high absolute loads *and* small incremental loads. Ideally, we want to choose exercises that allow us to increase the max weights used, but we need the ability to take baby steps towards those maxes.

Absolute maximum load is generally a limiting factor for bodyweight exercises. Push-ups, for example, are a great exercise in principle, but it can be impractical or impossible for well-trained individuals to make them difficult enough.

Incremental loading is a limitation for many other exercises, especially for women. Machines have fixed weight increments in their stacks and most gyms only have dumbbells that increase five pounds at a time. Even barbell exercises can only be loaded with the smallest plates in the gym multiplied by two, because lopsided bars are a bad idea, no matter how small the extra is on one side. While beginners and intermediates may be able to progress with such rigid increases, the ideal incremental load should ideally be measured in a percentage of the working weight, not necessarily a strict 5 or 10 pounds. Five pounds may be a good incremental increase for squats, but it's excessive for a lateral raise. Any increment over 2.5% is often problematic. Cable lateral raises, for example, are a great exercise, but the minimum weight on the stack may already be too much for some trainees, especially women and the elderly. Weight jumps of 5 kg (10 lb) are also very problematic for this exercise. You'll quickly get stuck at a certain point where you cannot go higher up in reps but you also cannot move on to the next weight. In this case, it's often best to replace the exercise.

Micro plates can be very useful to make progressive overloading smoother and safer. Small magnetic add-ons, like PlateMates, are even better, because you may be able to tag the magnets onto machines, cable stacks and dumbbells, not just barbells.

Exercise selection: practical application

Now that you've made it through the list of exercise selection principles, let's apply the selection criteria to a few basic movements.

To refresh your memory, a good exercise for a muscle…

1. **has it as a limiting factor,**
2. **trains it at long lengths**
3. **with a good tissue stress distribution**
4. **and eccentric contractions**
5. with good microloadability,
6. unilaterally, if all else equal.

Let's look at a few examples of popular exercises that don't live up to the hype and then discuss better exercises.

Example 1: triceps isolation work

Let's look at an example. We're hitting triceps today. Should we do two-arm kickbacks, rope pushdowns, or unilateral standing cable overhead triceps extensions?

From left to right: two-arm kickbacks, triceps pushdowns and overhead triceps extensions.

1. The Limit Factor: the triceps is clearly a limiting factor for all 3 lifts.
2. Stretch-mediated hypertrophy: overhead triceps extensions clearly win out here, which is confirmed by research as mentioned before, because they stretch the long head of the triceps with the shoulder flexion and place maximum tension at all heads in the bottom position when they are lengthened. Pushdowns have minimal tension in the stretched position and kickbacks even put the long head close to active insufficiency.
3. Tissue stress distribution: Overhead extensions can be hard on the elbow tendons for some individuals, whereas pushdowns and kickbacks are quite joint-friendly. However, the ratio of connective tissue stress to muscle stimulation isn't necessarily worse with overhead extensions, as they do well in terms of muscle stimulation.
4. Eccentric contractions: All 3 exercises have these.
5. Microloadability: This depends on your available equipment, specifically the increment between the available dumbbells and cable stacks. Since you can only lift a paltry weight during kickbacks though, the relative increment is almost always a problem for this exercise, so it loses out in this regard.
6. Unilateral > Bilateral: Overhead extensions are the only exercise of the 3 not suffering from the bilateral deficit, so they win in this regard.

All in all, unilateral overhead triceps extensions score best and are thus often preferred when someone's elbows tolerate them. Pushdowns come second and kickbacks are generally only useful when someone has injury prone elbows and cannot do any other triceps isolation work.

Example 2: the powerlifting deadlift

Now let's look at the deadlift. Many people say deadlifts are magical must-have mass-builders, but how does the deadlift really score against the criteria?

First, powerlifting deadlifts are practically purely concentric when traditionally performed – pulling the weight up from the floor and then dropping it – so they don't have good eccentric contractions, a major downside.

Second, deadlifts put the ankles, knee and hips through a limited range of motion which is arbitrarily determined by the radius of the standard 45-pound plate (or whatever plates you're using). Deadlifts will therefore likely not stimulate maximal stretch-mediated muscle hypertrophy.

Third, the limiting factor for deadlifts is often your grip or erector spinae strength, not your leg muscles. For your grip, you can use straps, but your back often remains the limiting factor. The following modifications make deadlifts better mass builders:

- Not resetting the weight between reps and controlling the descent to get good eccentric muscle actions.

- Using a very wide (Snatch) grip or elevating the feet on a deficit to increase ROM.

A problem with these changes is that they anecdotally make deadlifts more injurious, as it's extra difficult to maintain a neutral lumbopelvic posture in the bottom position when you're closer to your end range of motion at the end of a tough rep. Some research and anecdotes suggest deadlifts require a greater recovery time than most other bodybuilding exercises. However, other research shows deadlifts induce the same amount of muscle damage and neuromuscular fatigue as squats and bench presses. The 'banged up' feeling after high-volume deadlifting is probably not because of extraordinary muscle damage but rather connective tissue stress. Deadlifts have a questionable tissue stress distribution, if not in theory then at least in practice, as maintaining ideal form is difficult when very fatigued. Anecdotally, the deadlift seems to be responsible for more serious back injuries than any other exercise.

Moreover, even with these changes, deadlifts remain a poor exercise for the quads. There is simply not enough knee flexion to stimulate stretch-mediated muscle hypertrophy. Plus, the lack of forward knee travel keeps the moment arm for knee extension small. As a result, the quads generally don't have to contract maximally during deadlifts. If you're not going to train the quads well in the first place, you're arguably better off with Romanian deadlifts. Those stimulate the posterior chain over their full ROM with dynamic muscle contractions with an anecdotally lower injury risk, probably because it's easier to maintain a neutral lumbopelvic posture.

In conclusion, powerlifting deadlifts are a great jack-of-all-trades exercise, but that also makes them a master of none. Powerlifters do them because they make you look really strong, don't require any equipment other than a barbell and, most importantly from a competitive point of view, they are very easy to judge. This makes deadlifts very suitable as an objective *test of strength*, but they are not an ideal muscle builder. Recreational trainees primarily interested in muscle growth are better off using more specific exercises that stimulate each involved muscle better, such as Romanian deadlifts with leg extensions (possibly in an antagonist superset for extra benefit: see exercise ordering module).

Example 3: rows

Rows are famous back builders... That sentence should by now trigger your broscience alarm. The 'back' is not a muscle group. The only proper response to anyone telling you about their 'back day' or 'back width' or 'the upper back' is: "Do you even functional anatomy, bro?" You should distinguish between the lats and teres major, the 3 heads of the traps, the posterior deltoids and the erector spinae. Most row variations are good for the lower and middle traps and the posterior deltoids, while providing little stimulation for the erector spinae. Rows directly train the lats, but if you logically apply the exercise selection criteria, you'll see there are much better options for the lats, primarily because rows don't train the latissimi dorsi at long lengths. Even if your back is fully horizontal while rowing, your ROM is only half (90° vs. ~180°) and you miss out on the most important part: the long muscle lengths that can stimulate stretch-mediated hypertrophy. Moreover, when your elbow travels behind your body, tension on the lats is lost, because the lats cannot hyperextend the shoulder.

Example 4: barbell biceps curls

Barbell biceps curls are one of the most well-known strength training exercises on the planet, yet they're not ideal biceps builders. For one, the barbell limits the range of motion (ROM) of the elbow joint by hitting your legs before your biceps attains a full stretch. You can achieve full ROM by leaning forward a little, but then you shorten the short head of the biceps – this must make it *really* short, huh? – which reduces how much tension it can generate. (Remember its length-tension relation from the functional anatomy module.) We want to keep our elbows at out sides for both maximum active tension as well as stretch-mediated hypertrophy.

Even if you train with a full range of motion, traditional dumbbell and barbell curls cannot optimally stimulate the biceps, as they provide no resistance in the bottom position. When performing a biceps curl, the external moment arm is equal to how much your forearm sticks out horizontally. At 90° of flexion, the lever arm of the weight is maximal and you face peak resistance. That's why the sticking point is at 90°. In the bottom position, the external moment is essentially zero, so you face practically no resistance in the bottom. Standing dumbbell and barbell curls thus woefully neglect the biceps in its stretched position, which is double unfortunate, because the biceps experiences peak passive **and** active tension when its lengthened. A study by Sato et al. (2021) found that training the biceps over the bottom 0-50° of elbow flexion – at longer lengths – resulted in triple the growth compared to training the biceps over the top 80-130° of elbow flexion – at shorter lengths.

Another issue with barbell curls is that they force you to stay in full wrist supination throughout the full set, which is not comfortable for some people, especially men, and can result in forearm pain.

Optimized Variation: Bayesian Curls

Bayesian curls are a cable biceps curl performed facing away from the cable station. During the exercise, you bend forwards slightly as you flex your biceps to get a good full contraction. Then you lean back again as you lower the weight to fully stretch the biceps. This is the opposite movement of what you will intuitively be inclined to do (which is cheating) so the exercise will feel weird at first. But over time you should be able to find a way to do the exercise that matches your body's natural movement pattern and provides great biceps stimulation during the entire exercise. Here's an exercise demonstration of the Bayesian curl.

Depending on your elbow flexibility, you should allow your grip to pronate slightly during the descent, rotating your palms slightly to the floor.

You can further individualize the exercise by positioning yourself further or closer away from the cable pulley station to match the resistance curve to your strength curve. Stepping away from the station increases the resistance at the bottom; stepping back increases the resistance at the top.

Recommended exercises

Now that you understand the principles behind effective exercise selection, here's a list of exercises that generally score well on these principles. You should customize your exercise selection and the specific execution of each exercise to the trainee's anthropometry, injury risk, available equipment and goals. When you perform multiple exercises for a muscle group, as should often be the case (discussed in the next section), make sure the total program's exercise selection has synergy rather than excessive overlap.

The exercises are categorized roughly in terms of target musculature from a practical programming perspective. Later in this module we'll go into detail on how to count exercise volume per muscle group.

Descriptions of how to perform the exercises, and many others, can be found in our exercise library. Note that most exercises can be performed in various manners depending on the goal of the exercise and your anthropometry. The provided exercise descriptions should be regarded as no more than a general template of one version of proper exercise technique.

➢ **Exercise library**

Pectoralis major

- Deficit or suspended push-ups
- Flys (with cables, DBs or rings)
- Dumbbell bench presses (flat or 15° incline), preferable over a barbell due to the extra ROM

- Chest press machines, preferably convergent ones that allow for a full pec stretch

Lateral deltoids

- Military press (elbows out; wide grip)
- Dumbbell overhead presses
- Cable lateral raises
- Side lying lateral raises
- Lean-in lateral raises
- Butterfly lateral raises

Upper trapezius

- Overhead shrugs
- Wide shrugs

Rear deltoids & lower/middle trapezius

- Reverse Bayesian fly
- Side lying reverse flys
- Shoulder-pulls
- Face-pulls
- High rows

Latissimus dorsi & teres major

- Lat prayers
- Chin/pull-ups

- Lat pulldowns
- Pull-overs

Biceps brachii

- Bayesian (hammer) curls
- Preacher/Scott curls
- Incline curls

Triceps brachii

- Overhead triceps extensions
- Skull-overs
- Forward leaning triceps pushdowns

Quadriceps

- Squatting movements, incl. hack and sissy squats
- Reverse lunges
- Leg extensions
- Reverse Nordic ham curls

Erector spinae

- Back extensions
- Squats
- Deadlifts

Hamstrings

- Glute-ham raise
- Romanian deadlifts
- 45° Hip extension
- Suspended/gliding leg curls (mostly if you have no machines)
- Leg curl machines (seated preferable)
- Goodmornings
- Pull-throughs

Gluteus maximus

- Squatting movements
- Lunges
- Leg presses
- 45° Hip extension
- Deficit hip thrusts
- Pull-throughs
- RDLs
- Goodmornings
- Reverse hyperextensions
- Glute kickbacks

Gluteus medius

- Full-stretch hip abductions

Calves

- Calf jumps

- Standing calf raises
- Seated/bent-knee calf raises (for soleus)

Rectus abdominis

- Ball crunches
- Reverse crunches

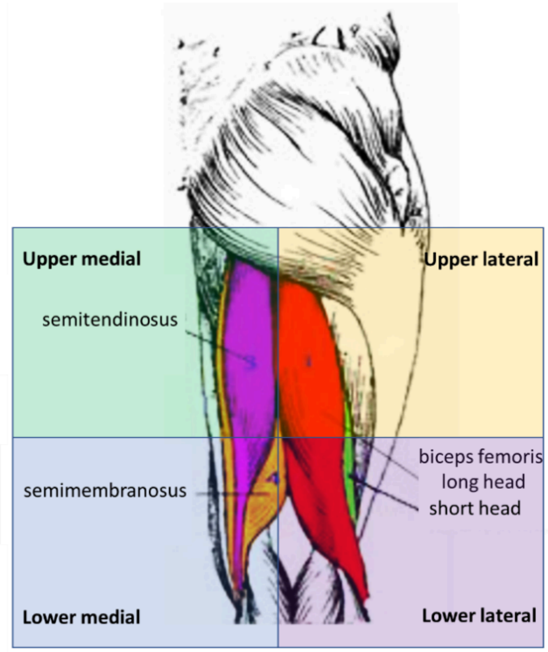
Exercise variety

Now that we've covered how to select between different exercises for the same muscle group, the next question is: how many exercises should we select per muscle group?

To answer this question, you need to understand functional differentiation. While it is often claimed that the body can only activate all muscle fibers in a muscle or none at all, this defies common sense. Just think about muscles like the traps, the delts and the pectorals. These muscles have separate heads with *opposing* functions. If you contract your upper traps, your traps are pulled upwards (scapular elevation). If you contract your lower traps, your traps are pulled downwards (scapular depression). It would be nothing short of an epic evolutionary failure if the human body could not separately control these different muscle heads.

Functional differentiation goes beyond different muscle heads. A muscle is often simplistically illustrated as a bundle of muscle fibers ranging through the entire muscle. In reality, muscle architecture is more complex; being divided into neuromuscular compartments. Neuromuscular compartments are different regions of a muscle which are controlled by individual nerve branches. As long as any 2 muscle fibers are operated – innervated as it's properly called – by separate nerves (motor neurons), they can be separately activated. Most functional differentiation in muscle occurs between muscle fibers running next to each other in slightly different angles, but muscle fascicles are also compartmentalized along their length: not all muscle fibers run along the entire length of the muscle fascicle.

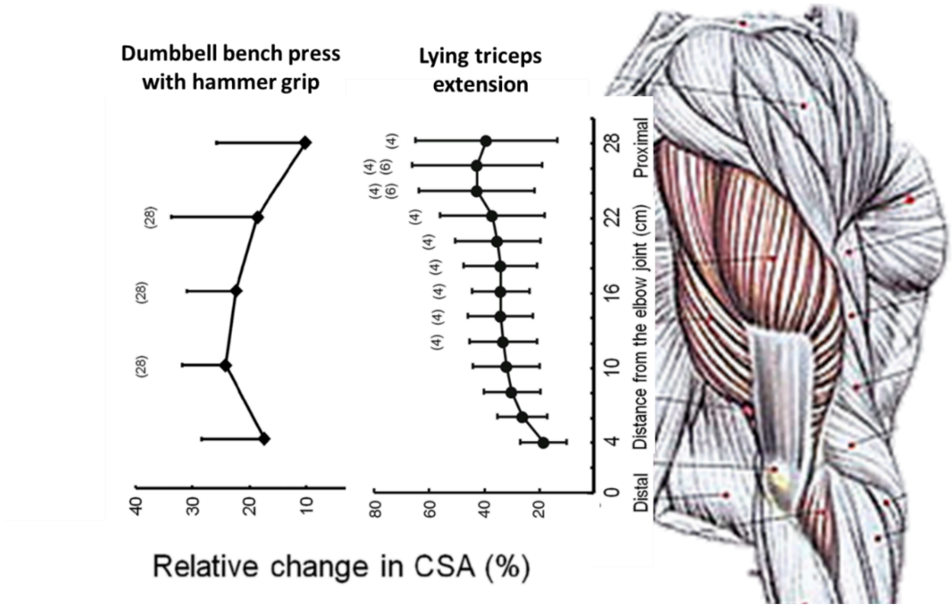
As such, the bros have always been right that muscles can be regionally activated. When you train a muscle, not all muscle fibers are uniformly activated [2]. For example, lunges are not a great exercise for the hamstrings as a whole, but they do significantly activate the proximal part of the long head of the biceps femoris. This corresponds with the high amount of soreness many people feel in the upper hamstrings, just below the glutes, after single-leg squats and lunges.



The differences in activity of different muscle fibers with different exercises can be very large, especially in large, complex muscle groups like the hamstrings. For example, Schoenfeld et al. (2015) studied muscle activation in the lying leg curl compared to the stiff-legged deadlift. Leg curls activated all parts of the hamstrings well, whereas deadlifts activated the upper parts more. The difference in EMG activity were very large, ranging from 60% to a whopping 170%. That the leg curls activated the lower lateral part of the hamstrings more is not surprising, because that's where the short head lies, which is only active during knee flexion, not during hip extension. However, that the lower medial hamstrings were activated more during leg curls was more surprising. This is strong evidence of functional differentiation beyond the level of individual muscle heads: different exercises can even cause different muscle activation patterns even within the same head of the muscle. Other research has also found preferential activation of the lateral (biceps femoris) vs. medial (semitendinosus) heads of the hamstrings with different exercises.

The exact exercise protocol seems to be very influential, as other research has found the ST head is more active than the biceps femoris (BF) regardless of exercise, whereas yet another study found not only that leg curls and deadlifts differed in activation pattern of the ST and BF, but even hip extensions and deadlifts had a different activation pattern.

In short, certain exercises stimulate certain fibers of a muscle more than others, which causes these emphasized fibers to grow more.

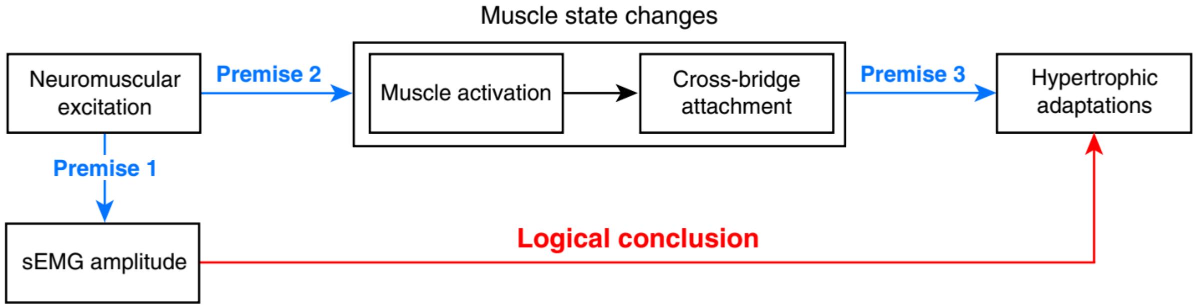


The different muscle growth patterns in the triceps muscle as a result of performing different exercises. [Source]

Technical sidebar: is EMG really relevant? *[Optional section]*

Some researchers question the relevance of differences in electrical activity in different regions of a muscle, as measured by electromyography (EMG). Indeed, EMG has many limitations and we cannot infer that a higher EMG signal in any setting predicts long-term muscle growth with reasonable accuracy. At best, it provides an estimate of the active mechanical tension generated by the muscle.

Many EMG studies are also improperly conducted. One major yet common mistake is not equating the training intensity of the different exercises. You cannot get much meaningful information out of comparing a few reps of push-ups and suspended push-ups, for example, as suspended push-ups are considerably more difficult than push-ups on the floor.



Mechanistic logic for using surface electromyography (sEMG) as a predictor of hypertrophic adaptations: all 3 premises can be challenged, especially premise 3. [Source]

However, for the purpose of exercise selection and determining which muscles are trained by which exercises, properly controlled EMG studies should be useful, because EMG has also been validated in multiple ways as a measure of muscular exertion. First, EMG muscle activity correlates with both objective exercise intensity (% of 1RM) and subjective exercise intensity (RPE) [2].

Second, the pattern of muscle activity measured by EMG during exercise correlates with the pattern of muscle activation and muscle damage estimated by MRI [2, 3]. The pattern of EMG activity also corresponds with muscle swelling measured by ultrasound. Muscles that show more EMG muscle activity, also show more subsequent muscle damage/activity in MRI scans and ultrasound measurements.

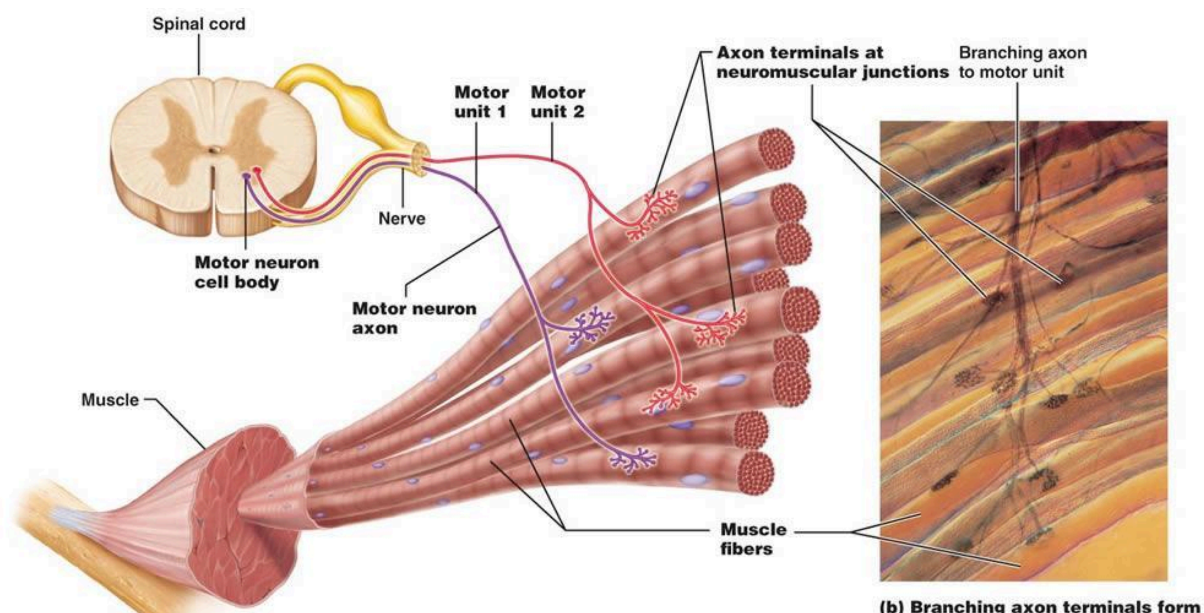
What is MRI?

Magnetic resonance imaging (MRI) is a sensitive method to detect physiological changes that occur in muscles activated during exercise. Exercise leads to changes in water distribution in tissue. These changes can be detected using MRI providing detailed anatomical analysis of soft tissues, which is lacking in electromyography experiments (EMG). As such, MRI can be used to measure acute muscle activation as well as subsequent muscle damage.

In turn, the regional differences in MRI muscle activity correspond with the pattern of subsequent muscle growth within the muscle during various exercises [2, 3 although contested here]. The muscle fibers that activate more, tend to grow more. We also see this quite well in EMG research on squats: the hamstrings and rectus femoris show low EMG muscle activity and little long-term muscle growth, whereas the glutes and quads achieve high activity and growth, exactly in line with their biomechanics. Analogously, leg extensions result in high EMG activity in all heads of the quads and also grow all of them effectively. In conclusion, EMG research can provide valuable data for the purpose of exercise selection, but the research has to be very well-conducted and we can never directly extrapolate EMG activity to muscle growth.

Exercise variety

The presence of functional differentiation and regional muscle growth have led some bodybuilders to conclude that you should do 10 different variants of the chest press and biceps curl to make sure they fully stimulate every single muscle fiber. This isn't strictly necessary though. Not nearly every muscle fiber has its own neural drive. Many motor neurons innervate many different muscle fibers at the same time, up to thousands in muscles where fine motor control is not required. After all, many muscle fibers are so close to each other that they have a virtually identical line of pull and therefore function.



(a) Axons of motor neurons extend from the spinal cord to the muscle. There each axon divides into a number of axon terminals that form neuromuscular junctions with muscle fibers scattered throughout the muscle.

(b) Branching axon terminals form neuromuscular junctions, one per muscle fiber (photomicrograph 330×).

Theoretically, to maximize muscle growth, a training program should thus include enough exercise variety to stimulate all a muscle's fibers but there is probably no need to have more variety than that. You generally achieve this with a selection of exercises that performs well on the criteria you learned in this module that target all major muscle functions of the target muscle. For the trapezius, for example, you want at least 1 exercise involving scapular elevation, depression and retraction. You can achieve this with a combination like wide shrugs (elevation), reverse flys (retraction) and lat pulldowns (depression), for example.

Theory aside, what do the data say? We don't have many studies on exercise variety, but several studies have investigated the effect of adding arm isolation exercises to compound exercises.

Arm training variety

Many men feel the need to do multiple different types of biceps curls on top of their compound work, but research does not that clearly support we need isolation exercises for the arms in the first place. Multiple studies have investigated the effect of adding arm isolation exercises to a compound exercise program for arm muscle hypertrophy. In these studies, the effect on arm muscle growth is inconsistent with some studies finding no significant benefit even when volume is not equated, while others do find benefits. Part of this inconsistency is likely because several studies rely on arm circumference as their measure of muscle growth, which is very unreliable. It's easily confounded by muscle edema, hydration status and changes in glycogen storage. In the research overview below, we've analyzed the data to calculate the effect sizes in the literature as a whole. There is a considerable trend for the inclusion of arm isolation exercises to increase arm muscle growth; however, the effect size difference is small enough that it's likely just because of the higher training volume in the groups adding arm isolation work, not because of the need for isolation work per se.

➢ Research overview

[Do you need arm isolation exercises for maximum arm growth?]

To isolate the effects of training volume and exercise variety, Costa et al. (2021) compared doing the same 1 full-body workout 3 times per week to 3 different full-body workouts once per week (illustrated below). All other training variables were the same between the groups. The participants were young, detrained men. After 9 weeks, there were no statistically significant differences in muscle growth between groups. However, in absolute terms, the varied exercise group experienced more growth in 10 of the 12 measured sites of muscle thickness. In the other 2, the gains were similar. The researchers did not compare the sum of all sites between groups, but this was 45.3 vs. 35.5 in favor of the varied exercise group. These results suggest there's no clear benefit to exercise variety, but there could be a small benefit.

Group	Monday	Wednesday	Friday
N-VAR	Bench press	Bench press	Bench press
	Lat pulldown front	Lat pulldown front	Lat pulldown front
	Arm curl	Arm curl	Arm curl
	Triceps extension	Triceps extension	Triceps extension
	Leg press	Leg press	Leg press
	Lying leg curl	Lying leg curl	Lying leg curl
VAR	Bench press	Incline bench press	Decline bench press
	Lat pulldown front	Lat pulldown neck	Lat pulldown narrow grip
	Arm curl	Preacher curl	Inclined dumbbell curl
	Triceps extension	Cable seated triceps extension	Triceps kickback pulley
	Leg press	Half squat	Hack machine
	Lying leg curl	Seated leg curl	Seated unilateral leg curl

Note: N-VAR = Group that performed the same exercises in all sessions throughout the intervention; VAR = Group that varied the exercises between sessions.

	N-VAR (n = 11)			VAR (n = 11)			Effects *P*		
Sites (mm)	**Pre**	**Post**	**Δ (95 % CI)**	**Pre**	**Post**	**Δ (95 % CI)**	**Group**	**Time**	**Interaction**
Lateral thigh									
Proximal	46.3 ± 6.3	48.5 ± 7.3 *	2.3 (0.0;4.5)	45.7 ± 7.7	50.3 ± 7.9 *	4.5 (2.3;6.8)	0.84	< 0.0001	0.15
Middle	51.7 ± 5.9	52.8 ± 6.6	1.1 (− 0.5;2.8)	51.0 ± 6.6	53.4 ± 6.7 *	2.3 (0.6;4.0)	0.98	0.007	0.28
Distal	49.8 ± ± 6.2	52.4 ± 6.9 *	2.5 (0.8;4.3)	47.6 ± 5.9	50.1 ± 6.0 *	2.5 (0.8;4.2)	0.40	< 0.0001	0.97
Anterior thigh									
Proximal	53.9 ± 6.9	58.3 ± ± 6.7 *	4.4 (2.0;6.8)	51.6 ± 8.3	55.8 ± 9.1 *	4.2 (1.7;6.6)	0.46	< 0.0001	0.89
Middle	51.1 ± 7.3	54.9 ± 6.9 *	3.8 (1.7;6.0)	45.5 ± 8.2	49.4 ± 7.9 *	3.9 (1.8;6.1)	0.09	< 0.0001	0.93
Distal	42.1 ± 6.5	45.7 ± 8.3 *	3.6 (1.2;6.0)	35.7 ± 7.1	39.5 ± 7.8 *	3.8 (1.3;6.2)	0.05	< 0.0001	0.90
Elbow flexor									
Proximal	30.5 ± 3.1	32.7 ± 3.8	2.1 (− 0.1;4.5)	27.7 ± 5.0	32.2 ± 5.1 *	4.5 (2;1;6.9)	0.32	< 0.0001	0.15
Middle	33.0 ± 2.2	35.3 ± 3.5 *	2.2 (0.5;4.0)	30.9 ± 5.6	34.0 ± 5.2 *	3.1 (1.3;4.8)	0.35	< 0.0001	0.50
Distal	38.0 ± 2.4	41.5 ± 2.7 *	3.5 (2.1;4.8)	35.1 ± 5.2	38.8 ± 4.8 *	3.7 (2.3;5.1)	0.10	< 0.0001	0.81
Elbow extensor									
Proximal	36.0 ± 4.2	39.9 ± 6.2 *	3.8 (1.5;6.1)	34.3 ± 5.8	38.2 ± 4.9 *	3.9 (1.6;6.2)	0.44	< 0.0001	0.95
Middle	35.6 ± 3.6	38.5 ± 5.7 *	2.8 (1.0;4.5)	33.1 ± 5.3	37.4 ± 5.3 *	4.2 (2.4;6.0)	0.40	< 0.0001	0.24
Distal	29.4 ± 3.2	32.8 ± 5.5 *	3.4 (1.7;5.1)	28.0 ± 5.1	32.7 ± 5.0 *	4.7 (3.0;6.4)	0.70	< 0.0001	0.28

Note: N-VAR = Group that did not vary the exercises; VAR = Group that varied the exercises. * $P < 0.05$ vs. pre. Data are presented as mean ± standard deviation (DP) and 95 % confidence interval.

Total: 35.5 for N-VAR vs. 45.3 for VAR

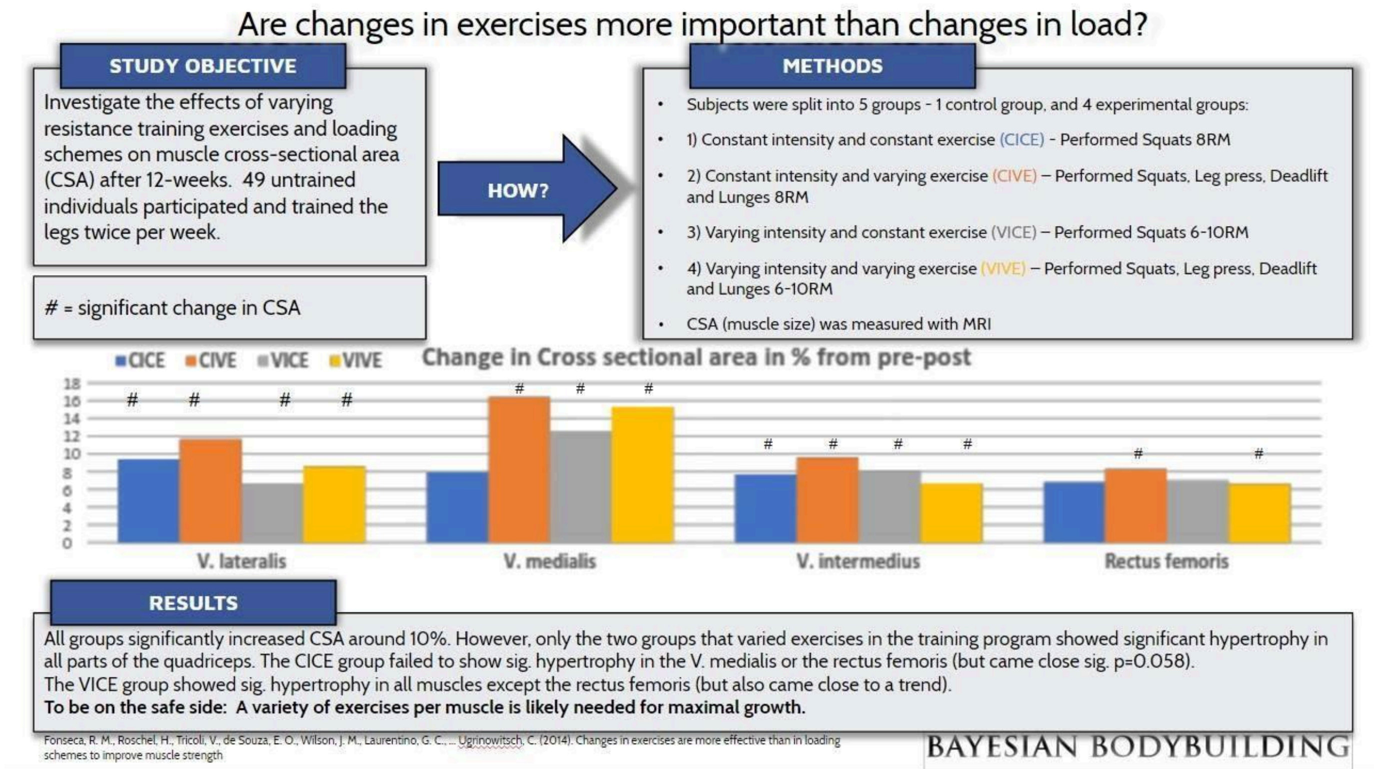
Study: Costa et al. (2021). Does Performing Different Resistance Exercises for the Same Muscle Group Induce Non-homogeneous Hypertrophy? Int J Sports Med. 2021. doi: 10.1055/a-1308-3674

If we look at acute measurements of muscle stimulation, there's also no clear benefit to doing multiple types of biceps curls. Barakat et al. (2019) had a group of trained lifters train their biceps once with 9 sets of biceps curls and once with 3 sets of 3 curls in different degrees of shoulder flexion (0°, -30° and 90°, illustrated below). Muscle swelling and muscle damage, as measured by echo intensity, didn't significantly differ overall between the groups during the recovery periods, suggesting no difference in training stimulus. Total muscle activity was higher with the exercise variety, but comparing EMG readings across different exercises is not very reliable.

Leg training variety

Fonseca et al. (2014) studied the effect of training the quads with either just squats or a combination of squats, leg presses, deadlifts and lunges with the same total set x rep volume in untrained men. Total quad size increased similarly across both groups, suggesting again that exercise variation does not significantly benefit muscle growth. However, squat strength (1RM) increased significantly more in the varied exercise groups than the just-squat groups with a large difference in effect sizes.

Moreover, the varied exercise groups experienced muscle growth in all heads of the quads, whereas the just-squat group didn't (data plotted below for the science lovers), suggesting regional differentiation in growth of the different exercises. Other research also shows that lunges cause more growth in the vastus medialis of the quads, whereas squats cause more growth in the vastus lateralis. Over the long term, just squatting will thus likely not maximize muscle growth in the quads and we need to add different exercises to maximize growth in all muscle fibers.



Earp et al. (2023) also found that leg extensions and squats resulted in similar total quadriceps volume increases but with a different regional pattern. Thus, you should probably do both a leg extension type and a squat type exercise for maximum quad gains.

Costa et al. (2022) could not replicate the finding that exercise variety benefits strength gains. The researchers found no difference between performing 1 exercise 3x per week or 3 different exercises once per week on strength development of the primary exercises. Unfortunately, the study was not very well-controlled. The varied exercise group had non-significantly but consistently higher intakes of all 3 macronutrients and the subjects were untrained before the study but had previously trained before, making muscle memory a confounding factor. Muscle growth was not measured; however, the non-varied group experienced a significantly greater increase in isometric knee extension strength (12% vs. 7%). Isometric strength strongly correlates with muscle size, as it's a measure of raw strength without much of a technical component, so this may suggest the non-varied group gained more muscle.

Kassiano et al. (2024) found no benefits to exercise variety for the legs. The researchers randomized 70 untrained women into 2 groups:

1. The constant exercise group just did leg presses and stiff-legged deadlifts (SLDLs) 3x per week.
2. The varied exercise group did that workout on Monday, hack squats and lying leg curls on Wednesday and squats and seated leg curls on Friday.

All other training and nutrition program variables were the same (e.g. 2 sets to failure at 10-15RM). After 10 weeks, there were no significant differences between the groups in muscle growth (muscle thickness measured in **8** locations of the thigh) or strength (1RM leg press and leg extension and total volume load progression). This study adds to the overall literature showing marginal benefits at best to exercise variety, but the results are unlikely to hold for well-trained lifters. The short head of the hamstrings is not trained by deadlifts, so you logically cannot maximize hamstrings growth with just deadlifts. For the quads similarly, there may not be benefits to doing different types of squats or leg presses, but previous research shows there will likely be benefits to adding leg extensions, especially for the rectus femoris.

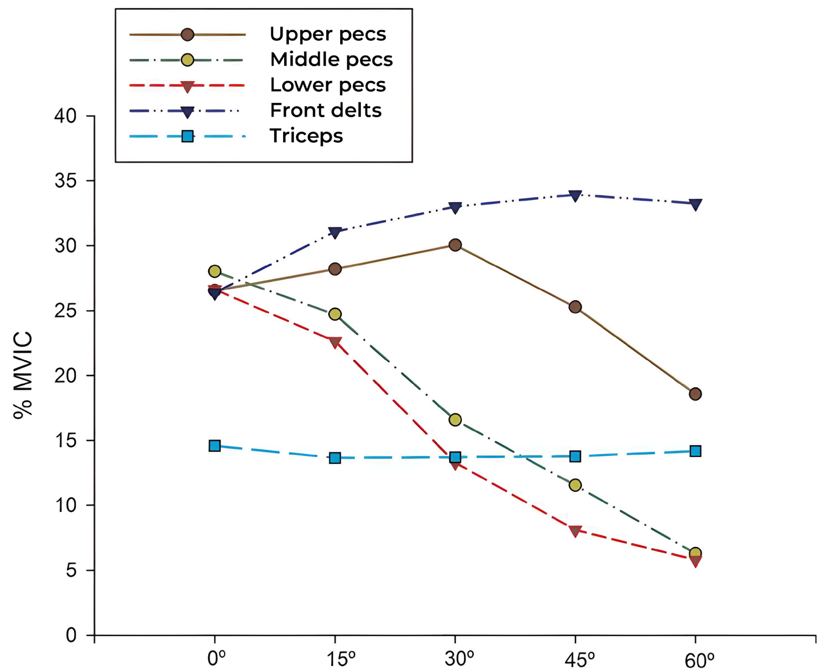
While targeted exercise variety may be beneficial, excess variety could be harmful. Baz-Valle et al. (2019) compared work-equated training programs consisting of either a fixed exercise selection or a random one in strength-trained men. The fixed exercise selection had around 2 exercises per muscle group: 1 compound and 1 isolation exercise. In the randomized exercise selection group, an app selected a new exercise each workout from a set of exercises stimulating the same musculature (e.g. pulldowns and pull-ups). The programs were otherwise identical in training structure. At the end of the program, there were no statistically significant differences between the groups in the improvements of body composition, quadriceps muscle thickness, and 1RM strength gains in the bench press and back squat. However, in absolute terms, the fixed exercise group made significantly greater gains: their BMI increased a bit more, while they were the only group whose body fat percentage went down, and their increases in 1RM bench press strength and muscle thickness of all 3 measured heads of the quads increased over 50% more(!) The considerably greater growth in all 3 heads of the quads is particularly striking. If we look at the exact training program, it makes sense, because the fixed exercise selection group was already hitting the quads with squats and leg extensions, which together stimulate all heads very well, and also did hip thrusts, leg presses and deadlifts. More exercise variety than this is evidently not needed. Excess exercise variety also makes progressive overload more difficult to implement. Every time you switch an exercise, you lose your progression trend and benchmark and if you do few sets of many different exercises, it's harder to progress than when you do more volume for fewer exercises. Overall, this study supports that having more than 2 targeted exercises per muscle group is not necessary and possibly detrimental for muscle growth. It's better to stick with an optimized, complementary set of exercises and perfect their technique with progressive overload than to implement a ton of exercise variety.

Chest exercise variety

Just like for the arms, many men feel the need to do many different pec exercises, but research does not clearly support this. A common recommendation is to include an incline press for the upper pecs and sometimes a decline press for the lower pecs, in addition to a flat/horizontal press. Biomechanically, you can emphasize the upper pecs with an incline, because the lower pecs don't flex the shoulder. So when the demand for (vertical) shoulder flexion becomes the limiting factor instead of horizontal flexion/adduction, the lower pecs will contribute less. When you incline the bench 90°

and you're doing a vertical overhead press, the lower pecs essentially no longer contribute at all. However, absolute upper pec activity should not increase compared to a horizontal press. The upper pecs are also horizontal shoulder flexors/adductors, so an exercise with horizontal flexion/adduction as the limiting factor should already require maximal tension from both the upper and lower pecs. Similarly, during a decline press, the upper pecs may contribute less as the force demand shifts from horizontal flexion/adduction to (vertical) shoulder adduction, but here it's less obvious that upper pec activity would be reduced, as the upper pecs are at least involved as shoulder flexors. An added downside of decline pressing is that you reduce the range of motion and stretch on the pecs in the bottom position, which may compromise growth in the entire pecs.

EMG research neatly supports the biomechanics. Multiple studies [2, 3] in both trained and untrained lifters have found that increasing a bench press's inclination significantly reduces lower pec activity but does not significantly increase upper pec activity.



Muscle activity during chest presses with various levels of bench inclination. Source

Ultrasound muscle swelling also corresponds with the biomechanics and EMG research. Incline bench pressing results in less post-workout swelling of the lower pecs but no greater swelling of the upper pecs than flat bench pressing.

Curiously, a 2020 Brazilian study by Chaves et al. found not only that there were no benefits to doing incline and flat presses in the same program, but incline bench presses were straight up superior to flat presses. The researchers had a group of physically active but not-currently-strength-trained men perform either flat bench presses, 44° incline bench presses or a 50/50 mix of the two. After 8 weeks, most differences between the groups did not reach statistical significance, but incline presses had the best outcomes on most measures. Upper pec muscle thickness (2nd intercostal) increased significantly more in the incline bench press group than the flat or combination groups. The trend was the same but non-significant for the middle pecs (3rd intercostal) and even the lower pecs (5th intercostal). The fact that incline presses resulted in over 33% more absolute growth in the lower pecs than flat presses suggests type I error, a fluke in which the incline group for some reason just had harder training or more genetically gifted individuals. A big limitation of the study was a 35% drop-out rate due to poor adherence, which is very high for a study that only required already exercising students to go to the gym 1 day per week for just 8 weeks. The strength gains were even more incredulous. The incline pressing group got better strength gains on the incline press than the combination group, in contrast to other research in which exercise variety was neutral or beneficial for strength gains. This finding also contrasted with the flat press strength gains. The flat press group did not have significantly better flat press strength gains than the combination group: their gains were non-significantly worse even. So it seems that the incline press group simply had better gains than the other groups, even for flat pressing strength. Isometric strength gains did not significantly differ between groups for either exercise, again in contrast to the expected movement-specificity we normally see for strength.

Considering the outlying findings compared to the rest of the literature and the very high drop-out rate, this study should be interpreted cautiously. However, it's at least in line with most research that exercise variety per se does not seem very beneficial.

It's worth noting that someone's arch and ribcage size during a bench press considerably affect their pressing trajectory. If you press with a substantial arch or you have a very big chest, a flat press often has you press at a less than 90° angle of shoulder flexion, essentially rendering it a decline press equivalent compared to someone pressing without an arch with a smaller ribcage. Biomechanically, you want a roughly 90° angle between your arms and chest when your arms are straight to stimulate all pec fibers well at the same time. If you press with an arch in your back, which is generally recommended for shoulder health and stability, a small incline may be beneficial to offset the 'declining' effect of the arch and achieve 90° shoulder flexion at the end of the press. So most people should arguably do most of their pressing with a ~15° incline, if available.

Practical application

Most research has found insignificant effects of exercise variety on muscle growth and strength development, but there is a trend for benefits related to regional differentiation. Therefore, exercise variety should be proportional to the amount of muscle functions a muscle has, regardless of whether the exercises are compound/isolation or single/multi-joint exercises. You should generally target every major muscle function of a muscle with at least one good exercise. More advanced trainees likely benefit more from exercise variety than beginners, because they should have more volume to allocate, they don't need to worry about technique development as much and it's more important to squeeze out muscle growth from every fiber to get appreciable results.

When incorporating multiple exercises for a muscle, select exercises that stress different muscle fibers or stress the muscles at different lengths.

You may prefer higher variety for psychological reasons or to avoid pattern overload injuries, but purely from a muscular gains standpoint, grinding away on 2-3 optimized exercises per muscle group is highly effective. For one, it minimizes muscle damage and soreness due to the repeated bout effect, thereby maximizing your recoverable volume. Second, it makes it easy to implement progressive overload consistently and accurately monitor your long-term progression. You'll need to switch out some exercises for some reason at some point anyway and that likely provides all the variety your muscles truly physiologically need.

Concretely, the following guidelines summarize how many exercises you want in a program for each major muscle group.

Pectoralis major

A single good horizontal press or fly can suffice, as the other pec muscle functions will already be worked with vertical presses and pulls.

Trapezius

Make sure each head (lower/middle/upper) is targeted. The middle and lower heads often get worked well with vertical pulls already. Deadlifts and overhead presses stimulate the upper head, but for maximum growth, adding a wide or overhead shrug is advisable.

Deltoids

Make sure each head (anterior/lateral/posterior) is targeted. The front head rarely ever needs isolation work, as it is stimulated by all horizontal and vertical presses, so it's more likely to be overworked than understimulated.

The lateral head needs a lateral raise or overhead press variant to emphasize shoulder abduction rather than flexion. During overhead pressing, you should keep your elbows out to the sides to emphasize the lateral delt instead of the front delt. A relatively wide grip makes this easier. Even better arguably, dumbbells activate the lateral delts more effectively than a barbell for most people. Standing also activates the sides of the shoulders better than sitting, as with sitting you often end up with a high-incline press. Plus, the bench restricts your natural scapular movement.

The posterior head is effectively trained with most pulling movements, but many of these don't achieve full ROM, so an added reverse fly or high row variant is advisable.

Latissimus dorsi

Due to the wide variation in muscle fiber angles, at least two different angle pulling exercises are recommended for the lats for non-novice trainees: one emphasizing shoulder extension and one emphasizing adduction, such as close-grip chin-ups and wide-grip pull-ups.

Biceps brachii

A single isolation exercise with the elbow kept at the side should suffice, assuming the program already has other pulling movements involving the biceps.

Triceps brachii

An isolation exercise for the long head is generally desirable. The lateral and medial head get sufficient stimulation from (horizontal) presses.

Quadriceps

While having little functional differentiation, a leg extension exercise is recommended in addition to a squatting movement to overload the quadriceps in full contraction and stimulate the rectus femoris.

Hamstrings

You need at least a knee flexion exercise, like a leg curl, and a hip extension exercise, like a Romanian deadlift, to stimulate all hamstring heads well along their full length.

Gluteus maximus (and medius)

Due to its large amount of muscle fibers with slight differences in angle, at least one bent-knee and one straight-leg hip extension exercise are recommended, such as hip thrusts and Romanian deadlifts. A hip abduction exercise is also advisable for maximum growth of the gluteus medius, though anti-adduction force during squats, especially unilateral squats, may suffice.

Calves

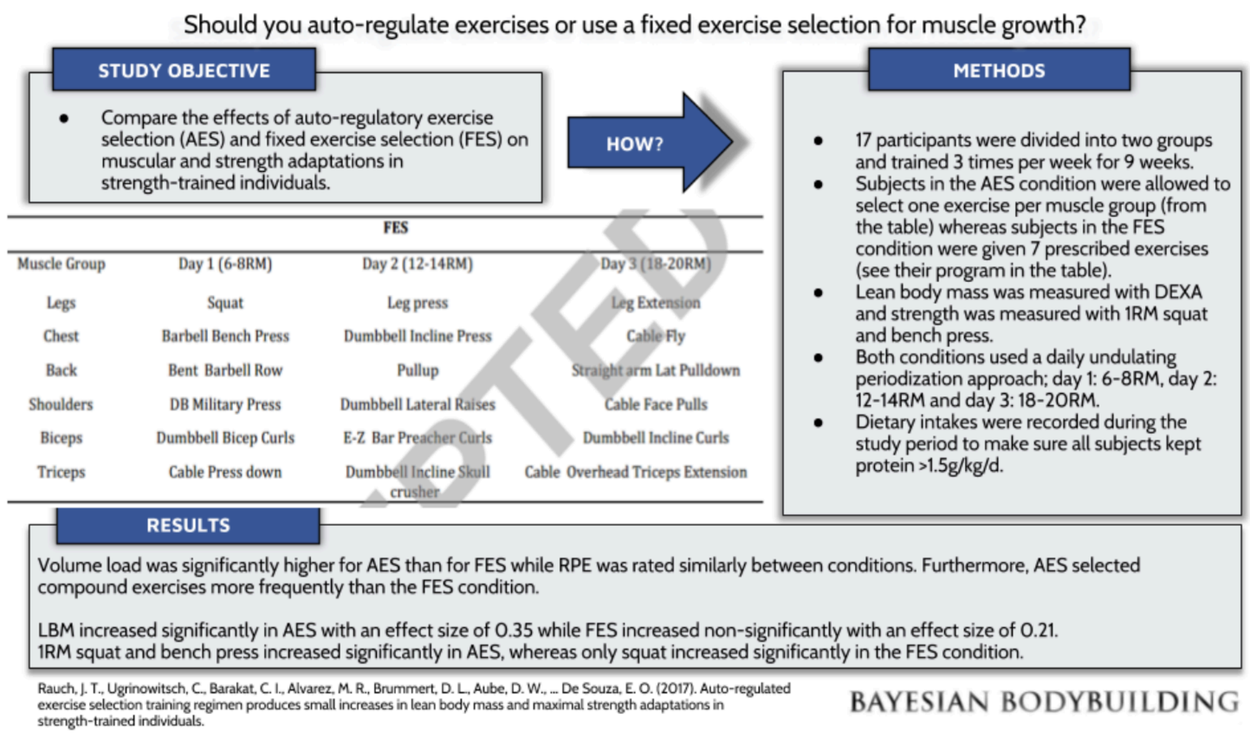
You need at least one straight-leg plantarflexion (calf raise) exercise in addition to one bent-knee plantarflexion (seated calf raise) exercise for the soleus.

Erector spinae

Squats and deadlifts often suffice in practice, but if injury risk is low and maximum growth is desired, a dedicated high-rep back extension exercise can be added.

Self-regulated exercise selection

Rather than prescribe fixed exercises to perform on certain days, it can also be viable for experienced trainees to self-select exercises from a list of similar exercises each training session. Rauch et al. (2020) found that this flexible training method improved strength development and muscle growth compared to a fixed exercise selection: see the infographic below.



The flexible exercise selection group in this case picked more compound exercises and completed a greater total training volume, which is the likely reason for their better results. The better strength gains in this case were also likely because they simply performed the tested exercises more frequently. As such, it's unlikely that in a program with an optimized training volume and exercise selection, increased flexibility is physiologically beneficial. While it could be argued to increase training adherence, this may also backfire in that certain individuals will stick to the easier exercises and, for example, rarely do unilateral work or always choose leg presses over squats.

In conclusion, flexible exercise selection can be viable and may enhance training effort in certain individuals, provided the trainees are experienced enough to know what they're doing, motivated enough not to always take the easiest way out and that the selection of available exercises for a given day is similar enough not to disrupt the planned structure of the training program.

How to count training volume

We've covered how to select between different exercises for the same muscle group and how to determine how much variety is needed. The next question is how many sets of each exercise to do. For example, if your optimal volume for the hamstrings is 10 sets per week, do 5 sets of leg curls and 5 sets of squats suffice? Probably not, since squats are a poor hamstring exercise, yet 5 sets of Romanian deadlifts and 5 sets of leg curls would definitely suffice. So when does an exercise count towards the volume of a muscle group?

To reach your target set volume for a muscle, you have to assign training volumes to exercises to denote which muscles are effectively trained by 1 work set of that exercise. You can generally ignore warm-up sets. For example, a set of Bayesian curls should arguably count as 1 set for the biceps and nothing else. An effective starting point is to count the agonists (also called 'targets') and synergists of each exercise as effective training volume and to ignore the other involved muscles. Most exercise science studies employ this method, for lack of a better one that's easy to standardize. The ExRx exercise directory is a good resource for this purpose. If you want to keep things simple, you may opt to just use this rule, but if you want to be precise – and we expect our alumni to be able to do this – you should assign fractional volumes to exercises.

For example, you learned that dumbbell rows stimulate only approximately half the muscle growth in the biceps as dumbbell biceps curls do. Thus, 6 sets of dumbbell rows should only count as 3 sets of effective biceps work. In other words, rows count only 50% for the biceps. The exact percentages you assign to exercises should depend on how well the exercise scores on the exercise selection criteria you learned, in particular The Limit Factor.

Another practical criterion you can use to determine how much an exercise counts towards certain muscle groups is how much neuromuscular fatigue it causes in those muscle groups. Neuromuscular fatigue can be assessed by performance loss during isolation work of that muscle group and *somewhat* by subjective indicators like the sensation of fatigue, the pump, soreness and the burn. Sometimes these factors are obvious. For example, the erector spinae should almost indisputably be counted as effectively trained during traditional deadlifts even though they're 'only stabilizers'. In contrast, the quads may be a synergist during deadlifts, but they're trained through only a limited range of motion without much muscle stretch and knee extension demands may not be maximal, especially not for hip-dominant lifters. So it's reasonable to count the quads only 50% during deadlifts.

The exact percentage a muscle contributes to an exercise depends on its exact execution (grip width, ROM, etc.) and also to an extent on an individual's structure (weak vs. strong muscle groups, lever arms, etc.), so it's impossible to give set numbers on how much each exercise targets each muscle group. However, you don't have to overcomplicate things. Don't bother with crazy fractionals like counting 84.9% of the volume of an exercise. The science isn't there yet to be that precise. A practical rule of thumb is to count exercises as 50%, 75% or 100% effective training volume for its involved muscles. You can probably round down anything below 40% stimulus to 0%. Muscles require a minimum tension that seems to be equivalent to around 40-60% of maximum voluntary isometric contraction strength to get stronger.

To be precise, you should optimize the training volumes of all the following muscle groups and their subdivisions separately in a program. If you understood the module on functional anatomy, this categorization should largely speak for itself, as these are the muscular compartments that are functionally distinguishable. You don't have to distinguish between muscles or heads with the same functions, as you'll generally train those together, so their training volumes will often be identical.

- The calves
    - Gastrocnemius
    - Soleus
- The quadriceps
    - Rectus femoris
    - Vasti
- Hamstrings
    - Short head of the biceps femoris
    - The long head and the semis
- Glutes
    - Gluteus maximus
    - Gluteus medius
- Rectus abdominis
- Erector spinae
- Lats
- Pecs
    - Upper pecs
    - Lower pecs
- Traps
    - Upper traps
    - Middle traps
    - Lower traps
- Delts
    - Anterior delts
    - Lateral delts
    - Posterior delts

- The elbow flexors (biceps)
- Triceps
  - Long head of the triceps
  - Lateral and medial heads of the triceps

As a guideline, we've created an overview of how much each muscle group is trained by the most useful and popular exercise groups. The exact contribution of each muscle to each exercise will depend on the specific exercise technique employed and the individual's body structure.

➢ **How much does each exercise train each muscle group?**

For more details regarding counting the volume of the core, forearms and neck, see the functional anatomy module.

Closing words

By now, you've hopefully absorbed enough to start making more deliberate and intelligent exercise choices. As with the optimizing of all training parameters, exercise selection should be a systematic process based on objective criteria.

It's tempting to do the convenient and comfortable exercises, or the ones that make you feel like a badass, but those feelings are short-lived. We know that the "fun stuff" isn't always the useful stuff, and vice versa. The physique you build from smart training is your walking billboard to your dedication to the iron.