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ADVANCED TRAINING TECHNIQUES

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Many people intuitively think advanced techniques are only for advanced trainees: beginners should ‘stick with the basics.’ However, we generally call a technique ‘advanced’ simply because it’s unconventional compared to straight sets, the traditional way of performing sets with the same weight and rest interval every set. There’s no physiological reason this makes the technique better for more advanced trainees. In this week of the course, we’ll analyze the physiological effects of all advanced training techniques you should be familiar with as a PT. Based on their effects, we’ll advise who can benefit from the technique.

➢Lecture [optional]

Advanced training techniques

Forced reps

What are they?

Continuing a set after reaching muscular failure by having a partner or machine help with subsequent reps. Example: 120 lb × 8, partner starts helping for 4 forced reps, rest, repeat.

What do they achieve compared to straight sets?

Since you're training post-failure, you would expect metabolic stress to increase exponentially and neural fatigue to increase linearly with volume. Technique necessarily suffers greatly and muscle damage should increase correspondingly.

Indeed, neuromuscular fatigue is significantly greater after forced reps than after the same volume of straight sets. However, muscle damage and metabolic stress do not appear to be higher given the same training volume. This suggests that forced repetitions induce high neuromuscular, possibly central, fatigue and are thereby a serious risk factor for overtraining, even more so than training to failure probably.

As if that's not bad enough, muscle activity decreases post-failure as many motor units are already exhausted.

As a result, the ratio of muscle stimulation to muscle fatigue is very poor for forced reps. For strength in particular, it's debatable if there's any value in the forced reps. For muscle growth, there should be, but it's most likely no greater stimulation than if you performed an equal amount of reps yourself in a later set. The mechanical tension achieved by the forced reps is largely identical to a drop set with less weight, as you have to subtract the assistance from the spotter to derive your own force production and thereby mechanical tension. The only benefits are, assuming your spotter is good, that you achieve accommodating resistance and eccentric overloading during the forced reps.

In support of the inferior training quality of forced repetitions, Drinkwater et al. (2007) found that 3 groups of athletes training the bench press with the same repetition volume but a different amount of forced reps gained the same amount of muscle (chest circumference and estimated muscle mass), bench press strength and power. In one group the forced repetitions resulted in 30% greater concentric time under tension and 40% greater total work, but evidently this did not translate into better training adaptations.

Who benefits from them?

No one really. It's a high-risk, low-reward technique, especially for strength development. Even for muscle growth, you generally have options that achieve a far better stimulation-fatigue ratio.

Drop sets

What are they?

Stripping off weight as soon as you hit failure and then continuing the set, possibly several times, e.g. 120 lb × 8, 90 × 8, 60 × 9, 30 × 14, rest, repeat.

What do they achieve compared to straight sets?

You accumulate a lot of muscle tension per set. However, metabolic stress goes through the roof because of the prolonged muscle tension. Neuromuscular fatigue is also very high because you're hitting muscular failure repeatedly. Muscle activity decreases once you train past the point of failure as some motor units will be exhausted and don't have time to recover. This can greatly extend recovery time. Technique also tends to suffer considerably due to the high acute neuromuscular fatigue combined with relatively high cardiorespiratory demands. As such, you would expect drop sets to have good time-efficiency but a poor stimulus-to-fatigue ratio. That indeed seems to be the case.

- Raeder et al. (2016) found that drop sets of 6 reps of Smith machine squats with 15% load reductions (85% → 70% → 55% → 40% 1RM) induce just as much neuromuscular fatigue, metabolic stress and muscle damage as 4 straight set of 6 with the initial weight (3 min. rest interval), even when failure isn't reached each set. So each drop set produced as much fatigue as each straight set despite the drop sets producing far less total work.
- A study by Costa et al. (2021) found greater neuromuscular fatigue after 2 drop sets of 10 reps at 12RM followed by 5 reps at 15RM with 6-minute rest intervals than after 3 straight sets of 10 reps at 12RM with 3-minute rest intervals. The drop set also induced more neuromuscular fatigue than a descending pyramid of 3 sets of 10 at 10RM, 12RM and 15RM, respectively. So there was greater

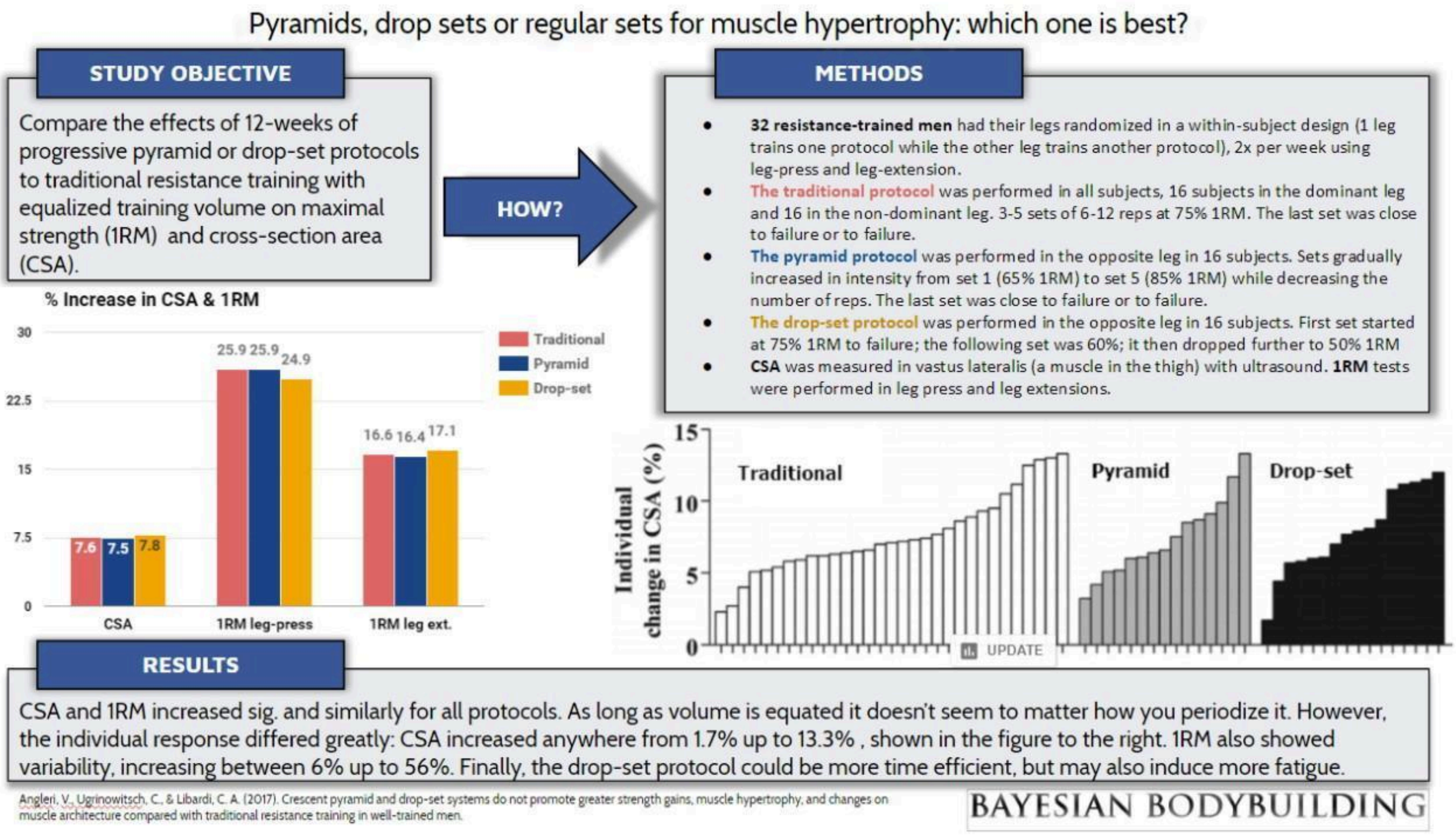
neuromuscular fatigue after the drop sets despite a lower total work volume and similar time investment. When you go to failure, drop sets likely perform even worse.

- Keogh et al. (1999) compared a traditional 6RM set in the bench press with a special type of drop set where the weight was reduced each repetition: 95%, 90%, 85%, 82.5% to 80% of 1RM. This resulted in several differences in the acute physiological response to the set. Unsurprisingly, force production was higher during the first rep but lower during the lowest rep in the drop set. Power was lower in the drop set, especially after the halfway point. Muscle activity in the pecs was similar across all reps and the only difference in the triceps was that muscle activity was higher during the first reps in the drop set. Metabolic stress, measured by lactate, was similar between the traditional set and the drop set. As such, even when you're starting with a higher weight, there aren't any clear mechanical, physiological or neuromuscular advantages to using drop sets compared to traditional sets.
- Enes et al. (2023) found that a given work volume of drop sets induces more psychological distress and requires greater perceived effort than that volume of traditional sets or a descending pyramid.

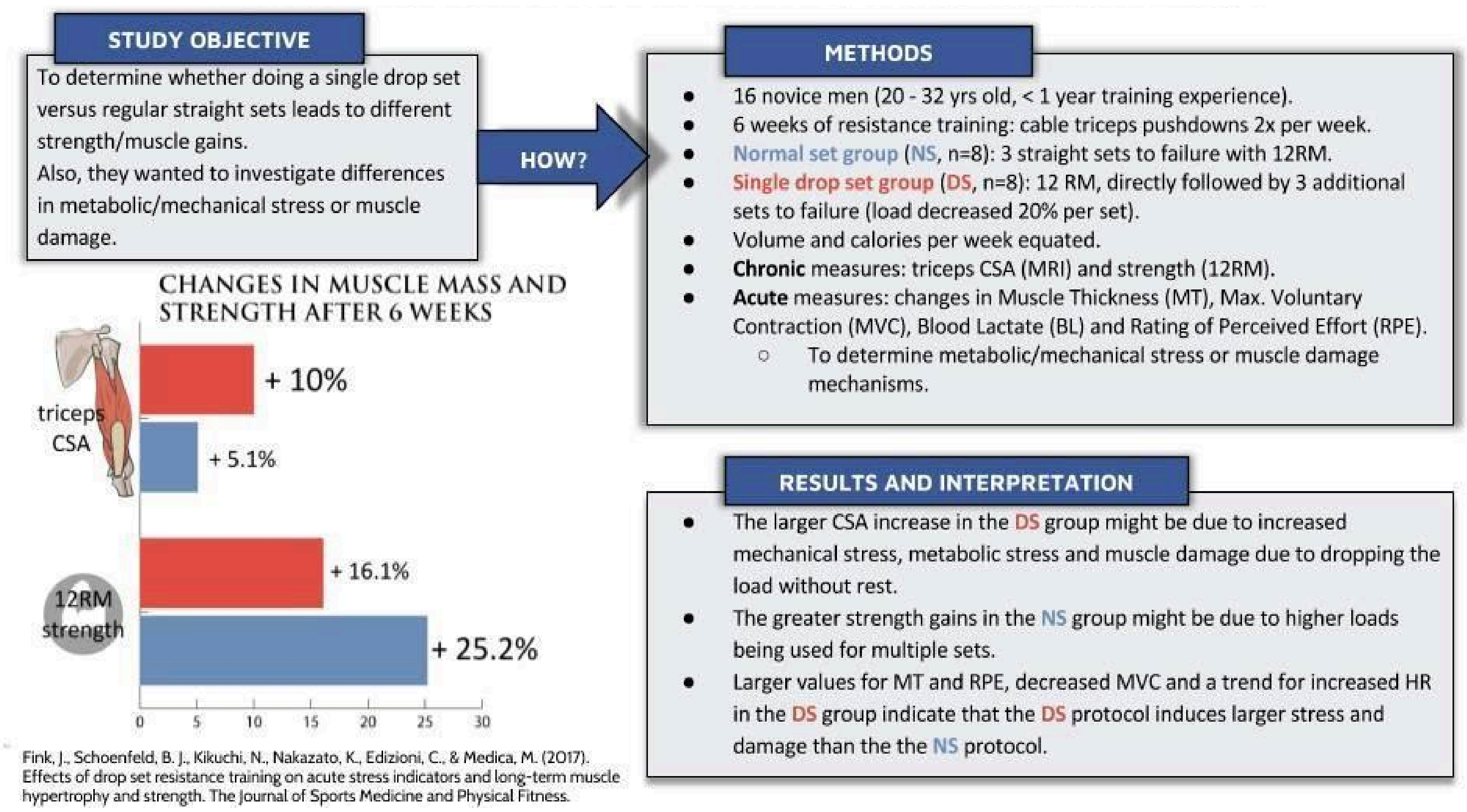
The most important question, of course, is: is the extra fatigue from drop sets worth it for the extra muscle hypertrophy or strength development you get?

A 2022 meta-analysis and another 2023 meta-analysis of the same literature concluded that on average in the literature, drop sets and traditional sets result in similar strength development and muscle growth. Their analyses did not include the entire literature and did not consider the effect of training volume, so for those interested, we'll go into more detail on the specific studies before summarizing the findings.

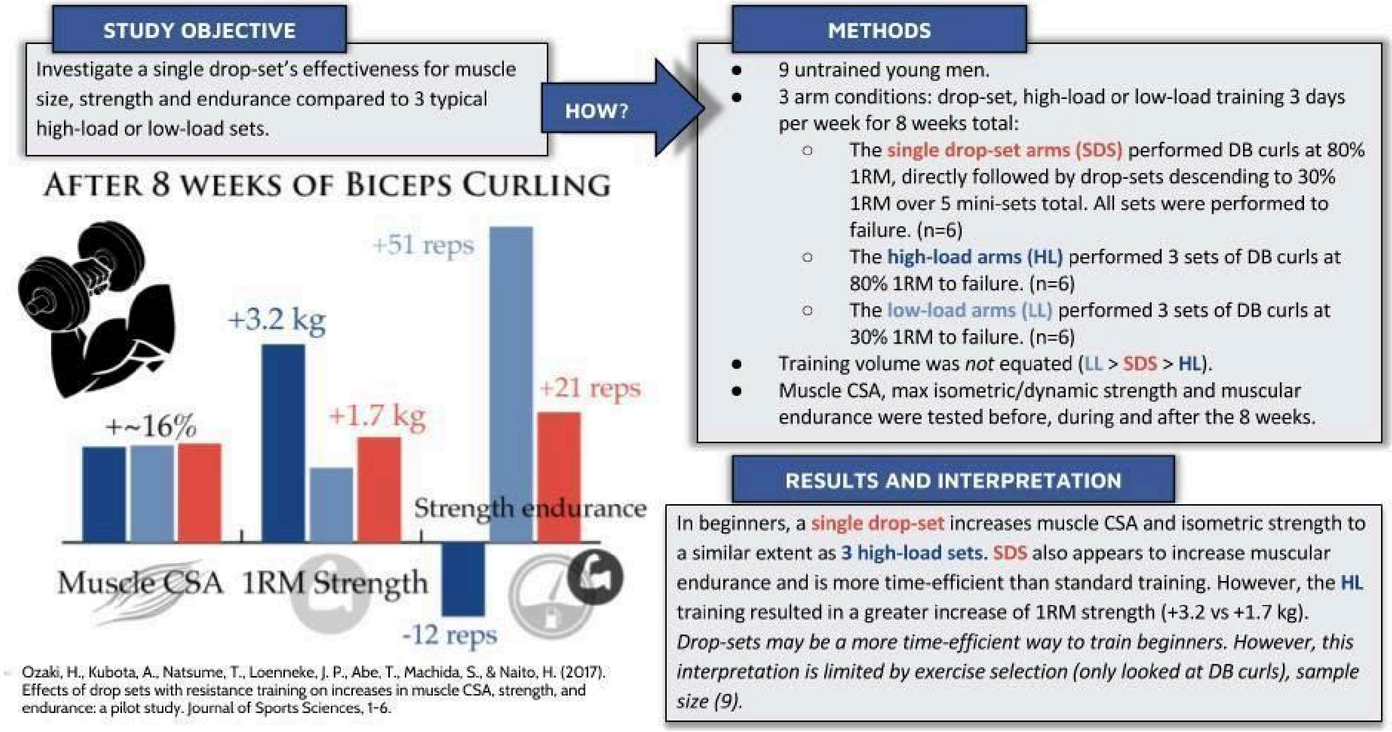
- Fisher et al. (2016), not included in the meta-analyses, found that adding 1 or 2 drop sets to a single set to failure did not improve strength-endurance or muscle growth despite an up to ~3 times greater training volume(!) A drop set group starting with a higher intensity weight performed just as badly as the group simply adding a drop set to the control group's training protocol. The participants were strength-trained. Fisher's research group is known to push their participants to true momentary muscle failure, so this study suggests there are strong diminishing returns to adding drop sets beyond the point of momentary muscle failure.
- Giessing et al. (2016), not included in the meta-analyses, studied a double 10% drop set with a 10RM (10 reps to failure → ~3 reps more with 10% less weight → ~3 reps more with 10% less weight again) and compared it to 3 sets at 10RM with 'self-determined repetition maximum'. The drop set group showed a trend for more muscle growth and strength development across the board, despite performing far fewer reps. However, given that the 3-set group tended to manage 30 reps with their supposed 10RM, they probably weren't training very hard and not implementing progressive overload rigorously. With only 2 workouts per week, recovery was not an issue. As such, this study primarily just shows that training harder results in better gains. Still, it's a good illustration that training volume has a limited ability to compensate for training effort per set. 1 Hard, double drop set can be more effective than 3 submaximal sets.
- Angleri et al. (2017), illustrated below, found that drop sets were just as effective as straight sets at developing strength and muscle growth when total training volume was equated. This was a relatively ideal scenario for the use of drop sets, since total training volume and frequency were very low, so recovery was not an issue, and the training was entirely machine based, so technique breakdown was also not an issue.



- Fink et al. (2017) found a trend for greater muscle growth with a triple drop set compared to 3 sets to failure with the same total volume, but the difference wasn't close to statistically significant ($p > 0.57$) and strength development also didn't differ between groups. The only significant findings were that the drop set group induced greater neuromuscular fatigue, as measured by maximum voluntary contraction (MVC), and was more effortful, as measured by ratings of perceived exertion (RPE). Thus, strictly speaking this study found that drop sets are not significantly more effective for your gains than straight sets on a volume-equated basis, but they are significantly more fatiguing.



- Ozaki et al. (2017), illustrated below, found no benefits of doing **5** drop sets after a single set of dumbbell curls at 80% compared to doing 2 more regular sets or doing 3 sets of curls at 30% of 1RM. Training volume was not equated: the drop set group had a higher training volume than the other 2 groups. The 80% × 3 straight sets group achieved greater strength development than the drop sets group. This study suggests drop sets have a poor stimulus-to-fatigue ratio and are suboptimal for strength development.



- [Varović et al. (2021)](#) compared double 10-20% drop sets starting at 5RM to straight sets at 15RM, all taken to failure, in a within-subject design with novice trainees. The drop set leg did 3-7 leg extensions to failure 3 times in a row each set, whereas the straight set leg performed just 1 straight set of 13-17 leg extensions to failure. The drop set legs logically ended up with a significantly higher total training tonnage. Over the course of the 8-week training program, strength gains, measured as peak and average isokinetic torque, were nearly identical between the legs. Given that the drop set group started with a much higher training intensity and accumulated a higher training volume tonnage, the lack of any positive effect on strength suggests drop sets are suboptimal for strength development. Muscle thickness gains did not significantly differ in the vastus lateralis at any of the 3 measured sites, although in the rectus femoris there was a trend for greater muscle growth in the drop set leg (significant time*group interaction but no significant group effect).

- Enes et al. (2021) found no benefits of work-equated drop sets and straight sets. 3 Drop sets from 75% to 55% of 1RM stimulated similar muscle growth and strength development as 4 submaximal straight sets at 70% of 1RM.
- A similar follow-up study by Enes et al. (2022) again found no significant difference in strength development between volume-equated drop sets and traditional sets.
- Fasihiyan et al. (2023) compared 2 drop set protocols to traditional strength training in trained men on an 8-week program of leg presses and bench presses 3x/wk. The traditional group did 4 sets of 10 with 75% of 1RM and a 1.5 min. rest interval. The single drop set group did 2 drop sets with 80% of 1RM to failure followed by an immediate drop in weight to 45% and going to failure again, followed by 1.5 min rest before the next set. The multi-drop set group did 1 drop set to failure, starting at 80% with drop sets at 65, 50 and 35% of 1RM. There were no significant differences in fat loss, skeletal muscle growth per InBody, isometric leg extension force or bench press strength gains; however, the 2 drop set groups saw better gains in leg press strength, likely due to training with a higher training intensity and possibly due to simply training harder.

All evidence considered, the benefits of drop sets are less consistent than those of additional straight sets, especially for strength development. At best, a given work volume of drop sets result in as much muscle growth and strength development as straight sets in less time, but this comes at the cost of greater neuromuscular fatigue. At worst, drop sets induce far greater neuromuscular fatigue for very little reward.

Who benefits from them?

Since the neuromuscular fatigue-to-muscle stimulation ratio is poor, drop sets offer no advantage over straight sets as a default training method, especially not when the goal is maximum strength development.

The only advantage of drop sets is time-efficiency: for individuals with a low training volume who are short on time, drop sets may offer a way to induce a high training stress in a short amount of time, but even then, training to failure may not be ideal. Myo-reps, discussed later in this module, may offer a superior time-efficiency and stimulus-to-fatigue ratio.

A further restriction is that since it's incredibly challenging to maintain good technique during drop sets, you can only safely perform drop sets with simple (isolation) exercises and machine work.

Reverse pyramiding

What is it?

After taking a set close to failure, the weight is reduced on subsequent sets, but unlike drop sets, there is a normal inter-set rest interval. The reps of subsequent sets should be higher than the reps of the first set for it to be a true reverse pyramid, e.g. 120 kg × 8, rest, 95 kg × 10, rest, 75 kg × 12.

What does it achieve compared to straight sets?

Reverse pyramiding has effects in between that of straight sets and drop sets. As such, it suffers from some of the same problems as drop sets. Reverse pyramiding induces greater neuromuscular fatigue and metabolic stress without resulting in superior strength development or muscle growth [3, 4, 5]. The increased stress is likely the result of the greater total amount of work done by using reverse pyramids and the use of a lower average training intensity. We know that lower-intensity training generally results in as much muscle growth as higher-intensity training, but it induces more neuromuscular fatigue due to the greater total work output.

Descending pyramids have had mixed effects on perceived training effort. Enes et al. (2023) found that a given work volume of descending pyramids required greater perceived training efforts and resulted in more psychological distress than the same volume in the form of straight sets. In contrast, Lima et al. (2018) found that descending pyramids may decrease perceived training effort in a study on biceps curls with either 0%, 5% or 10% load reductions across sets. However, this study did not find a significant increase in training volume load as a result of the reverse pyramiding and the subjects trained to volitional failure, so it may be that the reverse pyramid group simply didn't train as hard. Lesser motivated individuals may be content with hitting the same number of reps each set despite lowering the weight, rather than trying to maximize the number of reps each set. That said, the participants in this study achieved the same increase in 10RM strength and muscle growth, so any reduced training effort didn't seem to be detrimental. In 2 studies by Hutchinson et al. (2020, 2023), practically untrained participants also reported higher enjoyability of exercise with reverse pyramids (decreasing intensity) than regular pyramids (increasing intensity). Psychologically, it's plausible that a decreasing intensity of exercise during the workout makes the workout feel easier: your first efforts make the rest of the workout feel comparatively easy (range-frequency theory). However, total training loads were identical and very submaximal in both groups, so it's questionable if these results would hold in serious trainees training closer to failure, and neither study compared reverse pyramids to straight sets.

Who benefits from it?

Injury-prone exercises and trainees, like the elderly, often benefit from the use of lower average training intensities without compromising muscle growth.

People short on time, especially novices where exercise intensity isn't that important yet, may also find reverse pyramids time-efficient because the use of lower intensities may reduce rest period requirements.

More advanced bodybuilding trainees often benefit from reverse pyramiding their high intensity work, as it is simply impractical to get enough total work done with straight sets above ~90% of 1RM. As a general guideline, it's good to reverse pyramid all sets with 4 or fewer reps.

In general, however, reverse pyramiding does not seem to increase muscle growth or strength development compared to straight sets and it induces greater neuromuscular fatigue. As such, it is probably suboptimal as a default technique during high-volume training.

Crescent pyramids

Progressive AKA crescent AKA ascending pyramids refer to sets in which you increase the weight every set and typically reduce the number of reps per set, for example: 70x12, 80x7, 90x2. As you learned in the topic on exercise ordering, you should generally perform higher-intensity work before lower-intensity work to maximize total work output and potentially benefit from post-activation performance enhancement (PAPE; discussed later on). A study by Mang et al. (2024) found that ascending and descending pyramids don't result in significantly different total volume loads across sets when matched for relative intensity and proximity to failure; however, the descending pyramids achieved that number of reps with significantly lower perceived exertion.

Furthermore, studies by Hutchinson et al. (2020, 2023) found that people reported higher enjoyability of exercise with reverse pyramids (decreasing intensity) than regular pyramids (increasing intensity). Since crescent pyramids generally only offer downsides without any advantages, reverse pyramids are almost always preferable.

Rest-pause training

What is it?

Taking a set to failure, taking a few breaths or resting for a short period, going to failure again, taking a few breaths again, going to failure again, possibly repeating this sequence two or more times. E.g. 120 kg × 12, take a few deep breaths, × 6, take a few deep breaths, × 3, rest, repeat.

What does it achieve compared to straight sets?

While it has a cool name, rest-pause training is objectively simply a combination of going to failure and using very short rest periods. The difference between intra- and inter-set rest is purely semantic in the case of rest-pause training. As such, the effects of rest-pause training can be expected to be similar to those of short rest intervals and training to failure. Considering neither is generally optimal, there's not much promise for rest-pause training.

Let's see what the research says about how rest-pause training performs.

Enes et al. (2021) compared training with 4 straight sets of 12 reps at 70% of 1RM to 3 rest-pause sets of 10 + 6 reps per set at 75% of 1RM with 20 seconds intra-set rest. The participants were trained men. Despite the rest-pause group performing the same number of total reps with a 5% higher training intensity, they did not gain more muscle over the course of their 8-week training programs. They did gain more strength, which was to be expected, as training with a higher training intensity generally improves strength development. A similar study by Enes et al. (2022) found there was no significant difference in strength development between the traditional and volume-equated rest-pause groups.

Fisher et al. (2016) compared 5 sets of 5 reps leg extensions to a form of rest-pause training: reaching 25 reps in as few sets as possible while reaching failure. The men performed one training method with one leg and the other method with the other leg. Since the rest-pause group performed the same volume in less time, they trained harder, and they reported significantly higher mean and peak ratings of perceived exertion. Despite training harder, the rest-pause group did not gain significantly more strength. There was a trend in effect sizes for greater strength development in the rest-pause group, but the lack of significant differences in a within-subject design does not make a compelling case for the rest-pause method.

Prestes et al. (2017) compared 3 sets of 6 at 80% to a rest-pause set at 80% to failure, followed by as many additional sets with 20 second rest periods as needed to reach 18 reps. 1RM strength gains were the same for both groups, as was the increase in muscle thickness in the chest and arms. However, the rest-pause group had a greater increase in thigh muscle thickness and developed more strength-endurance on the leg press. This study again shows rest-pause is a time-effective training method, but the greater gains were likely simply due to training much harder, stuffing the same volume into less time along with training to failure.

Moro et al. (2024) found that rest-pause sets didn’t increase anabolic signaling (e.g. IGF-1/AKT/mTOR) compared to traditional sets. A group of novice level strength-trained men did leg extensions with a different leg on different occasions.

- The traditional workout was 3 sets of 15 repetitions at 60% 1RM with 1.25 mins rest between sets.
- The rest-pause workout was 3 sets at 80% of 1RM followed each by 3 mini-sets of 1-2 reps with 20 seconds rest in between. They rested 2.5 mins in between the 3 rest-paused sets and they trained to failure in each part of each rest-pause set, leading to total 12-15 reps in most rest-pause sets.

The 2 workouts resulted in similar anabolic signaling with "similar protein synthesis activation and possibly translating in similar muscle growth responses."

Lastly, hardly worth mentioning, [Marshall et al. (2012)]() found that a rest-pause protocol in the squat elicited higher levels of muscle activity without greater neuromuscular fatigue than 2 control workouts. However, the control workouts weren't very useful as reference points. All exercise protocols involved 20 squat repetitions, prescribed at 80% of 1RM. Protocol A consisted of 5 sets of 4 repetitions with 3-minute inter-set rest intervals; protocol B was 5 sets of 4 repetitions with 20 seconds of inter-set rest and the rest-pause method was an initial set to failure with subsequent sets performed with a 20 second inter-set rest interval. Neither control protocol thus had the participants train remotely close to failure and it was more strength-endurance work than traditional strength training. Since these were advanced strength trainees with an average squat close to 400 pounds (179 kg), it's likely that the rest-pause workout resulted in higher levels of muscle activity simply because it had the trainees approach failure. As such, this study mostly supports the need to train close to failure, but it says nothing directly about the efficacy of rest-pause training compared to traditional straight sets.

All in all, the literature shows a given training volume of rest-pause training tends to be more effective than that volume of straight sets, but this is likely simply due to training harder. Rest-pause training is time-efficient, but it comes at the cost of significantly greater fatigue. This makes rest-pause training unsuitable as a default training method in high-volume programs. To illustrate the difficulty of reaching a high training volume with rest-pause training, imagine training each muscle 3 times per week with 2 exercises for 3 sets each at an average of 80% of 1RM, taken 1 rep to failure, that's a very realistic training volume (18 sets per week) resulting in ~36 reps per session. To achieve that with rest-pause reps, your reps will probably go like 8 + 2 + 1 in the first set. Then you've already hit failure 3 times and you haven't even completed a third of your training volume for that muscle. Your next set is likely to go something like 5 + 1. Then you're still not halfway. By the time you've achieved your desired training volume, you'll have hit failure more often than Justin Bieber's career. Even if you manage it, it's very unlikely you can recover from that with a high training volume.

Who benefits from it?

As a default training technique, rest-pause training is best avoided because repeatedly hitting failure induces high neuromuscular fatigue. Rest-pausing can be time-efficient, but as we'll discuss later, there are better options.

Myo-reps

What are they?

Myo-reps, as per the creator Borge Fagerli's definition, have changed over the years. The most recently publicized method is as follows:

"After warm ups and a few minutes of rest, unrack the chosen load and do reps until you hit the failure point (leaving one rep in the tank can be a good idea). This is the 'activation set'. Re-rack the weight, count three to five deep breaths, unrack, and do a set of three to five reps. (That's about a quarter of your first set. For example, complete five reps when you did 20 reps on the first set.) Now re-rack, rest, and repeat until you hit another failure point. This is the autoregulation aspect. On some days and on some exercises, you may only get something like 20 + 5 + 4 reps, but on other days/exercises, you may get 20 + 5 + 5 + 5 + 5 + 5 (or more). The point is to achieve high muscle fiber activation on the activation set and extend this effect by balancing on the verge of fatigue to perform more "effective" reps, taking advantage of all the hypertrophic signaling effects of occlusion training."

What do they achieve compared to straight sets?

When the first set is taken to failure, myo-reps are comparable to rest-pause training. However, taking the first but not the later sets to failure in combination with a low intensity makes myo-reps much more useful, since this allows for the accumulation of a high training volume. As such, myo-reps should be very time-efficient.

The low weights that are generally used also make myo-reps very joint friendly.

Downsides of myo-reps are that the short rest and low intensity make it a poor method for strength development. The inevitable technique breakdown and major cardiorespiratory component also make myo-reps unsuitable for technical exercises, like the powerlifts.

Unfortunately, there is no direct research on myo-reps to test if these theoretical predictions pan out. A 2021 meta-analysis found that no alternative set structure with intra-set rest periods improves muscle growth or strength development compared to straight sets with only inter-set rest when total work (sets × reps) is equated between groups, but myo-reps might be an exception to this due to more of the reps done being 'effective reps'.

Who benefits from them?

Without direct research establishing their effectiveness, myo-reps are not recommended as a default training strategy. However, the theory for their use is sound and certain populations could benefit from myo-reps.

Myo-reps are particularly suitable for injury prone exercises and trainees, like the elderly. However, KAATSU training, discussed below, has much more scientific support and seems to have similar effects as myo-reps, so it's arguably preferable in most scenarios.

The high cardiorespiratory requirements of myo-reps restrict their use to mostly simple/untechnical (isolation) exercises.

For strength development, myo-reps are not typically recommended because of the low rest periods, high cardiorespiratory demands and often resultingly low training intensities.

Cluster sets

What are they?

The use of intra-set rest periods, i.e. resting in between every rep or every 'cluster' of reps instead of only in between sets (inter-set). E.g. 120 lb × 2 reps, rest 5 seconds, 120 × 2, rest 5 seconds, 120 × 2, rest 5 minutes, repeat.

What do they achieve compared to straight sets?

When you cluster a set, you are trading metabolic stress and thereby often muscle activity for increased power and work output [2, 3, 4, 5, 6, 7].

For muscle growth, these effects are generally neutral, especially if you don't use them to increase training volume: cluster sets generally do not affect muscle anabolic signaling or myofibrillar protein synthesis [2] and the available literature shows an average null effect of cluster sets on muscle growth compared to traditional sets [2, 3].

Cluster sets' effects are specifically suited for strength and power training. The lower metabolic stress makes it easier to maintain good technique and a higher velocity of movement throughout the set. Some research indeed finds that cluster sets are superior to straight sets to develop strength and especially power [2] without compromising muscle hypertrophy. However, most research found no difference between cluster and straight sets for strength development, especially when the regular training group was already lifting explosively.

To make cluster sets most effective, you must take advantage of the greater potential work or power output. If you perform the exact same training volume with the same intensity in the same amount of time, cluster sets generally do not increase strength development compared to straight sets. They may still improve athletic power movements [2, 3, 4], but you may also gain less muscle [2], as you're simply not training as hard.

To take advantage of the greater potential power output, you should perform cluster sets with an explosive lifting tempo. Giessing et al. (2016) studied a full-body training program consisting of a single set for each exercise in strength-trained individuals. One group performed all exercises as a traditional set to failure at 80% of 1RM (~9 reps per set). The other group performed all exercises in cluster fashion at 90% of 1RM with ~5-20 seconds of rest between each repetition (~18 reps per set). So the cluster group used a 10% higher intensity and performed double the training volume compared to the traditional training group. Despite their lower intensity and volume, the traditional training group experienced considerably better body recomposition and strength development than the cluster group with ~50% larger effect sizes. The inferiority of cluster training was likely because all subjects were required to use a very slow repetition tempo of ~10 seconds per rep. This may have cancelled out any positive benefits in terms of power and force production from the cluster sets, especially when going all the way up to 18 reps per set.

Cluster sets should be done with a high intensity, as the combination of a low intensity with intra-set rest may not cause sufficient neuromuscular fatigue to reach optimal levels of muscle activity and muscle tension. A study comparing 120 seconds of isometric work done either as 40 clustered contractions or 4 long, continuous contractions found that the continuous contraction group gained more strength and size, likely due to the greater metabolic stress they experienced. Similarly, a study comparing 3-5 sets of 10 reps performed either with or without a 30 second break halfway through the set found that the traditional protocol resulted in greater strength and size gains.

Plus, when sets of 1-3 reps are employed and the sets aren't taken to failure, as most strength and power athletes do, the difference between cluster sets and straight sets becomes marginal.

Who benefits from them?

- Power athletes.
- Powerlifters. The deadlift in particular should almost always be trained using cluster sets, as you should train to lift from a dead stop anyway. You should generally stand up in between every rep.
- Cluster sets can also be a good way to learn proper technique in beginners without the interference of high metabolic stress.

You should generally perform cluster sets with an intensity of at least 80% of 1RM. The intra-cluster rest period should be kept short enough that every cluster comes within 5 reps of concentric failure, as those reps should experience maximal motor unit recruitment.

Machines can make cluster sets much easier to implement. For example, you can use cluster sets for high-intensity unilateral leg curls performed in an alternating fashion, i.e. one leg rests while the other leg is performing a cluster.

A practical issue with cluster sets for barbell exercises is the constant unracking and reracking of the bar. Since you'll often want to employ them for the powerlifts, most trainees find they need the constant presence of a spotter for the bench press. Squats are an annoyance too, but within reason, you can 'rest' in the top position instead of racking the bar every cluster ('breathing squats'). Deadlifts and the Olympic lifts, on the other hand, are absolutely perfect for cluster sets.

Weighted stretching

What is it?

Stretching a muscle under resistance, such as in the bottom position of a dumbbell fly.

What does it achieve compared to traditional sets?

The traditional broscience hypothesis was that stretching muscle or connective tissue, specifically the fascia, gives the muscle room to expand, but this theory does not make much logical sense. Fasciae are sheets of fibrous collagen fibers that wrap around muscles and organs. They're connective tissue that compartmentalizes the body. Evolutionarily speaking, it would be quite odd if muscle tissue had adapted to grow in response to mechanical tension, yet be unable to do so because other tissue was in the way. Indeed, fascia is highly elastic and most muscle growth is preceded by swelling that's greater in magnitude than the resulting muscle growth, indicating the room for expansion is there.

If the room for expansion wasn't there, it's unlikely we could actually make way by stretching our fasciae. Fascia is too stiff to stretch in length. We're talking "you'd have to pull on this with a tractor" too stiff [2]. A primary function of fascia is to transmit forces generated by your muscles, so it would be highly biomechanically inefficient if your fasciae would lengthen greatly. It's a good thing our fasciae are stiff.

When asked to provide any evidence to support the notion that tissue length of any kind is a limiting factor in the process of muscle hypertrophy, Antonio & Gonyea (1985) is often mentioned. Many people don't read the full text of studies, but in this case, it seems that no one even reads the abstract. This study shows that when you hang heavy weights on to the wings of birds, their wing muscles get stronger and bigger.

Shocker! This has nothing to do with stretching per se. It simply demonstrates the basic physiological principle of muscle growth: high muscle tension causes muscle hypertrophy.

Subsequent research in humans did not support any hypertrophic effect of loaded stretching. Fowles et al. (2000) studied the effect of stretching the calves for almost half an hour. “The procedure began with the subject’s foot locked into the maximal tolerable dorsiflexed position without pain and thereafter, every 2 min, the magnitude of the stretch was increased and a new maximal joint angle established, as limited by the tolerance of the subject. On average, this protocol resulted in a 6–7° increase in joint angle, beyond the original maximal tolerable stretch”. Even this medieval level of stretching did not induce any muscle growth as measured by fractional synthetic rate in the soleus. Moreover, a control group performed an isometric contraction at the same level of force as was used to induce the stretch and these guys did experience a 49% increase in protein synthesis. Quoting the researchers, “Since the magnitude and the duration of the stretch in this experiment vastly exceeded that encountered during a typical resistance training session, and yet were still not sufficient to stimulate protein synthesis, it is apparent that minimal muscle stretch occurs during weightlifting… muscle stretch per se is not the stimulus for the muscle hypertrophy that occurs with resistance training.”

Over the next 2 decades, research on stretch-mediated hypertrophy began accumulating, providing a much more plausible mechanism of action for hypertrophic effects of weighted stretching than fascial expansion: increased passive mechanical tension on the muscle could directly stimulate muscle growth. In 2017, Simpson et al. found the first promising effects of stretching. Untrained men intensely stretched one of their calves 5 times per week with the assistance of a machine. This calf experienced an increase in muscle thickness and muscle fascicle length but not strength (torque) compared to the other leg, although the results were not super clear. An important limitation was that the stretching protocol included calf raises as a ‘warm-up’ along with post-workout protein supplementation, so this strength training might have been the actual cause of their gains rather than the stretching. Even if we assume stretching can cause muscle growth, the researchers noted the following regarding its practical implication: “to attain the magnitude of the changes stimulated by this protocol, the stretching intensity must be sufficient to induce muscle damage, repair, and subsequent growth, likely beyond the voluntary limit suggested by subjects.”

In 2021, Panidi et al. confirmed the potential for stretching to improve muscle growth. Female adolescent volleyball players stretched one of their calves to the point of over 8 out of 10 pain for 9-15 minutes 5 times per week for 12 weeks. That calf experienced a bigger increase in cross-sectional area, some measures of muscle fascicle length and jump strength but not muscle thickness. The stretching was mostly combined with volleyball sessions, so it’s possible that the negative effect of static stretching on muscle strength may have made the volleyball sessions more intensive and thereby caused greater growth, but the increase in muscle fascicle length was compelling.

In 2022, Warneke et al. finally provided compelling, well-controlled evidence that static stretching can directly stimulate muscle growth, at least in the calves of untrained individuals. The stretching protocol lasted an hour a day for 6 weeks with the use of an orthosis, a similar ankle brace type stretching device as in the above study. This type of hardcore stretching resulted in significant muscle growth (CSA) and isometric strength development in the gastrocnemius.

In 2023, Warneke et al. built on their last study and compared their stretching protocol to conventional strength training. The strength training consisted of 5 sets of straight-leg calf raises in a leg press at 12RM 3x per week: a respectable 15 sets per week of calf work. The stretching protocol consisted of tool-assisted calf stretching (see image below) for 1 hour per day at a 7-8 out of 10 pain intensity. There were no significant differences between the groups in their strength and size gains, measured via maximal voluntary contraction, muscle thickness, pennation angle and ankle flexibility. Stretching can thus rival strength training for your gains(!) And these weren't untrained individuals. They were strength-trained at least twice a week and most were athletes. However, the researchers concluded that "the practical application seems to be strongly limited as a weekly stretching duration of up to 7 h a week is opposed by 3 × 15 min of common resistance training." Another follow-up study from Warneke et al. (2023) with a similar hardcore stretching protocol demonstrated that stretch-mediated hypertrophy still occurs in the calves of strength-trained athletes that already trained their calves.

Fig. 5 Orthosis used for calf muscle stretching

In 2024, Wohlann et al. found that weighted stretching can also rival strength training for the pecs. The stretching group stretched their chest 15 minutes per day, 4 days a week, in a custom-made butterfly pec deck machine. The machine stretched the pecs up to maximum discomfort for the full 15 minutes. Ouch. The strength training group did 3 workouts per week of 5 sets of 12 reps in the conventional butterfly pec deck. After 8 weeks, both groups had similar gains in pec muscle thickness, as well as isometric strength in the stretched position. The stretching group unsurprisingly experienced greater gains in pec flexibility.

Another similar study by the same lab, Wohlanne et al. (2014), found that 15 minutes of maximum-intensity band-assisted pec stretching at home 4x per week also significantly increased bench press strength as well as isometric strength.

A 2024 meta-analysis by Warneke et al. confirmed that static stretching can induce muscle growth and strength development and virtually all the effect came from long-duration, high-intensity stretching interventions.

Interim summary

In conclusion, (loaded) static stretching can directly stimulate muscle hypertrophy and even strength development. The muscle growth occurs partly via an increase in muscle fascicle length but also via muscle thickening, strongly suggesting sarcomerogenesis in parallel, just like you'd get from lifting weights. Passive tension seems able to stimulate muscle growth in a similar manner as active tension. While weighted stretching can stimulate robust muscle growth, the intensity and volume of the stretching must be very high to the point that the practical use of this knowledge is questionable. Weighted stretching decidedly falls under the 'no pain, no gain' category. Regular static stretching protocols do not typically stimulate any muscle growth [2]. Static stretching before your workouts can even decrease muscle growth by decreasing motoneuron excitability, effectively relaxing the muscle too much to contract maximally.

Moreover, it's still questionable how well weighted stretching works for muscles that cannot reach passive insufficiency, as they won't experience the same level of passive tension. If muscles don't reach passive insufficiency, muscle length is not the limiting factor of flexibility in most movements.

Even if we can induce enough passive tension on a muscle to grow, it may induce a lot of muscle damage and have a poor stimulus-to-fatigue ratio. Until we have more research on practical use cases of weighted stretching with an acceptable cost-benefit, you're likely better off training with dynamic strength training exercises that expose the muscles to high tension when they're lengthened than trying to stretch your way to the Olympia.

Inter-set stretching

Another line of research has looked at inter-set stretching: stretching in between sets, in particularly straight after your sets. Stretching after instead of before a set may not confer as much negative effect on muscle performance and it might potentiate the stress of the stretch. Light 'active recovery' type stretching and antagonist stretching have even been found to improve performance. However, when we're talking about stretching to induce stretch-mediated hypertrophy, we're talking about intensive static stretching of the agonist muscle, such as quadriceps stretching in between sets of leg extensions. Static stretching can reduce motoneuron excitability and thereby reduce muscle activation, force production and consequently total work output during training. It shouldn't come as a surprise then that this type of intensive static inter-set agonist muscle stretching has still been found to reduce how many reps you can do in the next set, thereby reducing total repetition volume. So is the likely loss of active muscle tension in your sets compensated for by the added passive tension or some other mechanism?

Evangelista et al. (2019) compared traditional, full-body strength training to another group of untrained adults doing the same program with an added 30-second hard, static stretch directly after their sets. The stretching did not significantly affect strength development, as measured by 1RM bench press and leg extension strength. The stretching also did not significantly affect muscle growth in the biceps, the triceps or the rectus femoris of the quads, but it did increase muscle growth in the vastus lateralis of the quads. One significant limitation of the study is that repetitions were equated between groups. Assuming the static stretching acutely reduced strength, as it usually does, that would mean the inter-set stretching group was training harder to complete the same workload, and that may be the reason they gained more muscle. For serious strength trainees that push for maximum progress, the stretching would hurt performance and they'd therefore achieve lower workloads, which would likely reduce rather than increase muscle growth (see the course module on stretching). Overall, this study does not provide compelling evidence that inter-set stretching augments muscular adaptations.

Nakamura et al. (2021) investigated the effect of a flywheel squat training program in which one leg performed static quadriceps stretches in between sets and the other leg did not. The stretching consisted of 30-second static quad stretches to the untrained men’s maximum tolerable intensity, repeated twice per rest interval starting directly after each set. The stretched leg did not gain more muscle size or dynamic, concentric or eccentric strength, but the stretched leg did gain more isometric knee extension strength.

Van Every et al. (2022) again found mixed support for inter-set stretching. The researchers had a group of untrained men train one of their calves with a normal strength training program. The other leg did the same program but ended their sets with a 20-second weighted stretch in the bottom position of the calf raise. After 8 weeks, the super-stretched soleus of the calves gained more muscle. Isometric strength gains in both the bent-leg and straight-leg position were also greater in this calf. However, the gastrocnemius of the calves, did not grow appreciably more from the weighted stretching. These results are curious, as we might expect more stretch-mediated hypertrophy from the biarticulate gastrocnemius than the soleus.

The above inter-set stretching studies were all done on untrained participants. In contrast, Wadhi et al. (2022) compared a bench press training program with and without inter-set weighted stretching with a cable fly machine in *trained* men. There were no significant differences between the groups in pec muscle growth or 1RM strength development. These findings cast major doubt on the efficacy of weighted stretching for trainees beyond the novice level. After a hard set, additional stretching may not further contribute much to the growth stimulus, similar to training beyond the point of muscle failure.

In conclusion, the intensity and duration of weighted stretching that are required for muscle growth make it difficult to effectively implement in between sets. Extreme static stretching can reduce performance in your next sets by inhibiting motoneuron excitability. Research findings have been mixed about whether the inter-set stretching stimulates greater gains in the first place, especially in muscles that cannot reach passive insufficiency. Even if it does, the effort-to-reward ratio seems to be poor compared to doing more sets or other advanced training techniques.

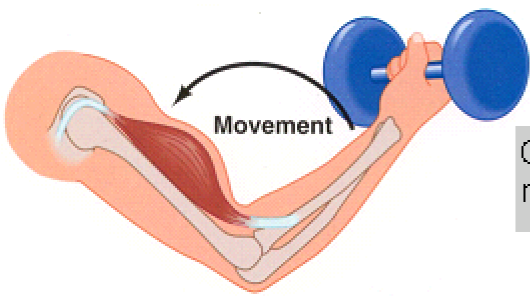
Who benefits from it?

…masochists? The current evidence is intriguing but does not lend much support to practical use cases.

Eccentric overloading

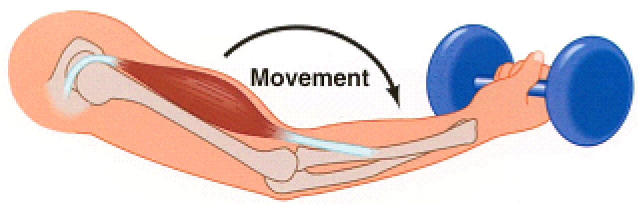
What is it?

Training in a way that makes the eccentric (muscle lengthening) portions of your exercises harder than the concentric (muscle shortening) ones.



Concentric muscle contraction—The bicep muscle is **shortening** while contracting.

Eccentric muscle contraction—The bicep muscle is **lengthening** while contracting.

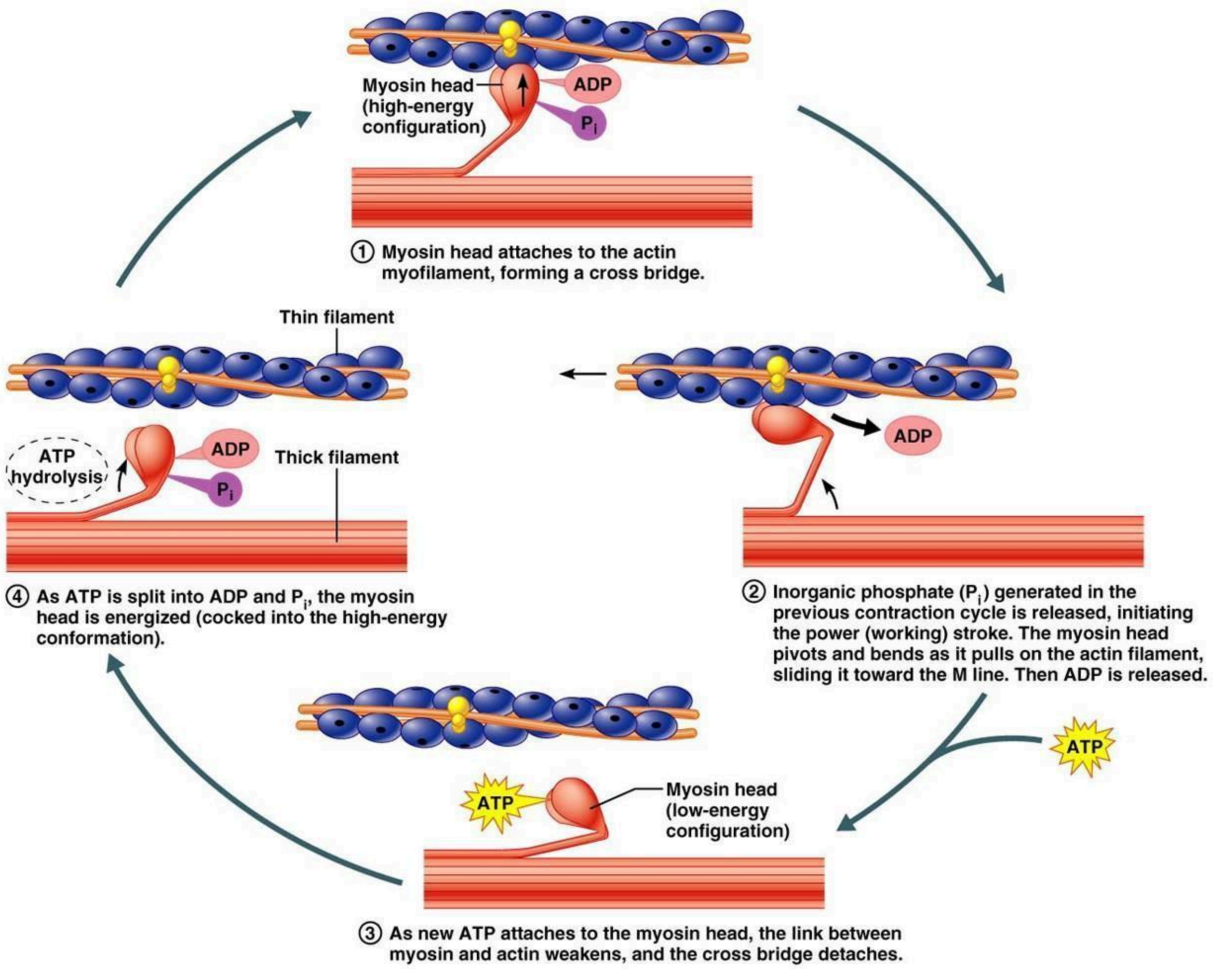


What does it achieve compared to traditional sets?

Muscles can generally produce around 40% more force during eccentric contractions than concentric contractions of the same movement [2, 3]. Eccentric force production is on average 40% higher than concentric force production, but the exact number varies from 14% all the way up to over a 161%, depending on the person, the training intensity, the velocity of movement and the exercise.

As intuitive as it seems that you can lower more weight than you can lift, the higher eccentric strength of muscle tissue is not as straightforward as that. Muscles can actually produce more total force eccentrically than concentrically, not just ‘control the descent a bit’. How can they do that?

During a concentric muscle action, the muscle shortens because actin filaments are repeatedly pulled over myosin filaments. This process is called actin-myosin cross-bridge formation. These cross-bridges have to be detached with a chemical reaction, the cleaving of an ATP molecule.



During eccentric contractions, the cross-bridges are separated mechanically as the muscle lengthens, so less energy is required to produce force.

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.

The result is that eccentric emphasized training allows you to perform more work and reach higher levels of muscle activity than during traditional sets. More mechanical tension should correspond with more muscle growth. We indeed see that a given number of sets of purely eccentric training tends to result in more muscle growth than purely concentric training [2]. The difference disappears when equating total work, indicating the hypertrophic advantage of eccentrics is likely mediated by higher mechanical tension per repetition. During dynamic contractions, several lines of research indicate eccentric overloading may also benefit muscle growth and strength development.

- Accommodating resistance training of any kind tends to outperform traditional constant-load exercise. In a literature review by Wernbom et al. (2007), accommodating resistance training had a 0.16% increase in quadriceps CSA per day, compared to 0.12% for conventional strength training and 0.11% for isometric training.
- The iso-inertial FlyWheel device, which is a form of accommodating resistance with eccentric overloading, tends to outperform traditional constant-load exercise in terms of muscle growth, strength development, muscle activity, total work output and carry-over to sports performance [1, 2, 3, 4]. The research is limited by low statistical power and mostly untrained subjects. One meta-analysis found that FlyWheel training resulted in more muscle growth and strength development than traditional, constant resistance strength training, but another concluded there's not enough evidence to say either way yet.
- Training with machines that have eccentric overloading has been found to result in more muscle growth than training with regular, constant-load machines,

seemingly mostly in type II fibers with an associated shift in muscle fiber type to more fast-twitch fibers in multiple studies [1, 2, 3, 4], although other studies found similar muscle growth [see full overview below].
(Interestingly, a study of eccentrically overloaded leg presses for rehab after ACL reconstruction found that eccentric overloading resulted in greater muscle growth but a shift towards type I fibers, possibly due to impaired neuromuscular functioning from the reconstruction [1].)
Strength development also tends to be greater with eccentric overloading than without it [1, 2, 3, 4, 5], though this isn't the case in all studies [1, 2, 3, 4, 5, see overview below]. Brandenburg & Docherty (2002) found 3 sets of eccentrically overloaded arm training were equally effective for muscle growth (insignificant in this study) as 4 sets of conventional training, but the eccentric overloading improved biceps strength development.
Many studies were likely underpowered to reach statistical significance. A 2017 review concluded: "The current research concerning both the acute responses and chronic adaptations to accentuated eccentric loading is inconclusive, but suggests it may be a superior method by which to enhance strength and power performance."

➢ Research overview

The effect of eccentric overloading on muscle growth and strength development

An additional benefit of eccentric overloading is that eccentric muscle contractions seem to be relatively joint-friendly. Eccentric exercise is well established to be effective for injury rehabilitation and in some research outperforms regular strength training to regain functional strength [2]. It seems that eccentric contractions place high stress on the muscle with relatively little stress on the surrounding connective tissues, such as your joints and ligaments.

The high muscle stress of eccentric overloading comes at a cost, however. Eccentric emphasized training induces significantly more neuromuscular fatigue than straight sets or even drop sets. Eccentric overloading increases your work output per set, so it makes set that fatigue increases correspondingly. If you implement a lot of eccentric overloading, especially true eccentric overloading with machines, you may not need to perform as many sets as otherwise to achieve a certain level of muscle stimulation and fatigue.

Who benefits from it?

Almost everyone interested in maximizing muscle growth: eccentric overloading is highly time-effective and will likely provide superior results compared to only regular isotonic exercise. So if you have machines or weight-releasers available to implement eccentric overloading, it's generally good to do so. If not, there are still several ways you can implement eccentric overloading in your training.

1. Bilaterally performing the concentric phase of an exercise, while unilaterally performing the eccentric. For example, during a machine leg extension or lying leg curl you can lift up the pad with both legs and then lower it under control with just one leg.
2. Using momentum to aid the concentric phase while controlling the eccentric. This can be used during, for example, calf jumps, butterfly lateral raises, step-ups, pulldowns and seated cable rows. (See the exercise selection course module for the exercise library with detailed exercise descriptions.)
3. Biomechanically decreasing your strength during the eccentric phase. For example, you could switch from a supinated to a pronated grip during chin-ups. Zottman curls are an exercise that inherently have eccentric overloading.

Strategy 2 is generally by far the most practical to implement.

Eccentric overloading is a particularly great training technique during (p)rehabilitation and it is well established in the scientific literature for that purpose.

Women may benefit more from eccentric overloading than men because their eccentric strength difference is greater than that of men. Women also have greater resistance to muscle damage (see course module on gender differences). So women have more to gain and less to lose from eccentric overloading than men.

PAP(E)

What is it?

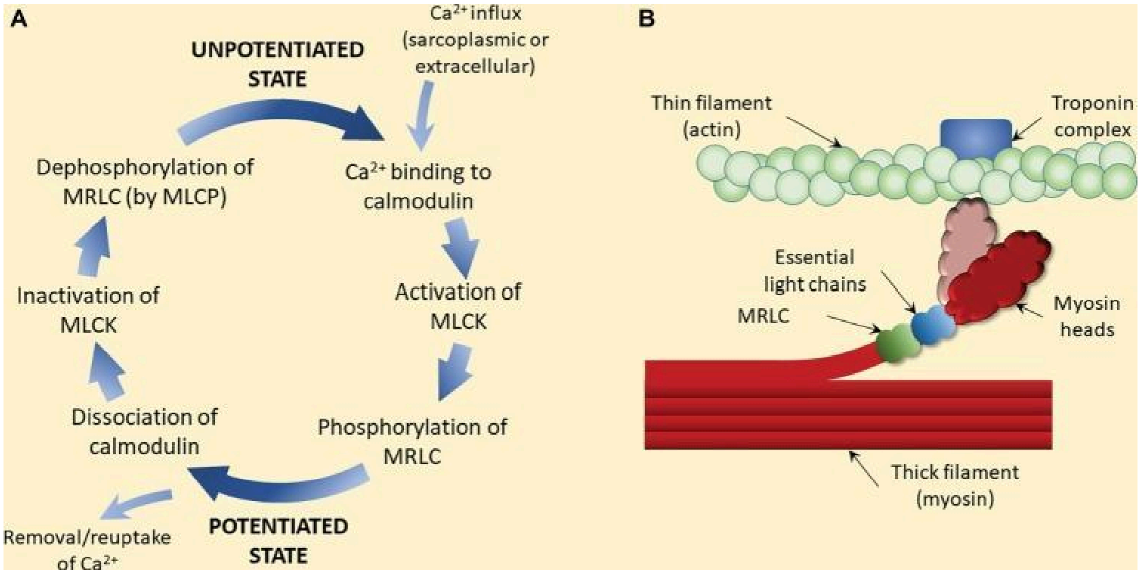
Post-activation performance enhancement (PAPE) refers to the phenomenon whereby high intensity muscle contractions can potentiate (= increase) subsequent lower intensity performance. The heavier your initial sets are, the more they can potentiate subsequent lighter sets. In other words, PAPE is a phenomenon where heavy strength training (1-5RM usually) induces more performance-enhancing changes in the nervous system and the exercised muscle's architecture than it induces fatigue. As a result, after certain (near-)maximal muscle contractions, you can temporarily become stronger despite being fatigued. For example, within a certain timeframe after a 1RM attempt, you may be able to perform more reps with 70% of 1RM and run the 400m sprint slightly faster. PAPE can also increase how many reps you can do across sets, though the effect tends to be virtually gone by set 3 [2].

PAPE is very closely related to post-activation potentiation (PAP). The term PAP is sometimes reserved for when the performance enhancement is immediate, within a minute, and exercise scientists often define PAP strictly as an increase in electrically-evoked twitch, whereas the term PAPE is used when the performance enhancement lasts longer, up to around 15 minutes, and is voluntary. Exercise scientists make the distinction because PAP and PAPE have different mechanisms, but many practitioners and scientists still refer to both phenomena as PAP.

What does it achieve compared to straight sets?

You may think the mechanism for PAP must be neural, but PAP can occur after a maximal contraction while voluntary muscle activity decreased. Also, PAP doesn't work for maximal contractions, only subsequent lower intensity ones, indicating the mechanism is not an increase in neural drive or muscle activity. Moreover, multiple maximal contractions or heavy sets can induce more PAP than a single one [2]. The most established theory is that PAP occurs due to increased myosin light chain phosphorylation occurring in type II muscle fibers [2]. As a result, the rate of cross-bridge formation is upregulated. During contractions where the number of cross-bridges would otherwise not be maximal – submaximal contractions – the muscle fiber can then build more cross-bridges and thereby produce more force. The rate of force development also increases in line with the rate of cross-bridge formation. Enhanced contractility is relevant not just for strength but also muscle growth.

PAP is very short-lived with significant loss in effect already after 28 seconds. Thus, to take advantage of it in the gym, you must perform your next set relatively quickly, like during antagonist supersets. For free-weight exercises, you should strategically load the bar so that it's easy to strip off the desired weight for your next set. For example, if your 1RM is 100 kg for the bench press and you want to do a 1RM followed by a set at 80% of 1RM, it's best to load the bar with a 10 kg plate on each outer side so you can strip those off quickly after the 100 kg 1RM to perform your set with 80 kg.



The mechanism of PAP in more detail than you need to know. Source

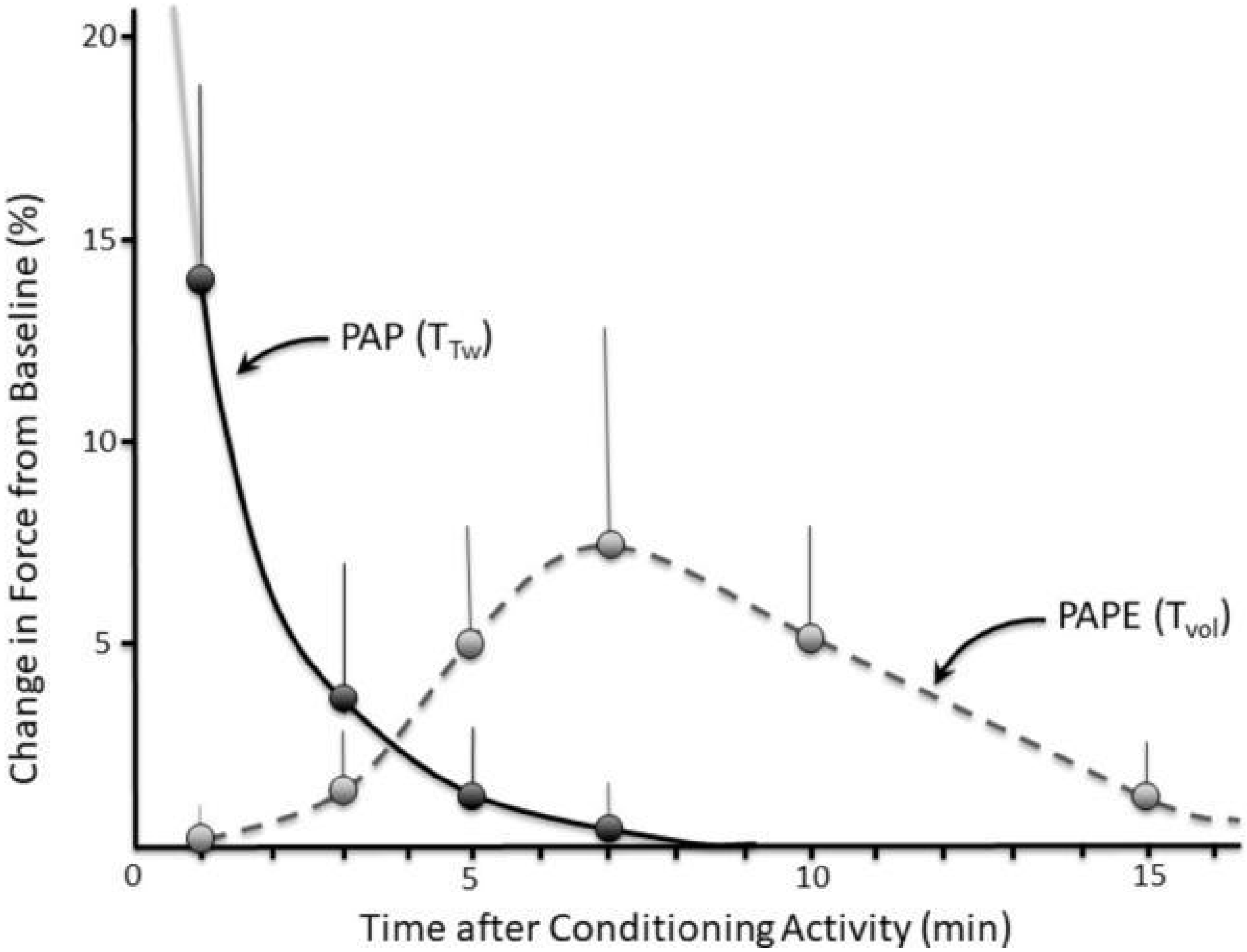
A 2020 meta-analysis found that PAP-type training with strength exercises immediately followed by power exercises, such as heavy squats followed by jump squats, tends to lead to greater gains in 1RM strength, jumping and sprinting performance than performing the power exercises separately later in the session.

However, many pure strength trainees don't experience considerable performance enhancement with PAP in the gym. PAP works best in muscles with many type II muscle fibers and for lower intensity but explosive exercise, such as speed work, plyometrics and other explosive athletics. In practice, most people only experience possible increases in how many reps they can perform after a 1-3RM followed by a set lighter than 80% of 1RM.

Fortunately, if you don't respond well to PAP, you may still respond a little to post-activation performance enhancement (PAPE) multiple minutes later [2, 3, 4, 5]. While PAP wears off quickly, neuromuscular fatigue also dissipates quite quickly and other potentiating effects may stay active for up to around 15 minutes, possibly including the following [2].

- 0.3-0.9°C higher intramuscular temperature.
- Increased blood flow leading to higher muscle hydration and increased electrostatic strength that prevents muscle cross-bridges from detaching, increasing the number of force-producing cross-bridges at any time and resulting in greater force production.

As a result, you may get another, longer-lasting PAP-like improvement in performance around 5-15 minutes after you did high-intensity training. For example, after moderately heavy doubles or triples on a powerlift, you may experience that you can do more reps to failure for that same exercise at 70% of 1RM 8 minutes later than when you didn't do the high-intensity set before. The following graphic illustrates how performance changes over time in a non-linear fashion due to the combined effects of PAP, neuromuscular fatigue and PAPE.



Theoretical time-course of PAP and PAPE, measured as the torque (T) produced during an electrically evoked muscle twitch ($_{TW}$) or a voluntary contraction ($_{VOL}$). [Source]

In practice, it can be very difficult to find the time you experience a considerable net increase in performance from PAP(E), because both the time-course of both the potentiating effect and the fatigue vary per individual. A guideline is that you benefit most from PAP within a minute but [benefit most from PAPE around 5 minutes later]. Optimization requires meticulous experimentation. Unless you're a professional athlete, that's probably not worth your time. [One study] found that PAPE was not significantly higher after testing 2- to 10-minute rest intervals in 2-minute intervals to find the optimal timing compared to using self-selected rest intervals. We might thus be intuitively aware of the optimal PAPE timing, or at least the professional athletes in that study were.

PAPE might be partly systemic. A few studies [1, 2, 3] have shown non-localized performance enhancements after high-intensity training in unrelated body parts, such as higher jumping multiple minutes after high-intensity bench pressing. However, the effects were very small, in the range of 1-2%, and highly inconsistent across measures: performance only increased in some measures or body parts, not others. There is no established mechanism by which PAPE could occur in unrelated body parts. PAP's primary mechanism of action is increased cross-bridge formation in the trained muscle. Given that the systemic PAPE studies measured performance 5+ minutes after the supposedly PAPE-inducing exercise, it's plausible that any residual improvement in performance was a generalized warm-up effect, such as increased core body temperature, mental arousal and increased blood flow. Without any exercise, the trainees may have already been cooling off in this period. Even if PAPE is partly systemic, it's clearly primarily local.

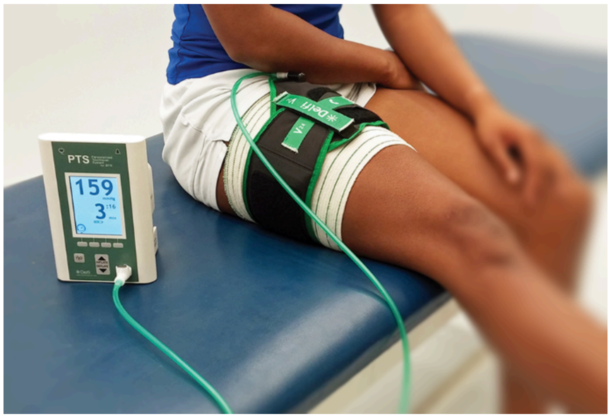
Who benefits from it?

- Powerlifters! If you're going to perform 1RMs, you may as well take advantage of PAP afterwards.
- Competitive athletes after meticulous testing, such as sprinters.
- Anyone employing training intensities over 90% of 1RM can use PAP as a superior form of reverse pyramiding to reach a good intensity-volume compromise. You get the strength gains from 1RM training but still enough volume for muscle growth.

For non-advanced, recreational lifters, PAP(E) is arguably not worth the effort. The repeated (near) 1RM training and systematic experimentation it requires to make it work well may detract from your regular training sessions more than it will benefit them. And it may not even work. Even when PAP(E) does work, it is highly contentious if a few percent increase in strength is worth performing a 1-3RM for if you're not a powerlifter. Going that heavy comes with a relatively high injury risk even though the acute fatigue is very low. As such, PAP(E) is a very advanced technique that's primarily of interest for powerlifters who perform regular 1RMs anyway.

KAATSU training

It’s not often that revolutionary training techniques are developed. Most are just re-marketed techniques or variety for the sake of variety. KAATSU training was developed by a Japanese sport scientist by the name of Sato in 1966 as a technique to increase muscle mass without having to use heavy weights. KAATSU roughly means ‘with added pressure’. He first developed the idea during a Buddhist ceremony where he had to remain kneeling for so long that he occluded the blood flow from his own calves and thought: “Hey, this feels like the burn I get in the gym”. Years of experimentation went into it before it became publicly known in the West in the 90s, though elite athletes have been using it since the 80s when KAATSU training gear became publicly available in Japan.



Implementations of KAATSU training.

What is it?

Blood flow restriction training. You occlude a muscle with an occlusion device or simply some elastic material like knee wraps before exercising the muscle with a light weight.

What does it achieve compared to straight sets?

Arteries pump blood into muscles, but the superficial occlusion prevents your veins from taking the blood out. The result is an accumulation of oxygen-deprived blood and metabolic byproducts, what you feel as 'the burn' and a big pump. The high local neuromuscular fatigue, including the oxygen deficit, lowers the recruitment threshold of higher-threshold motor units so that muscle recruitment patterns mimic that of heavier weight training. Basically, muscle occlusion makes light weights stimulate your muscles like heavier weights. Correspondingly, at any intensity you cannot perform as many reps with occlusion as without. At 50% of 1RM some people can only manage 10 reps with blood flow occlusion, though most people can perform over 20 reps normally.

With KAATSU, intensities as low as 20% of 1RM can induce similar muscle growth as heavy strength training, according to the latest 2024 meta-analyses [2, 3]. High intensity training generally outperforms low intensity KAATSU training for maximal strength [2, 3, 4], but low-load KAATSU training improves strength development compared to low load training without KAATSU [2]. It's mechanistically difficult to maximize maximal strength with very low weights, as you won't reach peak muscle activity. Moreover, it seems that blood flow restriction exercise does not promote increases in voluntary activation, possibly due to central nervous system fatigue as a result of high group III/IV afferent feedback during high metabolic stress.

While you can use very light weights with blood flow restriction, it's certainly not an excuse to train with low effort. To maximize muscle growth per set, you need to train close to failure and use loads of at least 30RM or 30% of 1RM. In studies without very high training efforts, KAATSU training expectedly underperforms high intensity training [1, 2, 3]. Since training at 30% of 1RM to failure is just as effective as higher-load training for muscle growth even without blood flow restriction (see course module on training intensity), it's questionable if blood flow restriction per se really enhances muscle growth during maximal-effort training. However, at the same training intensity, you can generally perform 30-50% fewer repetitions with blood flow restriction [2, 3]. Thus, the worst case-scenario is that you achieve similar gains with greater time-efficiency and a lower total workload, which is useful for (p)rehabilitation. Moreover, since a 30RM with KAATSU involves a lower weight than without it, it's likely that the minimum training intensity for maximum muscle growth is in fact lower with KAATSU, probably lower than 30% of 1RM.

KAATSU training may promote similar increases in tendon thickness as heavy load training [2, 3, 4], but long-term research in well-trained lifters is lacking. Trained individuals might require heavier loading to stimulate continued tendon growth, as tendons don't grow as reliably from training as muscles (see course module on training intensity). Low-intensity blood flow restriction training does not stimulate the same bone health improvements as high-load training, despite it increasing bone metabolism more than low-load training, according to a 2023 meta-analysis.

In contrast to what you might expect, KAATSU's mechanism of action is not metabolic. It's not the metabolic stress from the blood flow occlusion that drives the extra muscle growth. Metabolic stress is not an independent growth stimulus, only a stimulus for increased muscle activation, as you learned in the module on understanding muscle growth. The resulting mechanical tension on the muscle fibers is still the primary cause of muscle growth. Multiple lines of research show that the metabolic stress from blood flow restriction does not itself cause muscle growth.

1. Blood flow restriction does not increase strength or size gains with heavy weights, despite increasing metabolic stress [2]. Therefore, blood flow restriction exercise is commonly done with training intensities of 20-50% of 1RM or 15-30 RM. There's no point in implementing it with heavy loads: you're better off just reducing the weight.
2. Blood flow restriction without exercise does not promote muscle growth or help prevent atrophy during detraining.
3. Combining low-load KAATSU and conventional high-load training doesn't improve strength development or muscle growth compared to only doing high-load training [2].
4. KAATSU training and traditional high-load resistance training stimulate similar increases in anabolic signaling pathways, indicating they operate via the same mechanism to cause muscle growth.
5. Counterintuitively, KAATSU training is effective for the non-occluded muscle groups in the trunk as well as the occluded limbs [2].

Restricting blood flow to your arms during the bench press increases muscle activity levels not just in the triceps but also in your pecs. As a result, occluding your arms during the bench press increases triceps **and** chest muscle hypertrophy; likewise, occluding your thighs during squats and leg curls increases quad **and** glute hypertrophy [2, 3, 4]. Blood flow restriction of the arms has even been found to increase shoulder growth during a shoulder isolation training program. However, occluding the thighs during squats did not increase calf hypertrophy and during walking it did not increase glute hypertrophy, likely because muscle activity levels in these muscles did not reach a sufficient level to increase muscle growth even with KAATSU. Blood flow restriction effectively makes the exercise as a whole more difficult, so all muscle groups must work harder to lift the weight. This probably only applies to exercises in which the agonists/synergists can at least partly compensate for each other, but that is the case for most compound movements.

That KAATSU aids non-occluded muscle groups strongly support that its benefits are mediated by increased muscle activity and subsequent mechanical tension, not the metabolic stress itself.

Despite causing hypoxia, KAATSU training doesn't preferentially activate anaerobic muscle fibers. On the contrary, compared to traditional heavy weight training, KAATSU training seems to preferentially active type I muscle fibers due to A) the relatively high reps commonly performed and B) poor recovery of type II muscle fibers during occlusion [2, 3, 4, 5]. Blood flow restricted exercise has been found to cause greater glycogen depletion and metabolic stress in type I than type II muscle fibers, in contrast to heavier-load training. Accordingly, a 2023 systematic review concluded that in KAATSU training interventions, more of the growth comes from the type I fibers than in high-load training interventions. However, research directly comparing occluded vs. non-occluded training have found mixed results on fiber-type specific hypertrophy so far. Combining low-load KAATSU training with high-load strength training also doesn't consistently influence which muscle fibers grow.

KAATSU training is also not easier to recover from than high-intensity training. While you may think metabolic stress is relatively easy to recover from, KAATSU training with 20% of 1RM induces as much muscle swelling, presumably caused by muscle damage, as training with 80% of 1RM. KAATSU training also induces just as much neuromuscular fatigue as high-intensity training, given the same total work performed and a given number of sets of KAATSU training at 20% of 1RM is just as hard to recover from as those sets at 70% of 1RM without KAATSU. The application of blood flow restriction without exercise also does not aid post-workout recovery, indicating blood flow restriction does not inherently enhance recovery. KAATSU training might be easier to recover from than high-rep training without KAATSU though: in particular, the lower duration and total work output of exercise compared to training with that weight without KAATSU seems to limit the accumulation of central nervous system fatigue.

Interestingly, despite KAATSU training not being easier to recover from than regular lifting, intermittent blood flow restriction may speed up post-exercise recovery [2, 3]. The effect seems to be mediated by the increased blood flow after you take the cuffs off. The durations required can be significant (5-30 minutes) and the effect is highly inconsistent in research with multiple studies showing no effect [2], especially for objective measures of strength, so it's questionable if it's worth the time and discomfort.

Is it safe?

In contrast to what you might intuitively expect, KAATSU training appears to be very safe for your muscles as well as your cardiovascular system, even in elderly populations, at least when sensible occlusion levels are used. KAATSU was originally developed mainly for injured athletes and the elderly. To be conservative, however, limit KAATSU training to 4 sets per exercise, as some unpublished research from Wernbom's lab has shown cardiovascular risks with higher volumes than that. Possible contraindications to implement KAATSU training are very poor cardiovascular health, especially high blood pressures, recent major muscle trauma, especially rhabdomyolysis, and perhaps pregnancy.

Since very low loads can be used, KAATSU training causes relatively little stress on connective tissue, so in terms of common exercise injuries it's very safe.

Who benefits from it?

Elderly and injured trainees benefit the most from the extremely low required training loads [2, 3] to spare their connective tissues. KAATSU training is arguably the best (p)rehabilitative exercise technique there is. Blood flow restriction is an extremely effective way to be able to train effectively with very light loads and training tonnages.

Since KAATSU training does not seem to result in a different anabolic signal than higher-load training, there is no need to incorporate KAATSU training by default.

Practical application

KAATSU training is traditionally implemented with special blood flow occlusion cuffs to reach 40-80% arterial occlusion pressure. However, there's no strict need to have fancy or expensive equipment. You can also wrap powerlifting knee wraps around your limbs. Any kind used by powerlifters will suffice. Occlusion with pressure regulating cuffs does not achieve any better gains than occlusion with unregulated cuffs according to a 2024 meta-analysis. The cuff width or the breadth of the knee wrap doesn't matter, and neither does the material (elastic vs. nylon), given the same occlusion, but wider cuffs require less pressure to get the same occlusion. Wider cuffs tend to cause more discomfort, so narrow cuffs are preferable in this regard.

Here's a video demonstrating where to wrap your legs for KAATSU training; and here's a video demonstrating how you can wrap your arms for KAATSU training.

Whether you take the wraps off in between sets or you keep them on until you're done with all sets of the exercise doesn't matter for muscle activity, muscle damage, muscle growth or strength development [2, 3], at least provided the intensity is at or above 30% of 1RM and there's enough occlusion from the cuff. Schwiete et al. (2021) even found that it doesn't matter if you implement the occlusion continuously or only in *between* sets. Keeping the wraps on has a similar effect as tightening the wraps more: more occlusion. That's not necessarily needed. Unpublished research from Davids et al. even suggests taking the wraps off in between sets improves muscle growth compared to keeping them on, possibly due to allowing a higher total work output and better recovery of type II muscle fibers without occlusion. Keeping the wraps on can also be uncomfortable and can increase RPEs [2, 3], so unless you really need maximal occlusion for (p)rehabilitation, it's advisable to take the wraps off in between sets.

How tight to wrap the limbs

Don't try to go 'super hardcore' and bind down your limb as if you have to make sure you don't bleed out. If the training intensity is sufficient, there is no point in increasing the cuff pressure [2, 3]. KAATSU training causes more pain and discomfort than conventional training, so it's not sensible to implement more occlusion training than you need. Over 40% of arterial occlusion pressure, more pressure barely influences blood flow further [2]. In fact, the goal of the occlusion is to let the blood pool in your veins **without** blocking arterial blood flow, so at some point, more pressure becomes detrimental. On a pressure scale of 1-10, aim for a 4-6 for your legs and a 3-5 for your arms [2]. A 7 leads many people to implement excessively high occlusion levels with full arterial occlusion in the upper body and ~80% arterial occlusion pressure in the lower body, so that's excessive. Full arterial occlusion may risk damaging the endothelial cells in your blood vessels. You can wrap your legs a bit tighter than your arms, because they have more fat on them and don't change shape as much when flexed. If you experience significant pain before even starting the exercise, numbness, tingling or skin whitening, the wraps are too tight.

On the other hand, if you do not experience an extreme pump and burn during the set, the wraps probably aren't tight enough. Pain tends to be higher during KAATSU training than during regular high intensity training and the greater the occlusion, the greater the pain. KAATSU calf training in particular might just be the most painful thing you'll ever experience in the gym.

Also, if you intentionally want to reduce your training loads as much as possible to limit connective tissue stress, tighter wrapping is an effective way to decrease your workloads without hindering strength development or muscle growth.

You can also objectively measure the tightness of the wraps by the length you stretch out the knee wraps, i.e. you grab the knee wrap at point A and stretch it out to point B. The difference in length of the knee wrap is a measure of how tight you're wrapping it around your limb.

How to program occlusion training

In terms of programming, implementation is simple. Assuming you can use a sufficiently high intensity (see section below), a set of KAATSU work is in principle interchangeable with a set of traditional heavy strength training.

You can also still rest until you're fully recovered, but since the first reps of high rep KAATSU sets are only 'primer' reps to induce enough fatigue to recruit your higher threshold motor units for reps that induce significant muscle growth, you can also rest only until you've caught your breath and refocused. As a rule of thumb, you want to rest long enough that you can manage at least 8 reps per set and at least 1 minute between sets.
With intensities below 20%, it's better to shorten your rest intervals so your sets do no not exceed 30 reps and muscle activity levels are high enough. Most research has employed rest periods of 30-60 seconds.

Just like with regular high intensity training, KAATSU training has a dose-response relation to intensity and muscle activity. It just peaks sooner. Metabolic stress can only compensate for lower weights up to a point to get the same mechanical tension in the muscle fibers. For maximum muscle growth, it's advisable to use at least 30% of 1RM (~30 reps).

If you're using KAATSU to intentionally reduce the load intensity, like during injuries, it can help to increase the cuff pressure to just below the point where you get side effects from it. The greater occlusion compensates for the suboptimal training intensity and mechanical tension, so that you can still reach high levels of muscle activity even with very light weights. That is arguably the main benefit of KAATSU training: to get the same stimulus for muscle growth with far lower weights and thereby lower joint stress.

Hyperventilating

While we're on the subject of quirky Japanese training techniques, a series of Japanese studies by Sakamoto et al. [1, 2, 3, 4] have established significant support for a hyperventilating technique that improves strength training performance. This technique is similar to some of Wim 'The Iceman' Hof's breathing techniques.

What is it?

Literally hyperventilating. Take a big breath every second for 30 seconds before you start a set. You'll likely feel the effect, but you should not experience faintness, dizziness or throat ache. 15 seconds was not enough according to Sakamoto et al., but excessive hyperventilation may slow oxygen delivery to the brain and muscles.

What does it achieve compared to traditional training?

When you breathe normally, your lungs already saturate arterial blood with oxygen to supply to the body, but by breathing faster, you can make your lungs expel more carbon dioxide. As result, hyperventilating induces a carbon dioxide deficit (hypocarbia). Carbon dioxide is essentially a waste product for the human body. It mainly breaks it down and expels it via the lungs. When it's broken down by red blood cells, chiefly to bicarbonate, this creates a free hydrogen ion (H+). Free hydrogen ions acidify the blood (lower pH). Thus, when you hyperventilate, you reduce blood carbon dioxide levels and thereby free hydrogen ion levels and thereby you alkalinize the blood. This is called respiratory alkalosis. To the extent that acidic blood impairs physical performance, hyperventilating can thus buffer against metabolic stress, very similar to sodium bicarbonate supplementation but considerably more effective. However, this hypothesized mechanism of action is challenged by several modern studies that show little effect of a muscle's pH on its contractile performance. Regardless of the insufficiently understood mechanism of action, hyperventilating does seem to enable us to perform more reps during strength training.

Tangentially, the brain does not monitor oxygen levels to control our breathing. It only increases respiration and the feeling of 'air hunger' to prevent high carbon dioxide levels. This is why it can be dangerous to breathe in air without oxygen: it can make you lose consciousness without you noticing it. Similarly, hyperventilating can make you hold your breath longer without discomfort yet with equal risk, because it will take longer for carbon dioxide levels to reach problematic levels, even though you're short on oxygen.

Who benefits from it?

In terms of acute performance, everyone may benefit from hyperventilating. It's reported to be very safe and quite effective. In Sakamoto et al. (2020)'s study, the benefits were substantial. Across 6 sets at 80% of 1RM to failure, hyperventilating resulted in 44 instead of 36 reps on the bench press and 64 instead of 50 reps on the leg press. That's around 2 extra reps per set, which would constitute a greater ergogenic effect than creatine or any supplement typically provides. Other studies have shown less stellar but still considerable benefits.

However, the question is: does this increased performance translate into increased gains? In many contexts, more active muscular work equals more gains. However, hyperventilating is a bit like reverse-KAATSU training. KAATSU increases metabolic stress, resulting in a compensatory increase in muscle activity, thereby allowing you to stimulate your muscles similarly with less total work. Respiratory alkalosis may achieve the opposite: requiring you to do more work to achieve the same level of muscle stimulation in the end. Having to put in substantially more effort to achieve similar results would of course not be desirable.

As per the Supplements module, sodium bicarbonate, beta-alanine and l-citrulline have also shown rather lackluster effects for exercise durations below 60 seconds. There's no considerable evidence these supplements enhance muscle growth or strength development, even if they improve performance in certain contexts.

Thus, hyperventilating is currently an interesting but unproven training technique. Future research will show us if it's the next big training revolution for serious trainees or just a gimmick that makes you have to work harder to achieve the same level of muscle stimulation.

Ischemic preconditioning

Ischemic preconditioning is a modern medical technique to protect the body against a lack of blood supply. It was first identified in 1986 and has been used in some medical practices to protect against heart failure. Ischemia means ‘restriction of blood flow’.

What is it?

Ischemic preconditioning (IPC) in exercise science consists of restricting blood flow to a body part (limb) for several minutes (ischemia), after which blood flow is restored (reperfusion). Cycles of ischemia and reperfusion are typically alternated multiple times before exercise.

What does it achieve?

Ischemic preconditioning can improve strength-endurance, allowing you to perform more reps across sets than a regular warm-up. It’s unclear how exercise performance improves exactly, but we know ischemic preconditioning widens blood vessels (vasodilation) and increases nitric oxide and endothelial growth factor production. Ischemic preconditioning can also improve mitochondrial functioning. Thus, IPC may buffer against metabolic stress and possibly increase energy production, delaying fatigue during exercise. Ischemic preconditioning before a workout also seems to speed up neuromuscular recovery post-workout. However, there’s no evidence yet that IPC improves our gains. Hammert et al. (2023) found no significant effect of 3 minutes of pre-exercise blood flow restriction on muscle growth or strength development from submaximal high-intensity strength training. Although there was a non-significant trend of benefits in muscle growth and the study was not ideally designed to study IPC, growth was not nearly comparable to a high-load group training to failure.

Who benefits from it?

There's no research on if the acute improvements in strength-endurance from IPC translate into greater long-term strength development or muscle growth. Just like with hyperventilating and other techniques that delay the accumulation of neuromuscular fatigue, it's quite possible they don't improve long-term progression, because they function as 'reverse KAATSU'. Neuromuscular fatigue during high-repetition sets is not necessarily undesirable for muscle growth, as it increases muscle activity.

Moreover, IPC's benefits fade over time with repeated application according to a study by Marocolo et al. (2016).

IPC is also impractical to implement. It takes a lot of time, because unlike with KAATSU, IPC generally requires occluding blood flow completely so that you have no more pulse in that limb for multiple minutes. You should not experience neural symptoms like tingling or numbness, however. A common protocol is alternating 5 minutes of ischemia and reperfusion 4 times, which takes 40 minutes(!) This appears to be safe in the short-term, but there's not much research on the long-term effects of its regular application in strength trainees. You may also need a professional blood flow occlusion cuff to perform IPC safely. Knee wraps could work, but you could damage yourself by tightening them too much, especially if they're narrow wraps.

For women, IPC is probably not even worth trying, because almost all positive findings for strength training are in men. Paradis-Deschênes et al. (2017) found that IPC is more effective at delaying neuromuscular fatigue during strength training in men than in women. Women tend to have better muscle perfusion than men, so they probably have less to gain from IPC.

Overall, IPC is an interesting emerging training technique that can acutely enhance strength-endurance in men, but it’s very questionable if it’s worth bothering with in the long run. As it stands, IPC is arguably only worth trying for male CrossFit and Strongman competitors before competitions.

How to save time in the gym

Several advanced techniques are particularly useful to save time. The following guide provides concrete guidelines on how to effectively compromise on your workout time while still stimulating as much muscle growth as possible.

➢ Guide

How to save time in the gym

Note: paired sets, (antagonist) supersets and circuit training are discussed in the topic on exercise order. Concentric, isometric and eccentric only muscle actions are discussed in the topic on exercise selection and repetition tempo.