Set Volume for Muscle Size: The Ultimate Evidence Based Bible

The Volume Bible was originally published in my **Research Review** where I keep you up to date every month with the latest research on muscle gain and fat loss. **Click here to learn more**. For some more free sample content before you buy**,** **sign up for my newsletter**.

TL;DR Version

- **On average, muscle growth tends to be best with around 8 sets per muscle group per training session in trained individuals. Frequency can be used to manipulate weekly volume.**
- **Individual results may vary widely from the average.**
- **2-3 sets per muscle group per training session is sufficient for beginners.**

Key Takeaways

- **Updated meta-analytic data shows an inverted U in terms of the relationship between training volume in a single session, and hypertrophy in trained subjects.**
- **Beginners do not appear to be very responsive to increases in volume.**
- **Hypertrophy appears to increase with increasing volumes of up to 8 sets in a single training session in trained subjects; it tends to plateau or regress at higher per-session volumes.**
- **There is an interaction between volume and frequency; higher weekly volumes (20+ weekly sets) only appear to be effective when combined with higher frequencies (3+ days per week), supporting the concept of a maximum effective dose per training session.**
- **Maximum effective doses observed across studies were up to 10 weekly sets when training each muscle group once per week, up to 20 weekly sets when training each muscle group twice per week, and up to 30-45 weekly sets when training each muscle group three times per week. The maximum number of effective sets may depend upon rest interval length and whether compound movements are being used (the max number of effective sets may be towards the upper end with compound movements and short rests of 90 seconds or less).**
- **Some evidence indicates that there are less non-responders with higher volumes, and that people tend to be more responsive when increasing their volume relative to what they were doing before.**
- **Given that people tend to be more responsive when increasing volume relative to what they were doing before, there is a theoretical case for cycling set volume. This would involve increasing volume over time to the highest effective per-session volume until a performance plateau is reached. Volume would then be decreased to a maintenance level for a period of time to re-sensitize the muscle to a volume stimulus. Volume would eventually be increased again, and this pattern would be repeated over time.**
- **Regardless of training volume, genetics play a strong role in hypertrophy. People who respond well to low volume will also tend to respond well to high volume, and people who don't respond well to low volume will likely still be a low responder to high volume (although the response will likely be improved).**

Practical Application

- Hardgainers may benefit from increasing their volume, compared to the popular strategy of reducing volume and frequency.
- 2-3 sets per muscle group per session is sufficient for beginners.
- Per-session volumes of around 8 sets per muscle group will likely produce the best hypertrophy on average in trained subjects, although individual results and needs may vary dramatically from that average.
- Volumes beyond 10 sets in a session may represent "junk volume" and may not be effective (or even cause regression), although this will likely vary from one person to the next. If one desires to train in the 10-20 weekly set range, it is likely best to split it up into 2-3 training sessions. If one desires to train for more than 20 weekly sets for a particular muscle group, then it is best to split it up into three or more sessions during the week.
- The classic "bro-split" of blasting a muscle group for very high volumes (like 20 sets) once per week is likely an inferior way to train, and it is better to split the volume up into frequencies of 2-3 days per week.
- If you're training a muscle group twice per week, 10-20 weekly sets is likely a good range to potentially maximize hypertrophy, although individual needs will vary.
- If you're training a muscle group three or more times per week, volumes of up to 30-45 weekly sets for a single muscle group may be beneficial, but the increase in gains at these volumes is not as high as the increase when moving from single digit weekly sets to 10-20 weekly sets. Thus, the best "bang for your buck" occurs in the 10-20 weekly set range, even at a frequency of 3 times per week. This represents the best balance between time investment and hypertrophy achieved.
- While 21+ weekly sets were associated with the greatest gains at a frequency of three times per week, this doesn't mean you should be doing 21+ weekly sets for every single muscle group. That is likely higher than most individuals can tolerate or have time for. A more realistic approach would be a specialization strategy. This is where you

use very high volumes for 1-2 muscle groups, while training with low to moderate volumes for others. After a 2-4 month period, you switch to a few different muscle groups for high volume specialization.

- **While the highest gains were observed with a combination of high volume and frequency, good gains are observed with low to moderate volumes as well, with moderate volumes giving the best trade-off between results and time investment. YOU MUST CONSIDER THE NEEDS OF THE INDIVIDUAL WHEN PROGRAMMING VOLUME, including schedule, volume tolerance, recovery ability, available time to train, importance of achieving maximal hypertrophy, injury history, etc.**
- **The maximum number of effective sets may be impacted by rest intervals, types of exercise used (compound versus isolation), and previous training volumes. Shorter rest intervals (90 seconds or less) with compound movements may require more sets to get the same response (and thus not necessarily save any time).**
- **People who have plateaued on low-to-moderate training volumes may benefit from an increase in training volume.**
- **This data doesn't mean you jump into doing massive weekly volumes, even for a single muscle group. It is important to build up to it.**
- **This data doesn't suggest you train with high volumes all the time. Periods of low volume training may be necessary to help with recovery.**
- **A volume cycling approach may be beneficial. In this approach, set volume is slowly increased over a period of time, until a maximum effective amount is achieved (around 8 sets per muscle per session, 2-3 times per week). Once a performance plateau is reached at this high volume, volume is reduced to a maintenance level (2-4 sets per muscle per session, 2-3 times per week) for a period of time to re-sensitize the muscle to a volume stimulus. Set volume is then ramped back up to around 8 sets per session, and the volume cycle is repeated.**
- **High volume cycles should probably not exceed 8-12 weeks in duration.**

TABLE OF CONTENTS

- **Wrapping it up**

"How many sets should I do?" is probably one of the most common questions that people have when trying to build muscle. In fact, the number of sets you should do to build muscle can be such a point of contention that people have fought internet and journal article wars over it. Entire training philosophies (i.e., High Intensity Training and Heavy Duty) have been built around how many sets people think you should do. In fact, for years, people have been arguing over whether you should train with a low number of sets, or high number of sets, to maximize muscle hypertrophy.

The best approach, of course, is to examine the scientific evidence, and consider where the overall weight of the evidence lies. In regards to training volume, it's not that easy, due to the limitations in the existing research. Still, that doesn't mean we can't come up with some solid evidence-based recommendations.

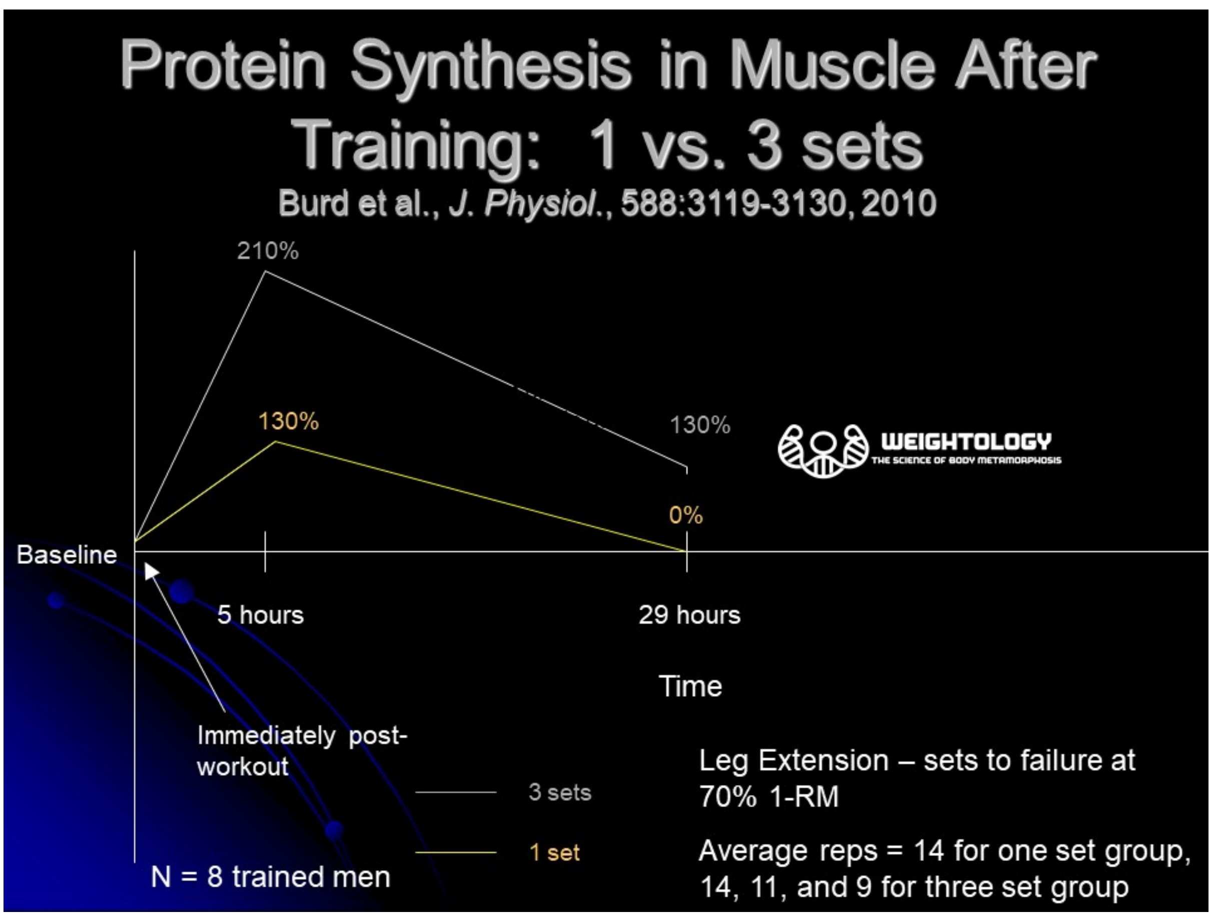
What Do We Mean by Set?

The first thing we need to clarify is what we mean by a "set." In a weight training workout, there are a lot of ways you can do a set, from a warm-up set that hardly pushes you to failure, to a gut-busting set of 20-rep squats to failure. In this article, a set is going to be defined as a set of moderate to high repetitions (approximately 8 reps or more) to muscular failure or near failure. I use this definition because high load, low rep sets do not produce as much hypertrophy as more moderate 8-12 rep sets, despite an equivalent number of hard sets. However, moderate-rep and high-rep sets to failure are similar in their impacts on muscle hypertrophy. Also, a set should be to near muscular failure, because stopping well short of failure will impair muscle hypertrophy. Finally, a set counts towards a particular muscle group if that muscle group can be considered a prime mover in the exercise that is being used. For example, 3 sets of bench press will count as 3 sets for triceps, since the triceps are active prime movers in a bench press. Three sets of bench press, and 3 sets of tricep pushdowns, would count as 6 total sets.

Set Volume and Muscle Protein Synthesis

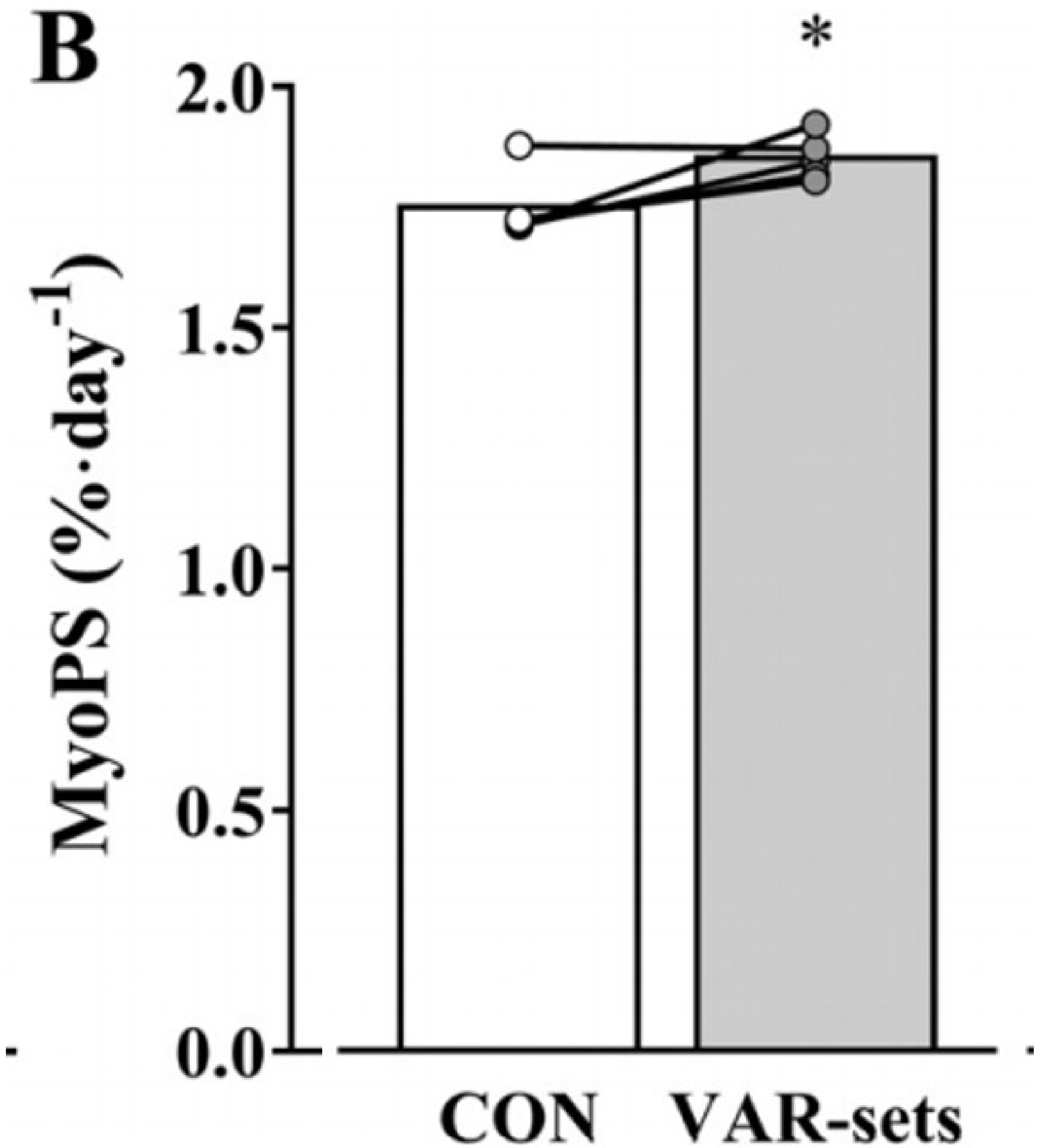
One of the first places we can look for evidence is in the impact of set volume on muscle protein synthesis. Remember that resistance training stimulates protein synthesis, the process by which your muscles build new protein. When this process of protein synthesis exceeds the rate of protein breakdown, your muscles grow. The elevation in protein synthesis happens very quickly after a training session, and continues for 24-48 hours after the session. If set volume impacts muscle hypertrophy, then it would stand to reason that it may impact muscle protein synthesis as well.

One study that examined the impact of set volume on muscle protein synthesis came out of the lab of Stu Phillips. The researchers compared 3 sets of leg extensions to 1 set of leg extensions. Both groups trained at 70% 1-RM to muscular failure. Fed-state muscle protein synthesis (the amount of protein your muscles make after you eat a meal, which is really important when it comes to building muscle size) was elevated by almost twice the amount in the 3-set group compared to the 1-set group. Protein synthesis was still elevated by 130% at 29 hours after the training session in the 3-set group, but was back to normal in the 1 set group. In other words, muscles were not only making more protein soon after the workout with 3 sets to failure, but they were still making more protein 29 hours later compared to 1 set. Since muscle protein synthesis correlates with gains in muscle size once you get past the initial muscle damage, this would imply that 3 sets is better than 1 set for putting on muscle.



In another study looking at the impact of set number on muscle protein synthesis, 6 sets of 8 reps at 75% 1-RM on the leg extension caused greater muscle protein synthesis up to 2 hours after the training session, as compared to 3 sets. This was true in both young and old subjects. Also, in the older (but not the younger) subjects, 6 sets of 14 reps at 40% 1-RM caused a greater muscle protein synthesis response compared to 3 sets. There are two major problems with this study. First, subjects did not train to failure...8 reps at 75% 1-RM, and 14 reps at 40% 1-RM, can be far short of failure for some individuals on a leg extension. Second, the researchers only measured protein synthesis out to 4 hours. Thus, this study might suggest that 6 sets per muscle group is better than 3 for muscle protein synthesis, but there are a lot of limitations to the study.

In a third study by Damas and colleagues, 12 sets to failure with 2 minute rests on the quadriceps (6 sets of leg press and 6 sets of leg extensions) only caused a small increase in muscle protein synthesis compared to 8 sets to failure (4 sets of each exercise) in trained subjects.



From Damas et al. (2019). VAR-sets did 12 sets in quadriceps, while CON did 8 sets. The increase in muscle protein synthesis from the additional 4 sets was very small, and was not related to hypertrophy.

This small increase in muscle protein synthesis was not associated with greater hypertrophy over 8 weeks, suggesting that the small increase may have been more due to a small increase in muscle damage. ***This data suggests that muscle protein synthesis may begin to plateau somewhere in the 8-12 set range.***

Finally, one rodent study found that muscle protein synthesis increased with an increasing number of "sets" of electrically stimulated muscle contractions, statistically plateauing at 5 sets but the raw mean peaked at 10 sets. Protein synthesis tended to be lower at 20 sets. However, a "set" in this study may not be equivalent to a a set as we define it. There are also other differences which I described in a research review. Regardless of these differences, this data does align nicely with the previous study by Damas et al., suggesting a plateau in muscle protein synthesis somewhere around 10 sets.

Given these studies, **we can say that multiple sets will create more protein synthesis than single sets to failure, and it looks like the response may plateau between 8-12 sets.**

Set Volume and Anabolic Signaling

Another place we can look is the impact of set volume on anabolic signaling. When you train with weights, the tension on your muscles sends molecular signals to muscle cells to start creating new protein. One important molecular signal is called p70S6K phosphorylation, which has been found to correlate with gains in muscle size when measured 5 hours after a training session.

There have been some studies that have examined the impact of set volume on p70S6K phosphorylation. One study showed 10 sets of 10 RM (leg press, 2 min rest) resulted in greater p70S6K phosphorylation compared to 5 sets of 10 RM when measured 30 minutes after the session. In the protein synthesis study out of Stu Phillips's lab that was mentioned earlier, p70S6K phosphorylation was significantly elevated at 29 hours after 3 sets of leg extensions, but not 1 set. In a third study, 3 sets of 6 RM of a leg press resulted in a threefold elevation of p70S6k phosphorylation, and 5 sets of 6 RM resulted in a sixfold elevation (i.e., double the response). In the rodent study mentioned earlier, p70S6K phosphorylation continued to increase with increasing "set" volume up to 20, although "sets" here cannot be considered equivalent to human sets. In a fifth study, phosphorylated S6K were 19% greater with 6 sets per muscle group performed in a training session versus 2 sets.

Another molecular anabolic signal we can look at is the mechanistic target of rapcomycin or mTOR, a protein that regulates muscle protein synthesis. In this study, 6 sets per muscle group per session resulted in 12% higher phosphorylation of mTOR compared to 2 sets. In this same study, the higher volume resulted in a 28% greater phosphorylation of ribosomal protein s6, another signaling molecule involved in muscle protein synthesis. The higher volume also caused greater levels of RNA (a marker of creation of ribosomes, which are the site of protein synthesis) and transcription factor c-Myc, which is important in initiating RNA transcription (one of the steps in muscle protein synthesis).

Overall, the anabolic signaling data tells us that "more is better" in terms of sets, but it doesn't give us an optimal range or tell us when "more" becomes "too much."

Set Volume and Satellite Cells

Muscle fibers have nuclei, which are the control centers for these muscle fibers and contain important genetic information. To repair or build new muscle fibers, you need new nuclei. Enter satellite cells, which are dormant cells located outside of muscle fibers. When a muscle fiber is damaged, satellite cells donate their nuclei to allow the fibers to be repaired and grow. Thus, satellite cells are an important component in the process of muscle hypertrophy. Thus, if set volume impacts muscle size, then one mechanism through how it does so may be through satellite cell activation.

Only one study has looked at the impact of set volume on satellite cell activation. In this study, 3 sets of leg press and 3 sets of leg extension (6 sets for quadriceps total done 3 times per week, or 18 total weekly sets) resulted in greater satellite cell activation than 1 set of leg press and 1 set of leg extension (2 sets for quadriceps per session, or 6 weekly sets). This was accompanied by a much greater increase in leg extension 1-RM strength as well (48% versus 29%). This would suggest that a total weekly set volume in the teens might be better than single digits, at least for legs.

In this study, researchers also looked at satellite cell activation in the trapezius, as well as shoulder press strength. They did not observe any impact of set volume on either satellite cell activity or shoulder press strength. However, given that the trapezius is not a prime mover in the upper body exercises used in this study (seated chest press, seated rowing, lat pulldown biceps curl, and shoulder press), the satellite cell activity in the trapezius may not give us sufficient information as to the impact of set volume on satellite cells in the upper body.

Overall, this data would suggest that a weekly set volume in the teens is likely better for hypertrophy than single digits, at least for the legs.

Beyond the Biopsies

So far, all of this data only tells us that, if you want to gain as much size as possible, multiple sets per muscle group are better than single sets, more sets are better than less (to a point), and weekly volume in the teens may be better than in the single digits. But this is all based on extrapolation from data derived from muscle biopsies. Ultimately, we need to look at what happens to changes in muscle size when you put people on training programs with different set volumes.

A fair number of studies have been done over the past few decades, that have looked at changes in muscle size when comparing different set volumes. Results have varied, with some studies (like this one) showing more muscle gain with more sets, while other studies (like this one) showing no significant difference with more sets. Differences in outcomes between studies might relate to differences in study design, in populations used, in training volume, in training frequency, etc. However, another key factor that may explain the differences is one of sample size (i.e., the number of subjects in each study).

To give you an idea of why sample size may impact the results, let's say you want to do a study that compares low volume training to high volume training. You need to know how many people you should recruit to your study. So, you do what is called a ***power analysis***. This gives you an approximation of how many subjects you will need to successfully detect a particular difference between groups. To do a power analysis, you need an idea of what sort of difference you are interested in seeing. For example, perhaps you think that high volume training will give you double the muscle gains. You then use data from previous research to get an idea of what the typical level of muscle gain in a study happens to be, and how much it tends to vary from one person to the next. This data goes into the power analysis, and you end up with an estimate of how many people you are going to need.

Let's go through this power analysis exercise with some real world data. Direct measurements of muscle size (like ultrasound) are superior to indirect measurements (body composition techniques like DEXA), so we'll stick with data that uses those types of measurements. Typical changes in muscle thickness, assessed by ultrasound, tend to be around 5-10% over a typical 8-12 week study. So, let's say I think a low volume group might experience a 5% change in muscle thickness, and a high volume group might experience a 10% increase in muscle thickness. Essentially, I'm guessing that I'll get double the gains with high volume over low volume.

So what is the number of subjects that I need? Using data from a rest interval study I collaborated on with Brad Schoenfeld, Menno Henselmans, and others, and then running the data through some online power analysis software called GLIMMPSE, it turns out ***I would need approximately 100 subjects per group to declare a 5% versus 10% gain in muscle size as statistically significant, 80% of the time!!!!!!*** If I reduce this to 50% of the time, ***I would still need about 50 subjects per group!***

In other words, ***if I did 100 studies, and wanted to be able to declare a doubling of muscle size as statistically significant in only 50 of those studies, I would need 50 subjects per group!!!!***

Now, what is the typical sample size of most weight training studies? Maybe 8-15 subjects per group?

Let's look at the statistical power if you only had 10 subjects per group. Running the same data through GLIMMPSE, I get a statistical power of approximately 30%. This means that, ***with only 10 subjects per group, you will declare a 5 versus 10% gain in muscle size as statistically significant in only 30 out of 100 studies!***

This means that ***most weight training studies on volume are essentially set up to fail to detect important differences***. Changes in muscle size are small, and vary a lot from one person to the next, and so you need HUGE differences between groups to detect a difference over a typical 8-12 week study that only has around 10 people per group. But the reality is that the impact of doubling your training volume isn't going to result in 3-4 times the gains. It ***might*** result in a doubling of gains, but, as you just learned, most weight training studies have sample sizes that are simply too small to detect even that amount. This is why you see disparate results among studies. Some will successfully detect a difference based on random chance alone, while others will miss a difference, even if a true difference exists (in statistics, this is called a ***type 2 error*** or false negative).

Here's an example of a possible type 2 error. Ostrowski and colleagues looked at the effects of weight training set volume on muscle size. They compared three volume levels: low, medium, and high. The following table shows the percentage gains in muscle size, as well as the effect size (a measurement of the meaningfulness of an effect), for each group:

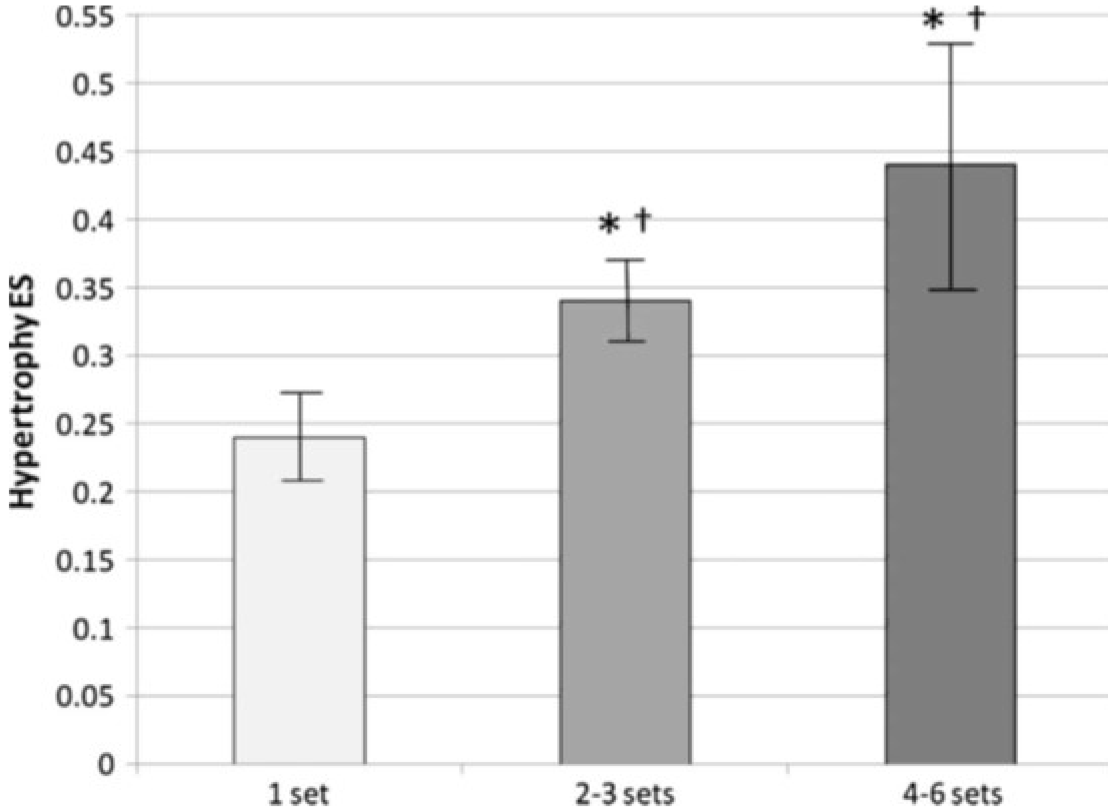
	3 weekly sets (7 for triceps)	6 weekly sets (14 for triceps)	12 weekly sets (28 for triceps)
Tricep Thickness	+2.27% 0.25	+4.65% 0.4	+4.76% 0.5
Rectus Femoris Cross-Sectional Area	+6.77% 0.30	+5% 0.29	+13.14% 0.78
Rectus Femoris Thickness	+3.03% 0.27	+1.05% 0.14	+6.35% 0.73

In this study, double-digit weekly set volumes resulted in approximately double the muscle gains (the orange cells), but these differences were not statistically significant. Why would this happen? This study only had 9 subjects per group, so there's a good chance this is simply a false negative or type 2 error.

Enter the Meta-Analysis

Realizing the limitations in the existing data, in 2010 I decided to do a meta-analysis on the impacts of set volume on muscle hypertrophy. A meta-analysis is a "study of studies." This is where you group a body of studies together, and statistically analyze them to see if there's an overall trend. In other words, it's a formal way of seeing where the weight of the evidence lies. A meta-analysis can be useful when you have a lot of studies with small sample sizes. The idea is, perhaps each study alone is too small to be able to detect a significant difference between groups, but if you group all the studies together, most of the studies should favor one group over another in terms of the raw average, if there's truly a difference. Basically, if a lot of studies have results like the one by Ostrowski that I mentioned above, then that's a pretty good indication that higher volumes truly are better...it's just that the studies are too small in size to consistently show it (i.e., a type 2 error as I mentioned earlier).

When I did this analysis, I found that multiple sets per exercise were superior for hypertrophy compared to single sets. Both categories of 2-3 sets per exercise and 4-6 sets per exercise were greater than 1 set. The magnitude of the average effect size (again, effect size is a value assessing the meaningfulness of an effect) tended to favor 4-6 sets over 2-3 sets, although that difference was not statistically significant. Here's a chart from the study:



Now, there were a number of limitations to this analysis. First, there were only 8 studies that met my inclusion criteria. There were only 2 studies that involved 4-6 sets per exercise. There wasn't enough data to determine if there were differences due to factors such as training status (i.e., trained versus untrained subjects). I was the sole author on this paper, so there was no one available to double check my work, and thus it's always possible some bias or error could sneak in. This analysis only tells us about volume in a single session, and not overall weekly volume. Finally, sets per exercise is not the same thing as sets per muscle group. For example, you could do 1 set of incline press, 1 set of flat press, and 1 set of decline press, and that's 3 sets for your chest, but in this analysis it would be categorized as 1 set. Still, more sets per exercise will still mean more sets per muscle group, so this meta-analysis clearly showed that your gains increase as your volume increases.

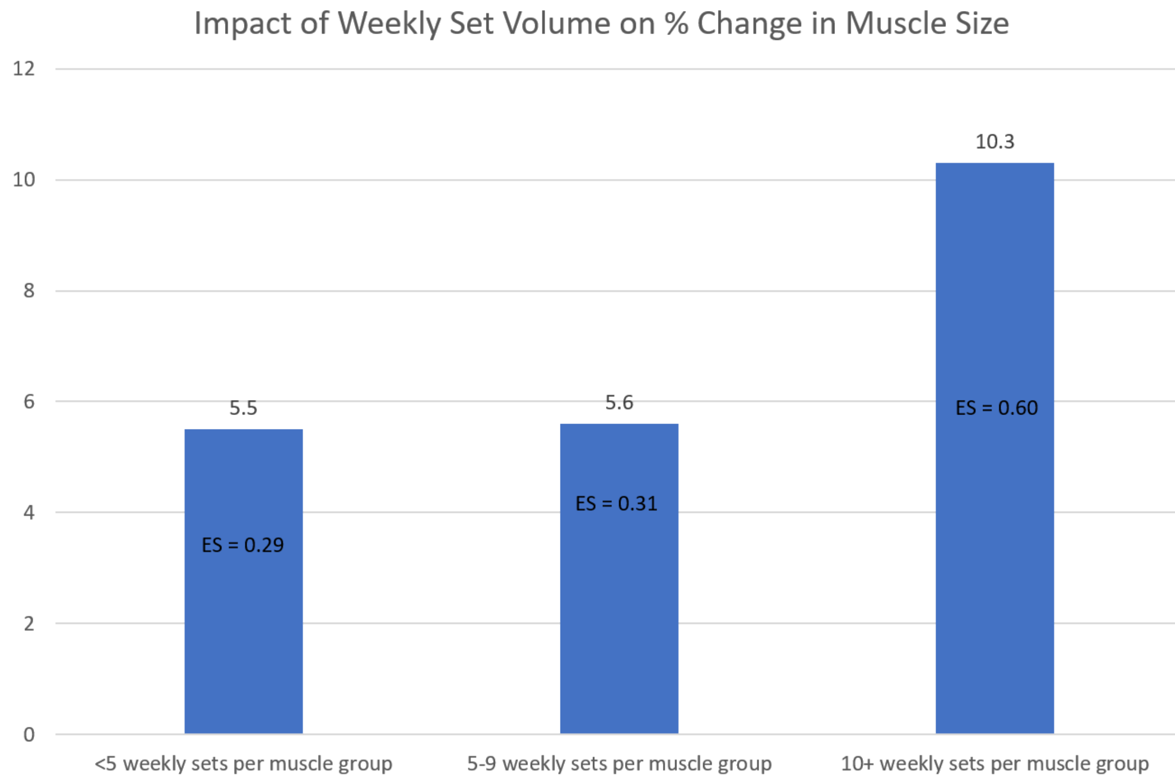
An Even Better Meta

Six years later, more studies on hypertrophy had come out. Brad Schoenfeld, Dan Ogborn, and I discussed doing an updated meta-analysis, with all of the new research included. In this analysis, we would have multiple individuals coding the studies to serve as a double-check on accuracy, and help reduce bias. We would also look at volume in terms of sets per muscle group per week, rather than sets per exercise. Our results were published in the June 2017 issue of the Journal of Sports

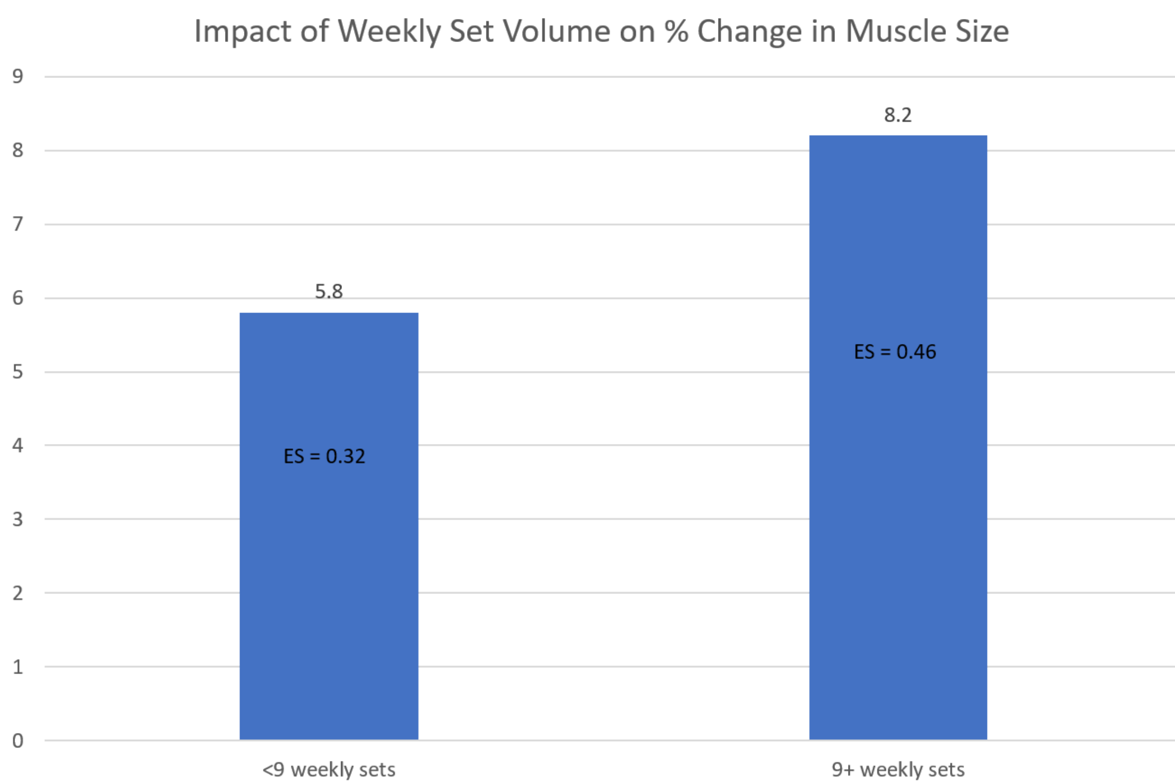
Science, and we confirmed a relationship between training volume and hypertrophy. ***I'll note that since that paper was published, we did discover an error in how volume was classified for a study by Correa and colleagues; we erroneously classified weekly volume as 9 sets in the high volume group and 3 in the low volume group, but it in fact was 18 in the high volume group and 6 in the low volume group***. While this did not materially impact the conclusions of the paper, it did impact the dose-response relationship so that it wasn't apparent as you moved from <5 sets to 5-9 sets (but it still existed for higher volumes). ***I'm reporting the fixed numbers to you this review, so they are slightly different from the published paper***.

First, we found a highly significant effect (with a P value of 0.003...remember that 0.05 is considered significant) for each additional weekly set. For each additional weekly set that was done, the effect size would increase by 0.027, and the percentage gain in muscle size would increase by 0.38 percentage points. So, if you did 16 weekly sets (such as 8 sets per muscle group, twice per week) compared to 6 weekly sets (like 3 sets per muscle group, twice per week), the effect size would be higher by 0.27, and the percentage gain would be higher by 3.8 percentage points (such as an 8.8% improvement in muscle size versus a 5% improvement). Now, this analysis assumes a linear relationship between set volume and hypertrophy, which in real life would likely not be the case. In other words, this doesn't mean you can just keep doing more and more sets and assume the gains keep going higher; at some point they will level off and possibly even regress due to overtraining. Unfortunately we didn't have enough studies utilizing really high volumes to get an idea where the upper limit for volume might be.

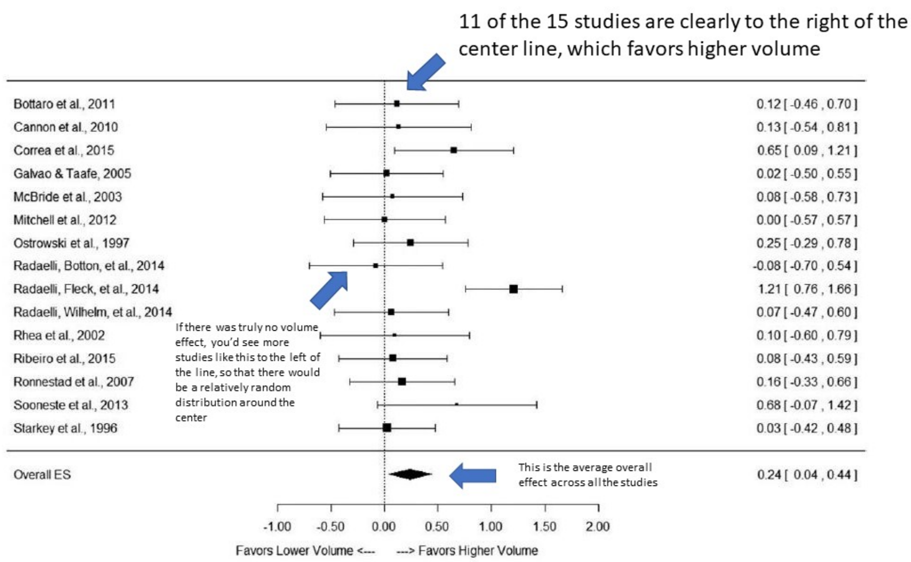
When categorizing the weekly set volumes into <5, 5-9, and 10+ weekly sets, there was a distinct advantage to double digit weekly set volumes, with nearly double the gains (ES = Effect Size).



We also divided weekly volume into less than 9 sets, or 9+ sets. Again, the higher volume was better.



Finally, here is a forest plot of all the studies included in the analysis. A forest plot tells you whether high volume or low volume was favored in each study. If a dot is to the right of the center line, it means that study tended to favor high volume. If it's to the left, it tended to favor low volume. The further to the right or left, the stronger the effect. The size of each dot represents the weight of the study in the analysis; studies with larger sample sizes get more weight. You can see that nearly all of the studies are to the right of the center line, indicating most studies favored high volume. Some are dramatically to the right of the line. In fact, only one study is to the left of the line. This is consistent with an impact of training volume on hypertrophy. If there was no impact of volume, then studies would be more randomly distributed around the center line, with some studies to the left, some to the right, and some on the center. However, this is clearly not the case. The average across all the studies is represented by the large black diamond at the bottom, which you can see favors higher volume.



Diving Deeper

Since that meta-analysis was published, there is now more existing data on the impacts of set volume on hypertrophy. Five studies have been published, which are described in more detail later on in this article. Four of these studies were eligible to be included in the meta-analysis, so all of these meta-analytic results represent the most up-to-date overview of the literature. With this new data, we now have enough studies with very high volumes (20+ sets) to examine the impacts of such volumes on hypertrophy. There is also sufficient data to examine whether there is an interaction between volume and frequency. In other words, is there a maximum effective volume per training session, so that you need to train with higher frequency to achieve effective high weekly volumes?

Problems With Previous Meta-Analytic Approaches, and the Inverted U Hypothesis

In the September 2018 update of this article, I had outlined how I approached performing the meta-analysis. Given some newly published research in the area, I've changed how I approach the meta-analysis. In the previous iteration, I had classified volumes within each study as "higher" or "lower." Given there are now a fair number of studies using 3+ different levels of volume in the same study, it's no longer appropriate to classify volume in such a way. It's also not appropriate because, if there is a maximum volume ceiling per training session, then dividing volume this way could mask this effect. In other words, if I were to use this classification, some studies might show higher volume to be better than lower volume, but others might show higher volume to produce a regression in performance. When aggregated together, it would suggest there is no benefit to variations in volume. However, if the latter study used a very high per-session volume that would exceed the theoretical per-session threshold, while the former study did not, it would be misleading to aggregate them together.

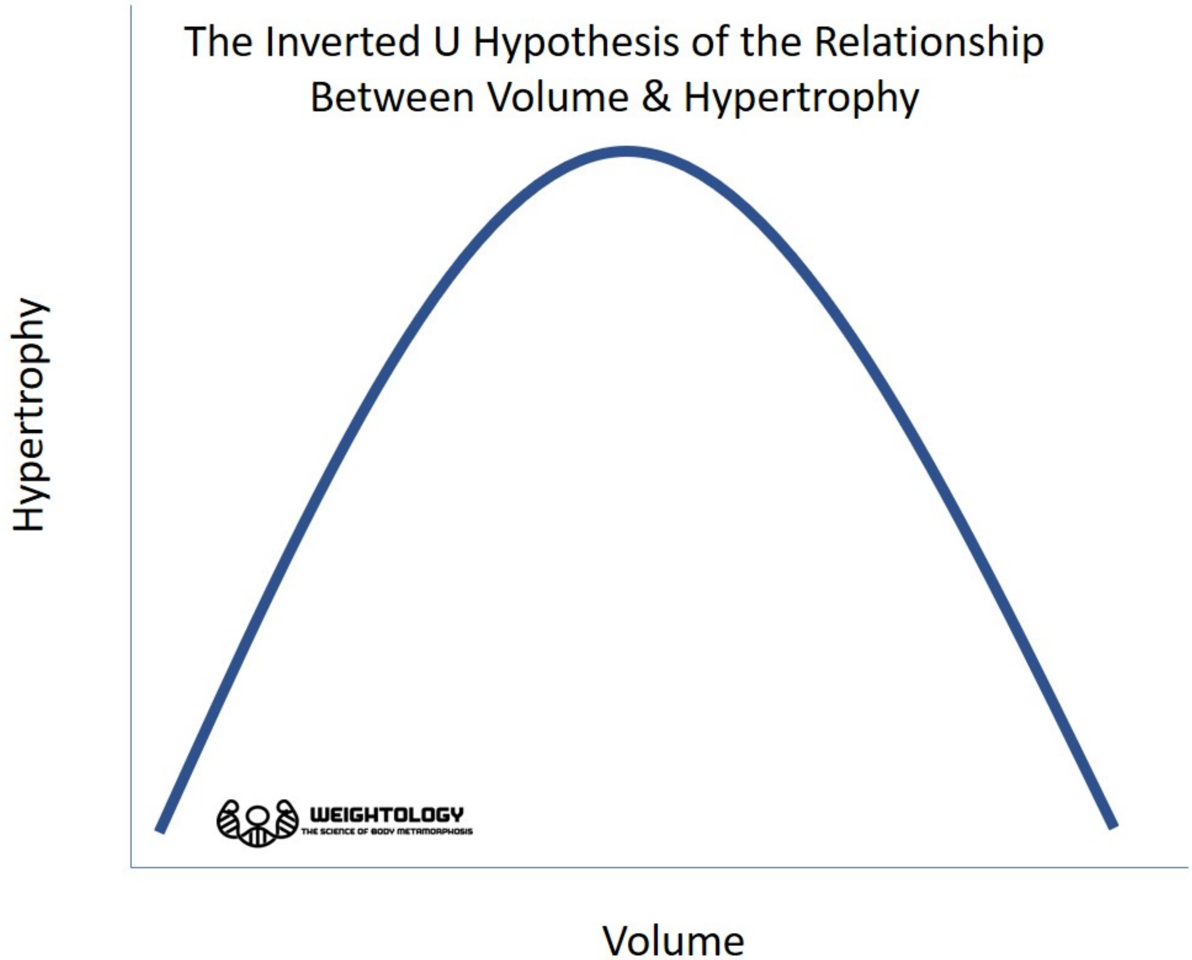
For example, let's say study #1 compares 9 weekly sets to 18 weekly sets, divided into three times per week. That's 3 versus 6 sets per session. Let's say study #1 shows a benefit to the higher volume.

Study #2 comes along and compares 9 weekly sets to 18 weekly sets, but only trains once per week. That's 9 versus 18 sets per session. Study #2 shows a benefit to the lower volume.

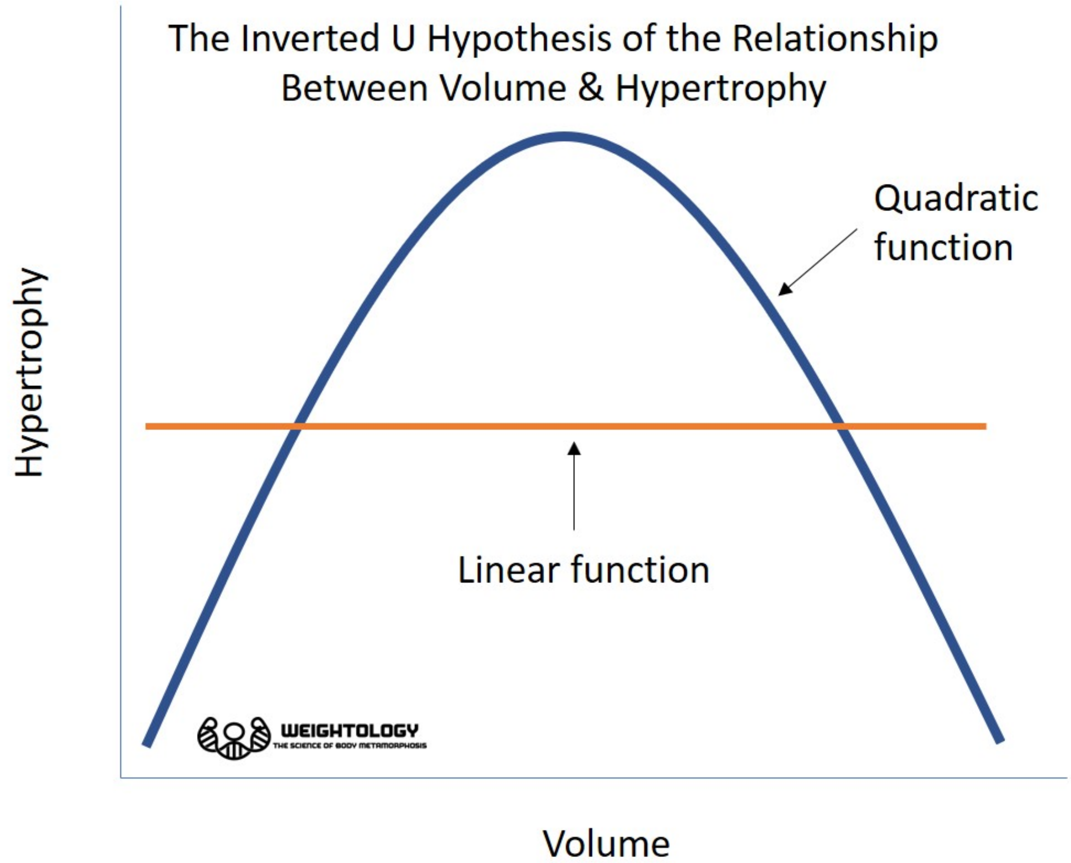
If I were to aggregate study #1 and study #2 together, they would appear to cancel each other out. Both compare 9 to 18 weekly sets, but show the opposite results. However, the two studies utilized different frequencies; it's very possible that study #1 showed a benefit because the per-session volume was fairly low, and study #2 showed the opposite because the per-session volume became excessive in the highest volume condition.

Thus, the previous approach I had used for meta-analysis (comparing higher versus lower volumes in each study in a binary fashion, or performing a meta-regression while ignoring frequency) is not a good approach. A better approach is to examine whether there is an interaction between volume and frequency. If there is, then it would indicate it is better to look at training volume on a per-session basis, rather than a weekly basis.

Another problem with my previous approaches is that my statistical models tested for a linear relationship between volume and hypertrophy. However, this doesn't effectively test the inverted U hypothesis of training. The inverted U hypothesis suggests that hypertrophy would decrease if training volumes became excessive.



If we were to test the inverted U hypothesis with a simple linear function, it would suggest a flat line and no relationship between volume and hypertrophy. However, this is simply due to the use of the wrong model. A more appropriate model would be a quadratic function.



It should be noted that the inverted U hypothesis would theoretically apply to both volume on a per-session basis, as well as on a weekly basis. In other words, there is likely an upper limit to "effective" volume in a single session. There would also be an upper limit per week, but this upper limit would likely be impacted by the training frequency if there is an upper limit per session. Thus, any analysis needs to take into consideration the potential interaction between volume and frequency, as well as the potential quadratic relationship between volume and hypertrophy.

Getting Technical

Here's what I did. Now, this section is a bit technical, so you can skip it if you don't care about methodology.

An effect size for each outcome was created by calculating the post-test mean minus the pre-test mean, divided by the pooled pre-test standard deviation. For example, if there were three levels of volume, then the pre-test standard deviation was pooled across all three levels. I analyzed the data using what is called *robust variance random effects modeling for multilevel data structures*. This probably sounds like a bunch of statistical gobledygook to you, so I'll explain it in laymen's terms. Basically, when you have a study, you can often have multiple outcomes from the same study (like quadriceps and biceps data). You have to account for the fact that those outcomes will be correlated, since they're from the same study (you can't treat them as independent). This is where the "multilevel data structures" comes in; my stats help account for this. Also, a "random effects" model, in laymen's terms, essentially means that I can't account for every possible source of variance between different studies, and that the "true" effect of volume may vary somewhat randomly (rather than be a single value), so I need to incorporate that uncertainty into my stats.

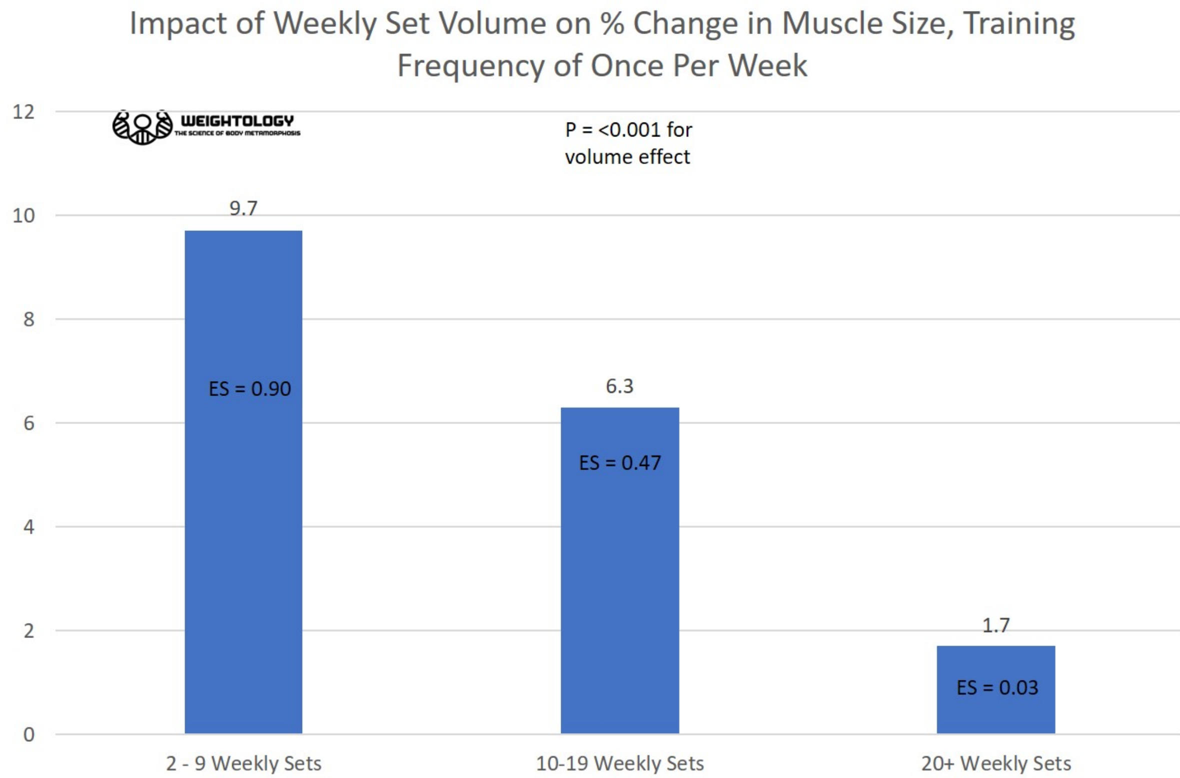
Now, each study is not weighted the same. Obviously, a study with a larger sample size (and hence more precision) should get more weight in the analysis. So, each outcome was weighted by the inverse of its variance (i.e., less variance = more precision = more weight).

Unlike my previous iterations of the analysis, I primarily ran set volume as a *continuous variable*. This means that, in most of the analyses, I did not categorize set volume into categories like high, medium, or low as I did previously. Also, rather than using weekly set volume, I used per-session volume and incorporated an interaction with frequency (1, 2, or 3 days per week). If there was an interaction, then I ran a separate analysis of weekly volume for each level of frequency (dividing weekly volume into 1-9, 10-19, or 20+). Finally, I took per-session volume and fit both a linear and quadratic function to the data. I used **meta-regression** to analyze the data.

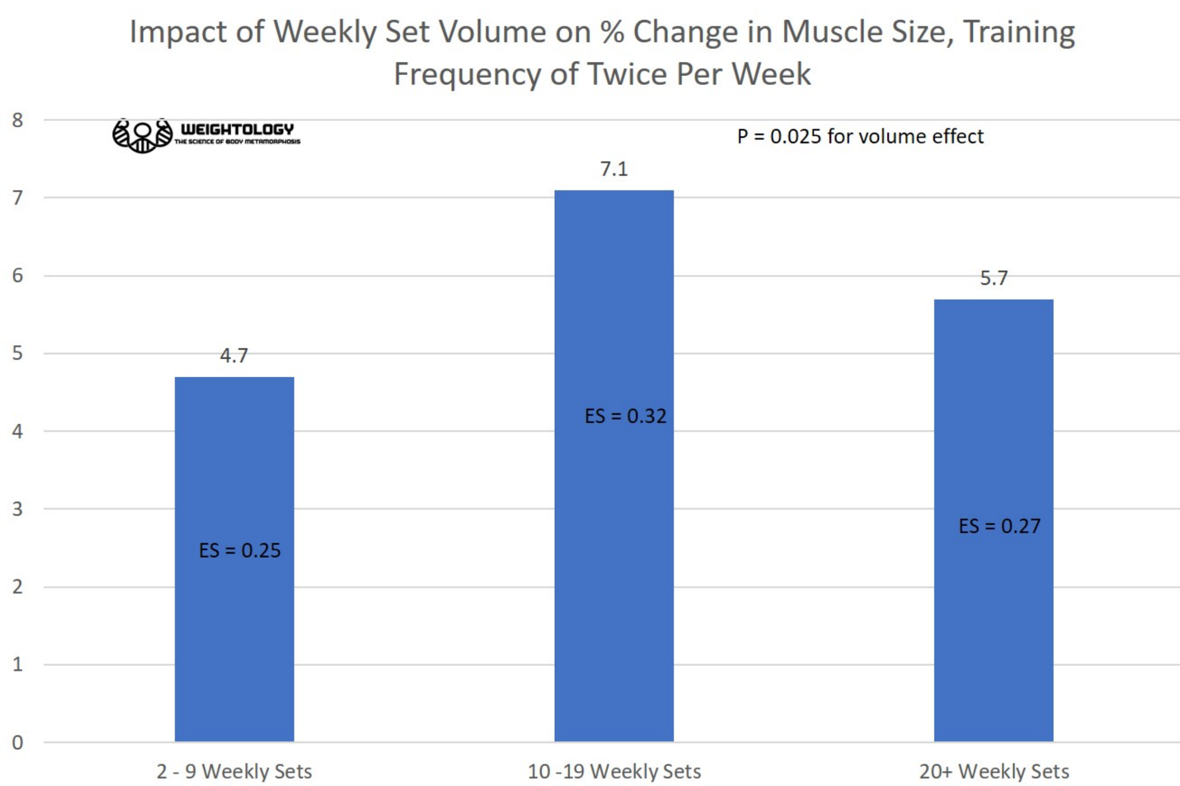
Meta-Regression Results

First, I ran an analysis that examined the interaction between set volume per session and frequency. The interaction between the two was highly significant ($P < 0.0001$), ***indicating that the effect of training volume is different depending upon the training frequency***.

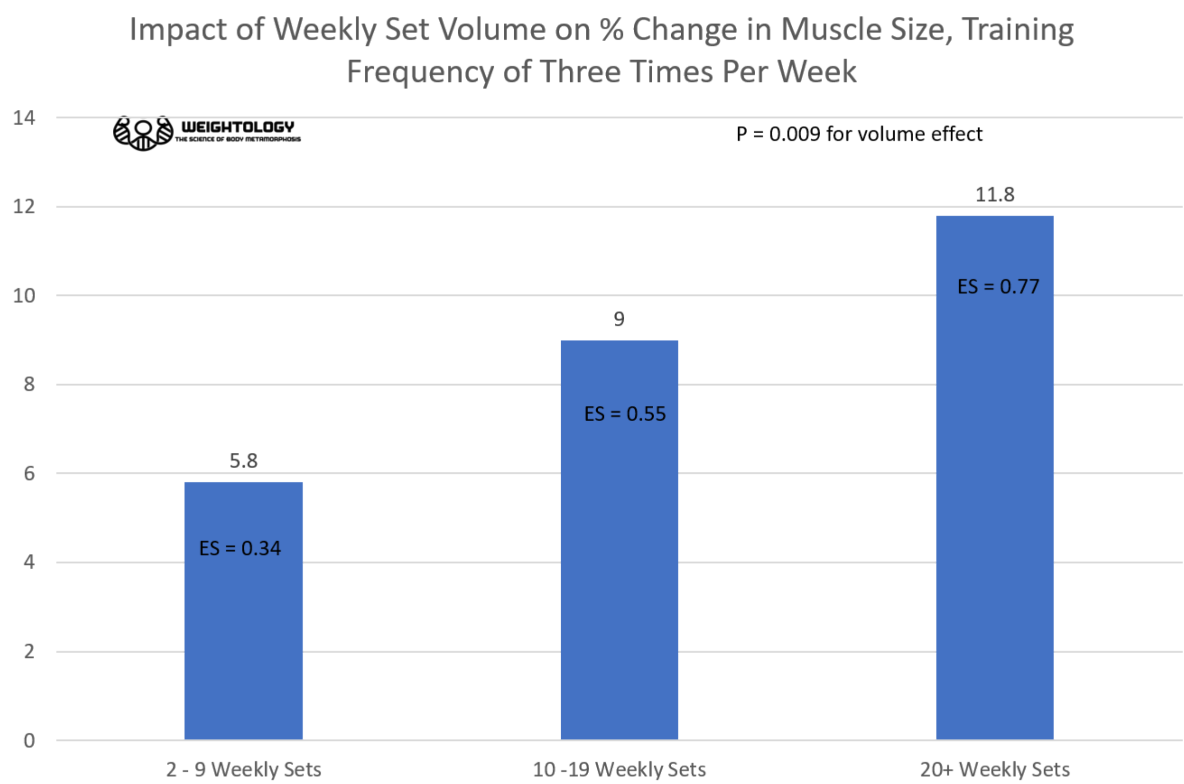
I then ran an analysis of weekly volume (as a categorical variable) for each level of frequency. At a low frequency of only once per week, weekly volumes of 10+ sets were inferior to 1-9 sets. However, this analysis should be interpreted with caution, as there were only three studies utilizing a frequency of once per week.



At a frequency of twice per week, the effects of volume did not quite reach statistical significance. In terms of the raw means, weekly volumes of 10-19 sets were better than weekly volumes of 1-9 sets, but there was no further benefit of 20+ weekly sets, and in fact a slight regression.



At a frequency of three times per week, the benefits of volume continued to increase up to 20+ weekly sets.



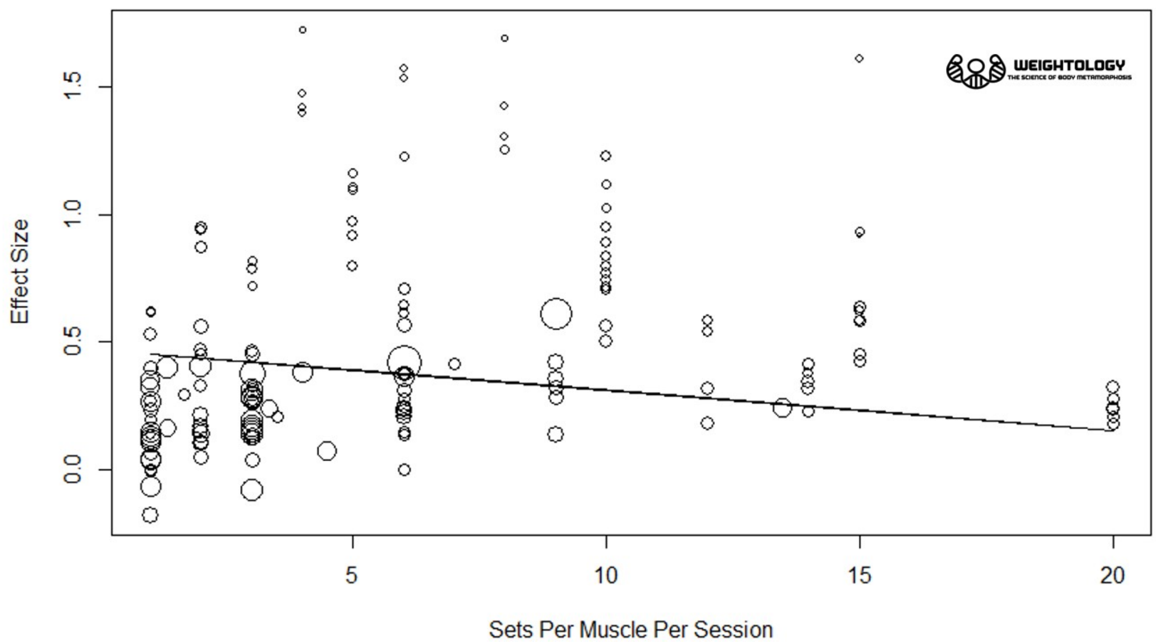
You can see the following pattern here:

- At once per week, 10+ sets (i.e., 10+ sets in a single session) doesn't offer any benefit and may result in less benefit.
- At twice per week, 10-19 sets tends to be the sweet spot, which is a per-session volume of up to almost 10.
- At three times per week, 20+ sets was best (in this case, it was 27-45 as there were no studies between 20 and 26). A weekly volume of 27 sets is 9 sets per session at three times per week.

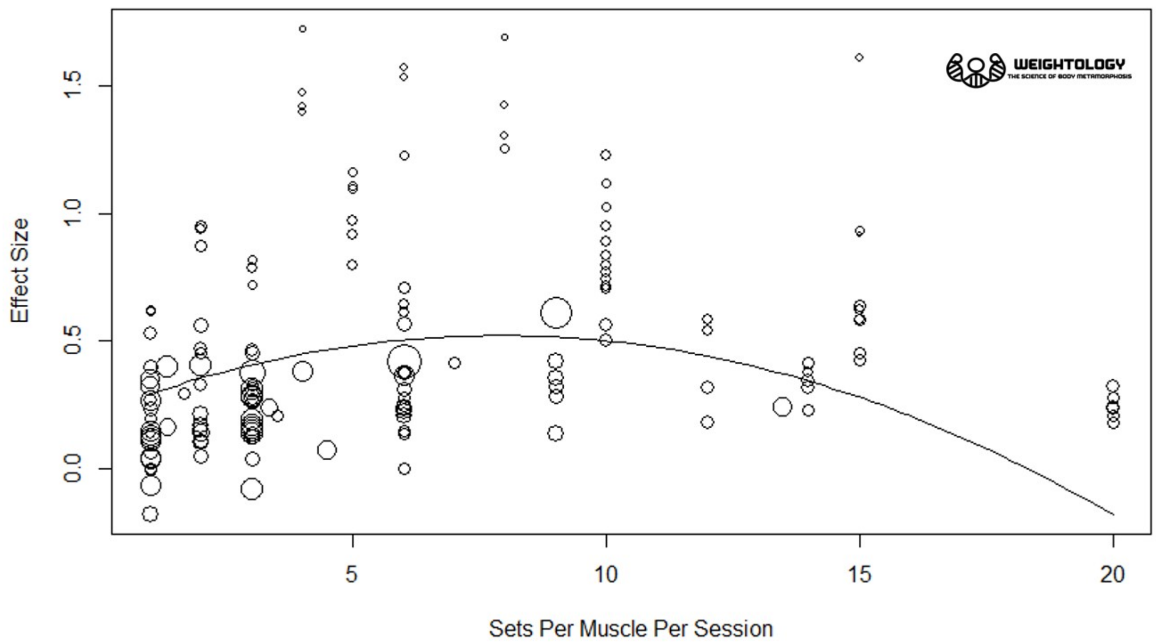
Overall, **this data suggests that there is an upper limit of effective volume that you can do in a single training session**. This limit appears to be around 10 sets in a single session. This why the benefits of very high weekly volumes only appear at frequencies of 3+ days per week, as the per-session volume remains around 10. At a frequency of twice per week, 20+ weekly sets becomes too much as the per-session volume will exceed the 10 threshold. At a frequency of once per week, weekly volumes beyond 10 become too much as it exceeds the per-session threshold.

Interestingly, the concept of an upper limit of effective volume of around 10 sets in a single training session is supported by the muscle protein synthesis data described earlier in this article, where muscle protein synthesis appeared to plateau somewhere in the 8-12 set range.

This is further supported when we look at the analysis where I fit either a linear or quadratic function on the data. If I try to fit a linear function on sets per muscle group per session, there is no significant effect of training volume (P = 0.51). The model fit, based on the Akaike's Information Corrected Criterion (AICC, an index of how well your model "fits" your data) is 259.22. Each data point in this graph represents an effect size from a study; larger circles have more weight in the analysis.

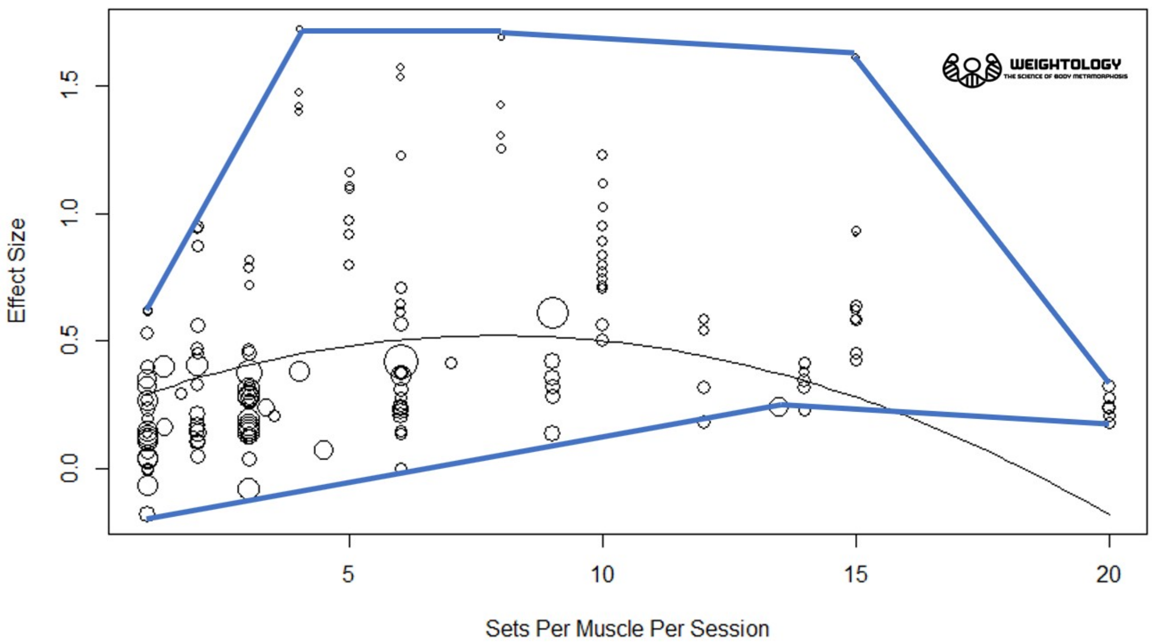


Remember, though, that the inverted U hypothesis is more consistent with a quadratic fit. **If I fit a quadratic function to the data, the effect of volume is highly significant (P < 0.0001)**. The AICC decreases to 148.54, which means a much better model fit (lower AICCs means your model is fitting the data better).



You can see that the curve peaks at around 8 sets per muscle group per session. This is in line with the categorical analyses I presented previously. This is also consistent with the inverted U hypothesis for a single training session. This is also consistent with the muscle protein synthesis data presented earlier in this article. You will also notice how the curve has shifted slightly down and to the left from the February 2019 update; the former peak was in the 8-10 range, but now the peak is clearly around 8.

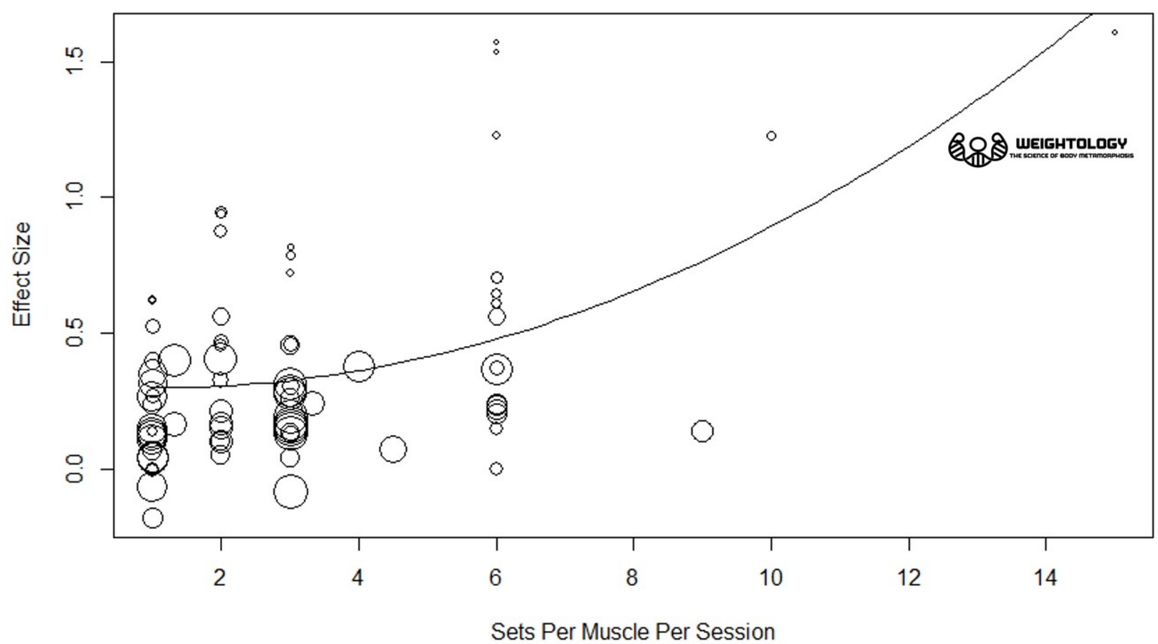
If we draw lines connecting the highest and lowest effect sizes for each level of volume, we again see a plateau, this time in the 4 to 13 set range, with a mid-point of 8.5.



Impacts of Volume in Trained vs. Untrained Subjects

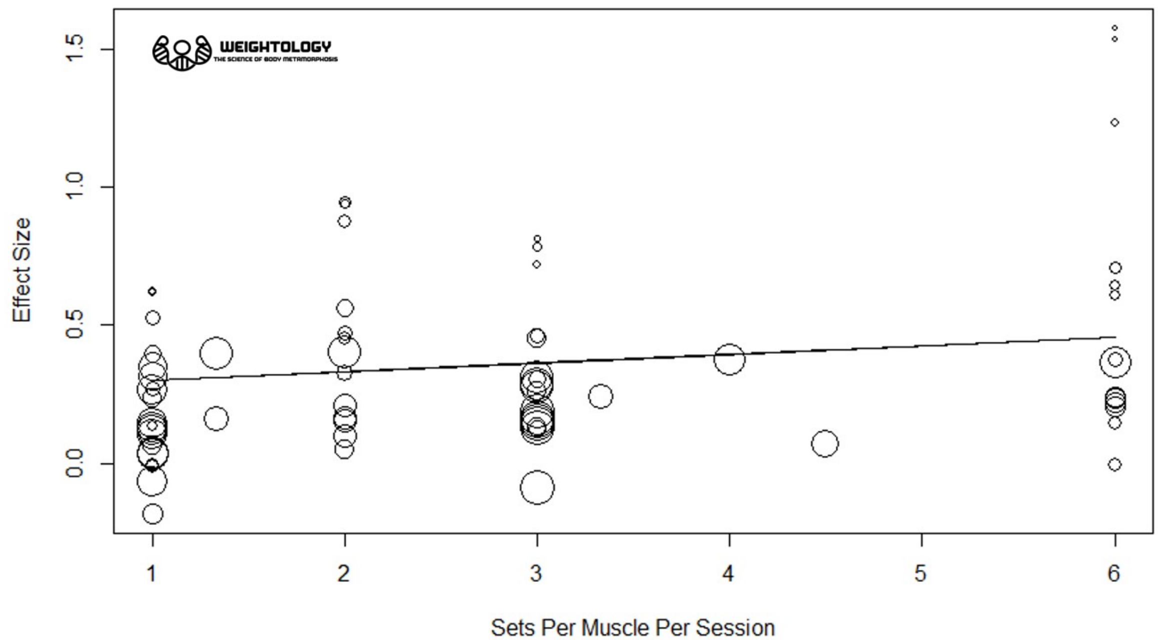
The analyses in the previous section include data on both trained and untrained subjects. However, it's very possible that the effects of volume may vary depending upon training status.

First, let's isolate the analysis to studies on untrained subjects. If we fit a quadratic curve on studies from untrained subjects, we get the opposite of the inverted U, with gains ramping up as you get to the highest volumes.



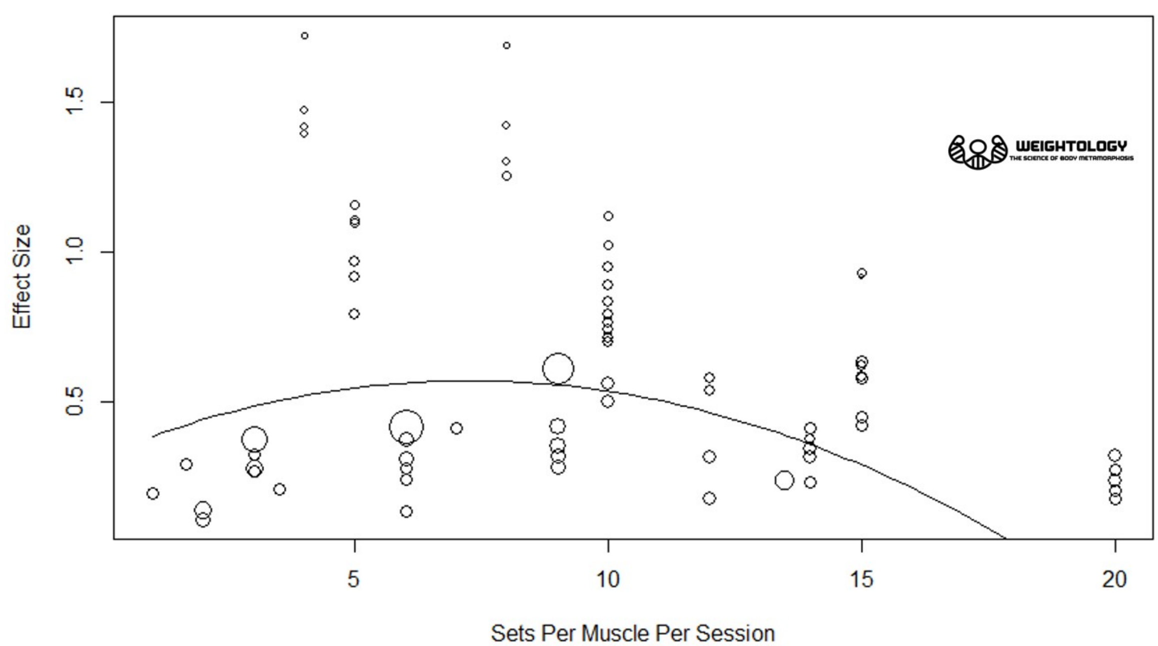
Of course, this doesn't make any sense. Why would gains continue to ramp up with higher volumes in untrained subjects? The answer here is due to a single outlier study by Radaelli and colleagues. It was the only study using very high session volumes of 9+ sets, and it lasted much longer than the other studies (26 weeks versus 6-14 for most of the others). Thus, it has an overly large influence on the curve.

If we remove the study by Radaelli, we find that a linear model fits the data better than the quadratic model (AICC of -13.8 versus -9.7, where lower means a better fit). The effect of volume is not statistically significant (P = 0.067), and the size of the effect is miniscule (an increase in effect size of only 0.03 for each additional set per session).



This suggests that **there is not much of a dose-response effect of volume in untrained subjects.** The implication here is that beginners will achieve good gains on low volume programs, and there is no need to utilize higher volumes.

What about trained subjects? Here, the inverted U fits the data very well, again showing a peak at around 8 sets per muscle group per session.



Thus, **experienced trainees are more responsive to increases in volume than beginners**. This makes sense from a theoretical perspective when we think about the concept of adaptation to a training stimulus. For a beginner, a few sets represents a large stimulus due to the novelty. However, as a beginner progresses to a more trained state, those few sets will no longer represent a novel stimulus. The beginner adapts to the stimulus, and thus the stimulus must be increased to achieve further gains. As one gains years of training experience, a low number of sets may no longer be sufficient to stimulate adaptation, and an increase in volume becomes necessary.

Summarizing the Meta-Regression Results

Overall, this data suggests **a threshold of somewhere around 8 sets per muscle group per training session for experienced subjects. For beginners, low volume programs of 2-3 sets per muscle group are sufficient**. This data has several important implications on training program design:.

- The weekly volume associated with peak hypertrophy depends upon frequency. With the peak of the curve in the 8 set per session range, that's 16 weekly sets if training twice per week, 24 weekly sets if training three times per week, and 32 weekly sets if training four times per week.
- If you're training each muscle group once per week, then you may not get more benefit beyond 10 sets per session per week. **This indicates that the "bro-style" of training each muscle group once per week, blasting each muscle with up to 20 sets per body part or more, is an inferior way to train**. If you're training each muscle group twice per week, then around 16 weekly sets likely represents the maximum stimulus on average. The benefits of training 20+ weekly sets only manifest themselves with a training frequency of at least 3 days per week; 8 sets per muscle per session, three times per week, is 24 weekly sets.
- While the data indicates a benefit for over 20 weekly sets when training at least 3 days per week, **most people will get the best "bang for their buck" in the 10-20 weekly set range**. This represents the optimal weekly volume when training each muscle group twice per week. When training each muscle group 3+ times per week, it gives approximately 55% better hypertrophy than training in the weekly single-digit range, and can still be performed by most people as it wouldn't require huge amounts of training time. At a frequency of 3+ days per

week, moving up to 21+ weekly sets gives approximately 31% better hypertrophy compared to the teens. The very high volumes would be best for individuals seeking maximum muscle growth (like bodybuilders). Now, even this data doesn't mean that you need to do 21+ weekly sets for every single muscle group to maximize changes in muscle size. Such volumes would likely need to be periodized (balanced with periods of low volume), or used in the context of specialization routines, where a very high volume is performed for only 1-2 muscle groups. It also needs to be considered that these are average responses across multiple studies. The responses of individuals to changes in volume will vary dramatically from one person to the next. **Weekly set volumes of 21+ are very high, and may be more than some individuals can tolerate.** Remember that gains are observed with low to moderate volumes, but the gains may not be as large**. You must consider the needs of an individual, including schedule, volume tolerance, recovery ability, available time to train, importance of achieving maximal hypertrophy, injury history, etc.**

- The curve represents the inverted U for a single training session. We currently don't know where the maximal volume lies on a weekly basis if training each muscle group 3+ times per week. It's important to note that the two studies showing a benefit for up to 45 weekly sets involved training three times per week. That's 15 sets per session, which exceeds the theoretical peak of around 10 sets. This could be due to random variance (remember that the theoretical peak of 10 sets is based on averages). It could also be due to the fact that these studies utilized shorter rest intervals (90 seconds - 2 minutes) and whole body workouts, which would increase central fatigue and thus you would need to compensate by doing more sets. A third possibility is that, with increased training frequency, you improve your recovery ability and your capacity to tolerate higher volumes within a single training session. A fourth possibility is that the high volume, whole body workouts to failure impaired subjects' ability to train to failure on each set, and thus the subjects needed to do more work to compensate.
- You might think that this contradicts information from the Frequency Bible, where there was little difference between training frequencies on a volume-equated basis. However, the vast majority of studies did not exceed the 10-set per session threshold. Only two studies involved a frequency where the per-session volume greatly exceeded 10 sets. Zaroni and colleagues compared 15 sets per session, done once or twice per week, to 3-6 sets per session, done

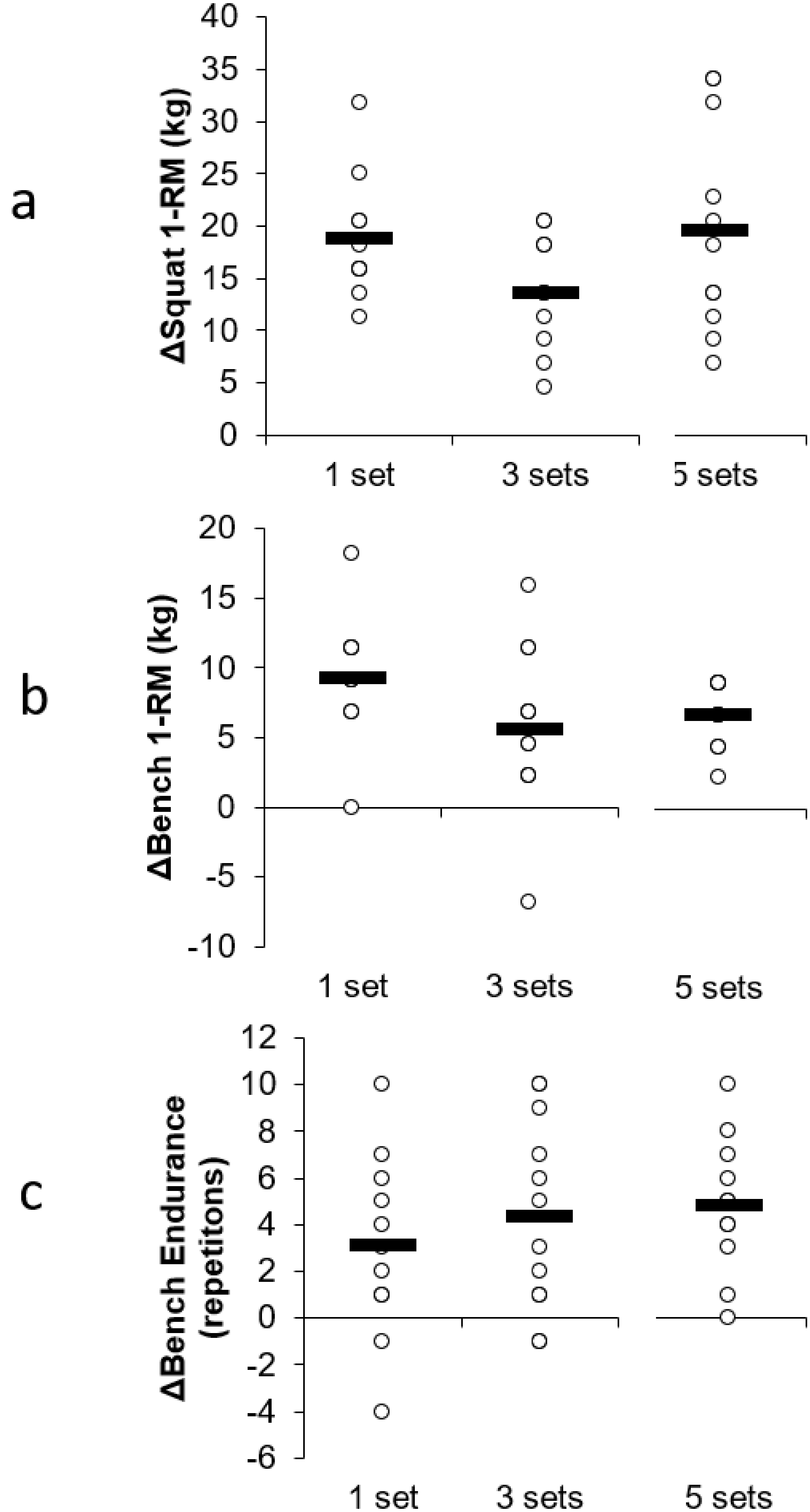
five times per week. Hypertrophy was superior in the higher frequency condition. Brigatto and colleagues compared 16 sets per session, done once per week, to 8 sets per session done twice per week. Hypertrophy was similar between the conditions. However, improvements in training load volume were superior in the higher frequency group. This would suggest that, if the study had been carried out over a longer period of time, that greater hypertrophy may also have followed in the higher frequency condition. Thus, training frequency likely doesn't make a difference when the per-session volume is less than around 10 sets. However, if it greatly exceeds 10 sets, then it may be more beneficial to split the volume into a higher frequency.

- The concept of "junk volume" is supported by this data. Per-session volumes of more than around 10 sets are associated with a plateau or even decline in hypertrophy.

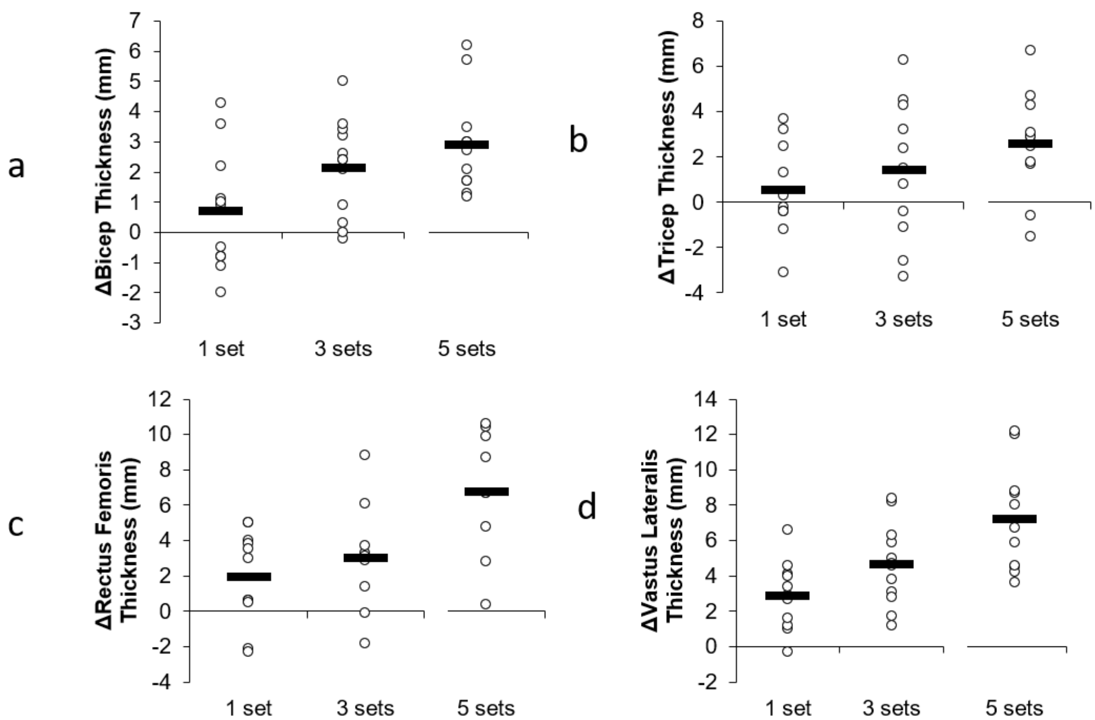
It's also important to note that, in the previous graph, there is a lot of variance. Within any given set volume, there is a huge range in effect sizes. For example, with a per-session volume of 6 sets per muscle group, effect sizes range from around 0 to around 1.5. ***This demonstrates why one should be wary of drawing too much conclusions from one study when it comes to set volume and hypertrophy***; different studies with the same set volumes per session can have widely different results. This also shows why meta-analysis and meta-regression are so important; it allows you to assess the overall trend.

Volume and Strength

In the original version of this guide, I used some strength data by Marshall et al., Ostrowski et al., and Baker et al. to make some inferences about the dose-response effect of volume on hypertrophy. I assumed a strong relationship between strength and size gains in trained individuals, and used the strength gains in those studies as a proxy for hypertrophy. However, as I've written in the Progression Guide, the relationship between strength and size is not as close as once thought, even in trained subjects. In fact, in a recent study that I was a co-author on, there were no differences in 1-RM bench or squat gains between three levels of volume (1, 3, and 5 sets per exercise) in trained subjects. This is despite the fact that there was a graded dose response in hypertrophy. There was also no correlation between strength gains and size gains in that study. The following charts show the strength gains and muscle thickness gains; you can see no difference in 1-RM or endurance gains, but a graded dose response in three out of the four muscle groups tested.


a
ΔSquat 1-RM (kg)
40
35
30
25
20
15
10
5
0
1 set
3 sets
5 sets
b
ΔBench 1-RM (kg)
20
15
10
5
0
-5
-10
1 set
3 sets
5 sets
c
ΔBench Endurance (repetitons)
12
10
8
6
4
2
0
-2
-4
-6
1 set
3 sets
5 sets

Impact of Volume on 1-RM and Endurance Gains (1, 3, or 5 sets per exercise)



Dose-Response Impact of Volume on Hypertrophy (Sets Per Exercise)

Thus, ***strength data cannot be used to make inferences about the impacts of volume on hypertrophy***.

How Much Is Too Much?

In the original version of this guide, I had suggested that an optimal volume lie in the 12-18 weekly set range, and that weekly set volumes of 20+ likely would not result in further gains. This was based on the following observations:

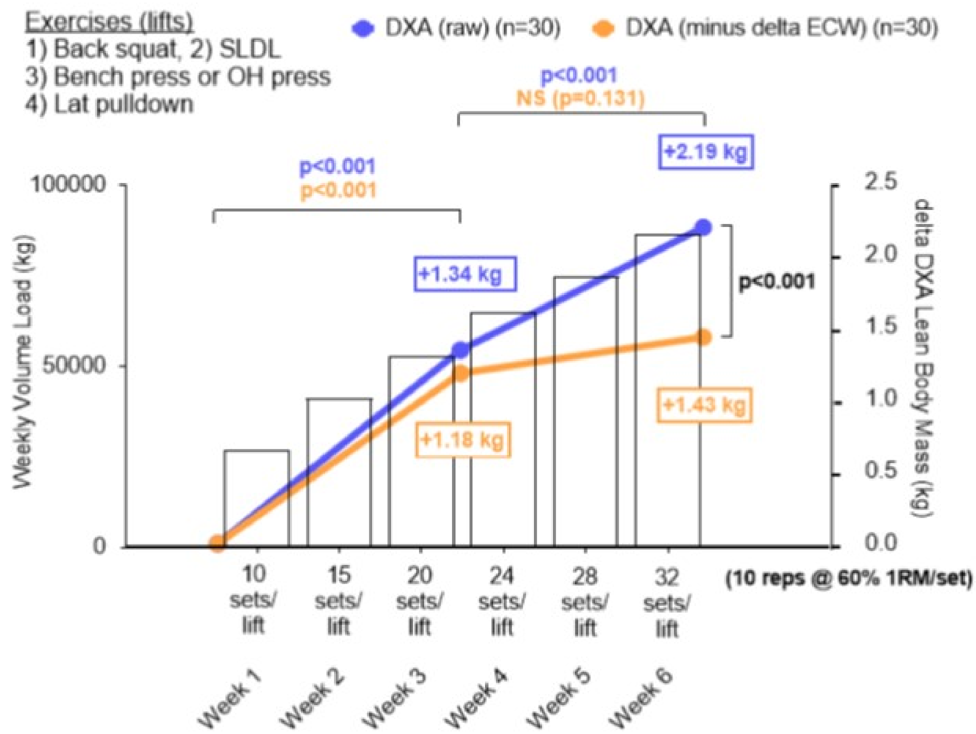
- In the study by Ostrowski and colleagues on trained subjects, the triceps were subjected to either 7, 14, or 28 weekly sets. Gains nearly doubled moving from 7 to 14 weekly sets, but there was no further increase with 28 weekly sets. Also, bench press performance dropped off with that level of volume. This suggested that perhaps weekly volumes in the high 20's may be more than necessary. However, one limitation of this study, which I did not address in the original version of the guide, is that the researchers did not assess bicep gains. They also did not do anything beyond 12 weekly sets for quadriceps. Thus, this study is insufficient for determining where an upper limit may lie, as only one muscle group was trained for more than 20 weekly sets. It's also important to note that the training frequency for triceps in this study was two times per week. Thus, the 28 weekly set condition involved 14 sets per session, exceeding the approximate 10-set per session threshold that we established earlier. Thus, the observed plateau in this study may be due to the frequency.

	7 weekly sets	14 weekly sets	28 weekly sets
1-RM Bench	+4.01% 0.29	+4.96% 0.43	+1.93% 0.15
Tricep Thickness	+2.27% 0.25	+4.65% 0.4	+4.76% 0.5

- In the original guide, I mentioned the German Volume study that I reviewed in a past research review. In this study on trained subjects, 24 weekly sets was not more effective than 14 weekly sets for quadriceps, and 28 weekly sets was not more effective than 18 weekly sets for biceps and triceps. However, it should be noted that many of these sets were not to failure. German Volume Training involves doing 10 sets of 10 with 1 minute rest, and you use the same weight for all sets. The subjects started with 60% 1-RM on most exercises. In many cases, people can do around 20 reps with 60% 1-RM (this will vary from one person to the next). This means that early sets were well short of failure; in fact, many of the early sets will fail to accumulate very many hypertrophic reps. Remember that, in this guide, we're defining volume as the number of "hard" sets to failure or near failure. In this study, the subjects were not doing 14-28 hard sets. In fact, it's difficult to ascertain how many hard sets the subjects did. Also, it likely varied from one person to the next since it was based on % 1-RM, rather than doing sets to a specific Reps In Reserve (RIR). In other words, one person might be able to do a lot more reps than another person with 60% 1-RM, so their initial sets will be much easier. Thus, this study is not a reliable data point for determining where an upper limit may lie. The same holds true for another 2018 German Volume Study; the methodology was nearly identical, and it again is not reliable for determining an upper limit for volume. It should also be noted that the training frequency was twice per week for upper body, and once per week for lower body in this study. Thus, the highest volume condition was doing 24 sets per session for lower body, greatly exceeding the theoretical 10-set limit. This group was doing 14 sets per session for upper body, again exceeding the theoretical 10-set limit. Thus, the training frequency and per-session volume may also be contributors to the lack of volume effect observed in this study.

- In the original guide, I mentioned is a study by Baker and colleagues that examined strength, not hypertrophy. In this study, 36-45 weekly sets did not improve strength over 12-15 weekly sets in trained subjects. I was using the gains in strength as a proxy for hypertrophy. However, as I pointed out earlier, gains in strength may not be a good proxy for hypertrophy, even in trained subjects. This might be particularly true in a study like this, where the cumulative fatigue from the very high training volume (36-45 weekly sets) might mask any hypertrophy-related strength gains. Thus, this study may not be a reliable data point for determining an upper limit for set volume.

Finally, a study performed was performed on high volume training by Haun and colleagues. Training lasted for 6 weeks. Subjects started 10 sets per exercise per week (split into three sessions per week), with approximately one compound exercise per muscle group (squat, bench press or overhead press, SLDL and lat pull). Subjects did 10 reps per set at approximately 60% 1-RM; the average Reps In Reserve (RIR) was around 4. Set volume was progressed each week, so that subjects were doing 32 sets by week 6. Lean mass (assessed via DEXA) significantly increased by 2.2 kg by the end of the study. The researchers used bioelectrical impedance spectroscopy (BIS) to estimate the amount of intracellular vs. extracellular fluid, and subtracted the extracellular fluid amount from the DEXA lean mass to estimate how much tissue gain was "true" tissue gain, versus extracellular water (which might be considered edema or swelling from the high training volume). The researchers found that, while lean mass continued to increase with progressively higher volume, there was no longer a significant increase in lean mass from the midpoint of the study to the end when the results were corrected for extracellular water.



This study has been used as evidence to indicate anything beyond 20 weekly sets isn't effective for hypertrophy. However, there are a number of problems with this conclusion:

- The changes in ultrasound-derived muscle thickness (a direct measurement of hypertrophy) were less than 1 mm and were not statistically significant, suggesting that there was very little hypertrophy that occurred in terms of muscle thickness in the muscle groups assessed via ultrasound (vastus lateralis and biceps). Average muscle fiber area also did not significantly change. This brings up whether the DEXA data reflects "true" hypertrophy in any way. Now, this doesn't mean there wasn't any true hypertrophy in this study. The increases in DEXA derived lean mass were fairly large. You can sometimes get increases in muscle size, assessed via cross-sectional area, without a corresponding increase in muscle thickness, as measurements of muscle thickness are done at a very specific point in the muscle. It's possible that this happened in this study. The increase in lean mass via DEXA was not statistically significant, although it did heavily favor an increase (the confidence interval ranged from -0.97 to 5.35). The BIS data showed an increase in total body water. This suggests the increase in DEXA lean mass was associated with an increase in body water, which is not always reflective of actual muscle tissue gain (although keep in mind that muscle itself contains mostly water, so this doesn't rule out muscle growth as a factor). Overall body mass tended to go in the same direction as the DEXA lean mass data, although not statistically significant. There are a number of possibilities for this study. There could have been an increase in muscle size that wasn't adequately captured by the muscle biopsy or thickness data. Another possibility is that the subjects may have been slightly overfeeding. Overfeeding alone can increase lean mass in the absence of training, although it also usually accompanied by fat gain. It is possible that, if the subjects were slightly overfeeding, it was enough to impact lean mass without significantly impacting body fat, especially given that the subjects were training. However, such an increase in lean mass would not be "true" muscle, and rather simply an increase in body water. A third possibility is fluid accumulation that is not related to increases in muscle tissue.

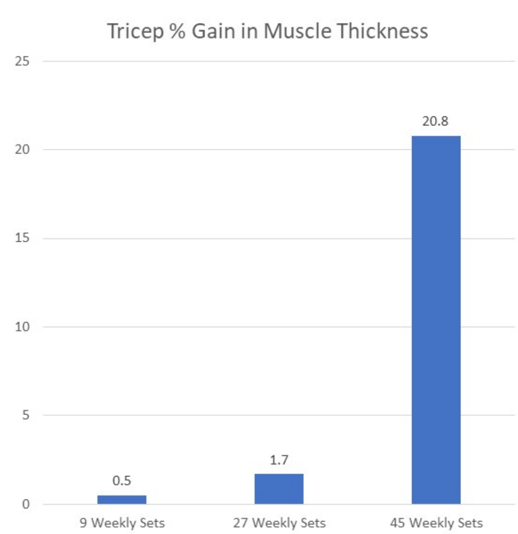
- Weights were 60% 1-RM, which can be as far as 10 reps away from failure depending upon the individual. The average RIR for all sets was around 4; in some cases it came near 5. Remember that this is the average, meaning that some sets were performed with a much higher RIR while others were performed with less. It should also be noted that the accuracy of RIR tends to fall off the further away you get from failure. Thus, subjects were training fairly well short of failure for a number of sets, and thus some sets don't fall into the "hard" sets category. There may have also been errors in their estimates for RIR. This makes it difficult to know the number of "hard sets" or "hypertrophic reps" in this study.
- The use of BIS to estimate changes in ECW and ICW in healthy individuals, specifically as a marker of edema in muscle, has not been validated. In fact, there is no data to indicate that subtracting the BIS-derived ECW from the lean mass in DEXA is valid for distinguishing muscle edema from other types of lean mass changes.

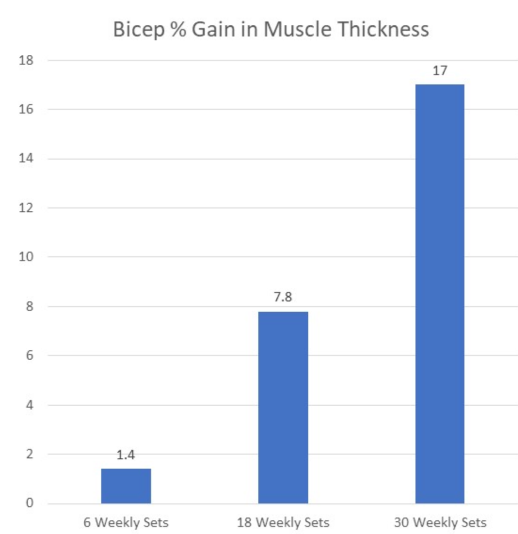
The results of the current meta-regression, discussed earlier, suggest that the upper limit for weekly volume is dependent upon frequency, with higher upper limits occurring alongside higher frequencies. Per-session volumes of more than 10 sets are where gains may start to plateau or degrade.

High Volume Training: Dose-Response Studies

Let's take a closer look at the dose-response studies that involved very high weekly set volumes.

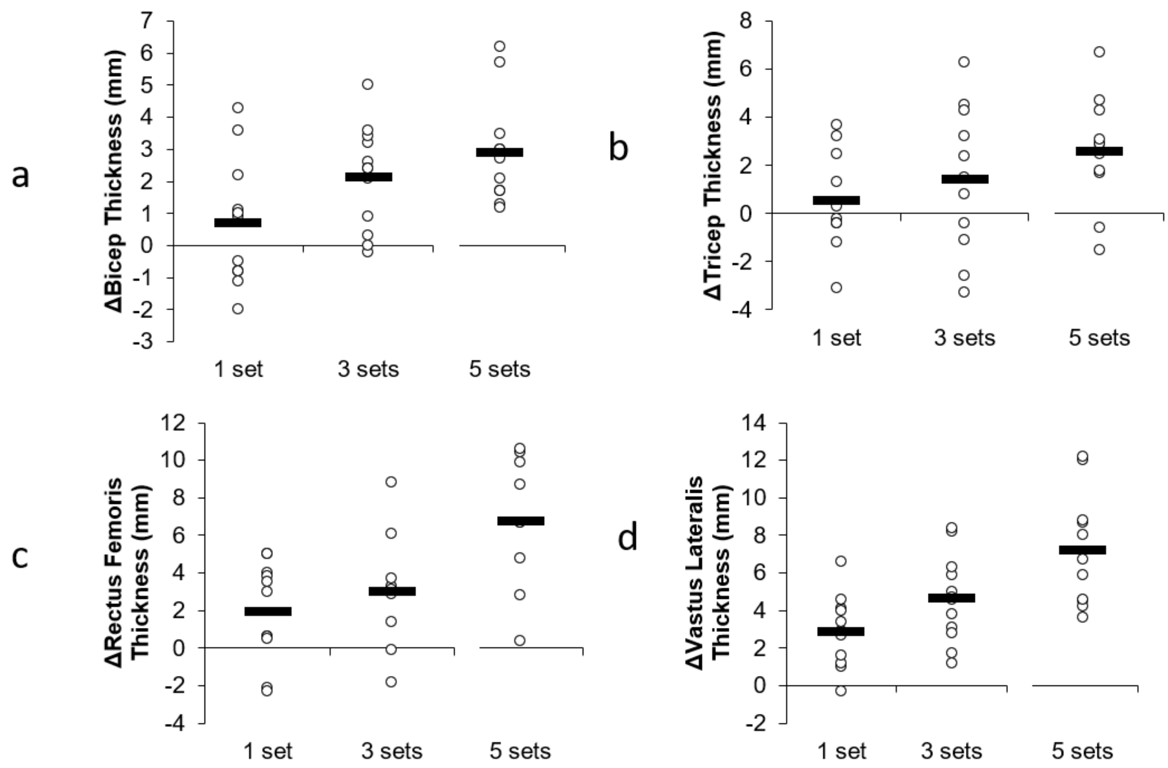
- In the study by Raedelli and colleagues, the researchers compared 1 set, 3 sets, and 5 sets per exercise, done three times per week. Sets were performed for 8-12 reps to failure, with 1.5 - 2 minutes rest. The subjects performed bench press, leg press, lat pull down, leg extension, shoulder press, leg curl, biceps curl, crunch, and triceps extension. If you count the pushing movements towards tricep volume, and the pulling movements towards bicep volume, the total weekly volume for each muscle group was 9, 27, and 45 for triceps, and 6, 18, and 30 for biceps. The study was carried out over a 6 month period, and was performed on untrained subjects. It was one of the most well-controlled studies on volume, given that it was performed on Brazilian Navy cadets confined to an aircraft carrier. Also, it was carried out for 6 months, compared to the usual 6-12 weeks of other studies. Here are the percentage gains for each muscle group and each volume level:





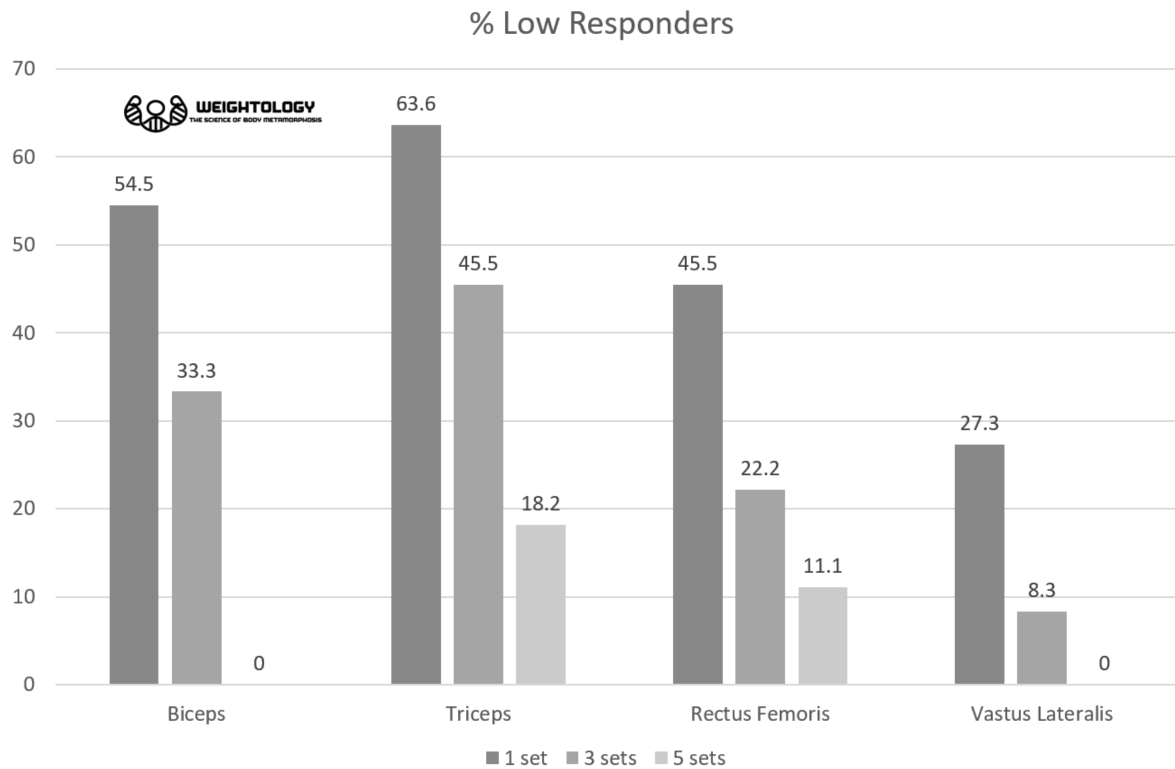
There was a clear dose-response effect in terms of volume in this study, especially in the biceps. In fact, the gains in muscle thickness observed with 30-45 weekly sets were 3-4 times what is typically seen in studies (most studies show around a 5% increase in muscle thickness). Now, one odd result of this study was that there was hardly any increase in tricep muscle thickness for a volume of 27 weekly sets. This is at complete odds with other studies that show significant gains in tricep thickness with much lower volumes in untrained subjects. The sudden jump to nearly a 21% gain at the highest volume is also very strange. However, this does not invalidate the study; as I've written elsewhere, you can get odd results like this from random chance alone. Overall, the study did support an effect of volume, and no plateau was observed for weekly set volumes of more than 20. It should also be noted that the researchers examined fat-free mass gains. There were no significant differences between groups in fat-free mass gains; however, this data is likely not reliable since it was assessed using skinfolds, which are not a reliable technique for assessing changes in fat-free mass. Also, the control group showed a significant increase in fat-free mass; this indicates potential error in the measurements as you would not expect the control group to show an increase.

- In a study of which I was a coauthor, Brad Schoenfeld and colleagues replicated the design of the Radaelli study, but with trained subjects. The subjects performed 1, 3, or 5 sets per exercise, for 8-12 reps to failure and 1.5 minute rests. They trained 3 times per week for 8 weeks. One difference from Radaelli, other than the length of the study, was that nearly all movements were compound movements (bench press, military press, lat pull, seated row, squat, and leg press; the only isolation movement was leg extension). Total weekly sets were 6, 18, and 30 for biceps and triceps, and 9, 27, and 45 for quadriceps. A significant dose-response effect was observed in the biceps, rectus femoris (part of the quadriceps), and vastus lateralis (part of the quadriceps). There was not a significant effect for triceps, although the overall pattern had similarities to the other muscles.

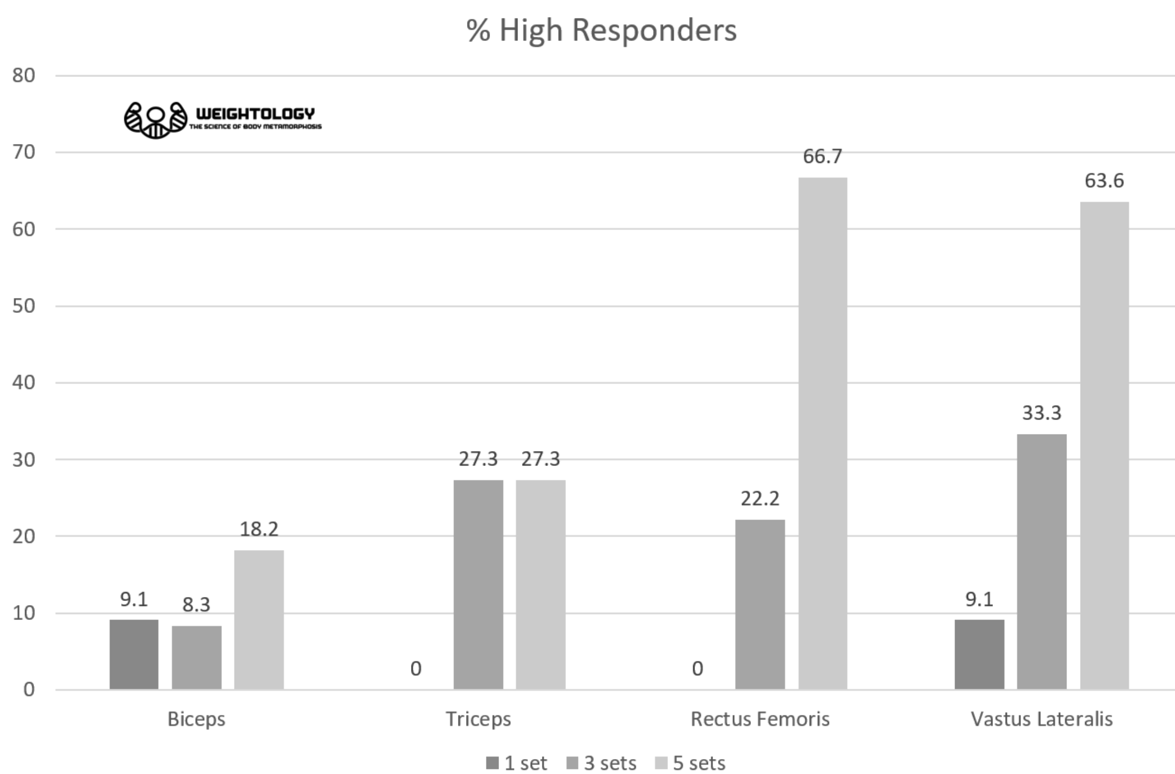


The big strength of this study was that it was mostly a replication of another study, and the results were similar. Replication is an important concept in science; when independent research groups can replicate results, it gives more credence to the findings. This study, along with Radaelli, provide evidence that the upper limit for weekly volumes may be higher than previously thought. You can also see the dramatic variation in how people respond to any given volume. For example, in the low volume groups, some people had higher gains in muscle thickness than some of the people in the highest volume groups.

If we classify subjects into "low responders" based on whether they met the "smallest worthwhile change" (which is at least 0.2 standard deviation units, or a "small" effect size), then the percentage of low responders decreases as you increase volume. In fact, there were very few low responders in the highest volume condition.

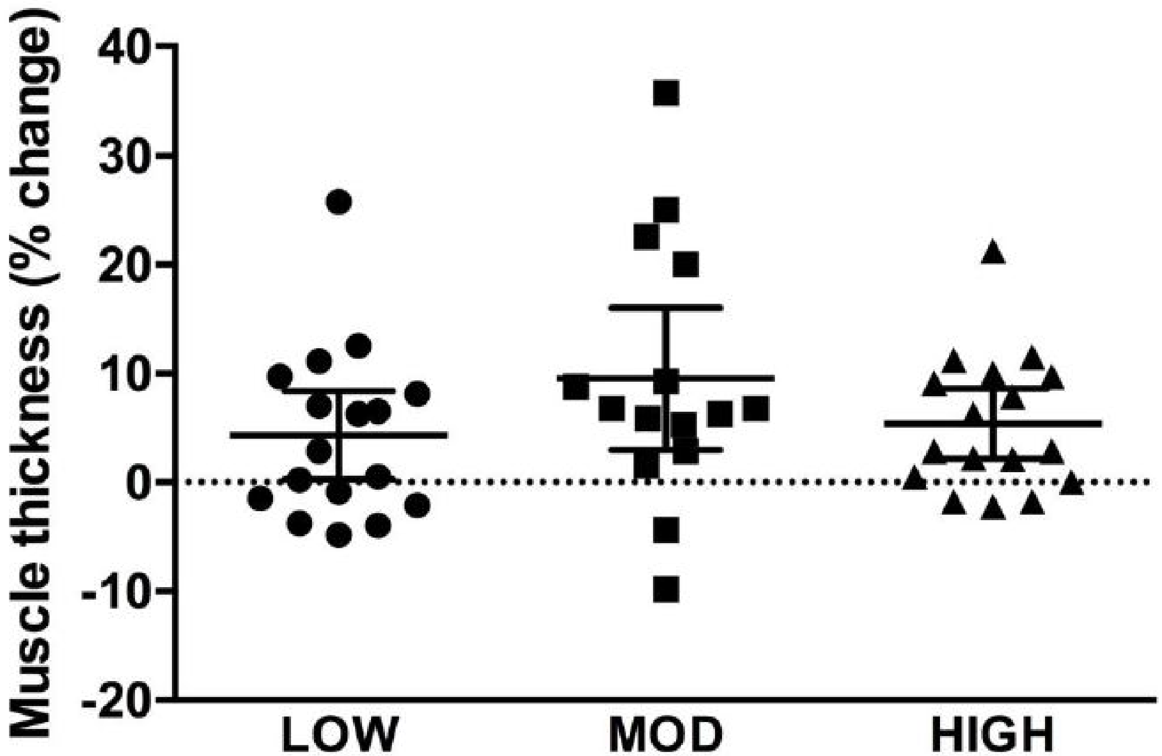


The same holds true for high responders (define as improving by at least 0.8 standard deviation units, or a "large" effect size). As volume increased, the percentage of high responders also increased.



This data would suggest that, for people who are "hardgainers", an increase in volume may be necessary. This is at odds with the conventional wisdom that hardgainers require less volume and more recovery. However, this data is in agreement with research on endurance training, where non-responders do show a response when subjected to more volume. Now, there are some limitations to this type of analysis. The percentage of responders could be a totally random phenomenon; if you were to replicate this study, you might end up with no apparent responder/non-responder effect.

- Heaselgrave and colleagues explored the impact of 9, 18, or 27 weekly sets on biceps thickness, isometric strength, and 1-RM strength. Trained males were allocated to a low volume, moderate volume, or high volume group. The low volume group performed 9 sets targeting the biceps once per week. The moderate and high volume groups performed 9 or 13-14 sets per session, twice per week. Exercises were seated supine biceps curl, supine grip bent over row, and supine grip pulldown. The low and moderate volume groups did 3 sets of each exercise. The high volume group did 4-5 sets of each exercise. Subjects performed each set for 10-12 reps, aiming for 2 Reps In Reserve (RIR). Rest periods were 3 minutes between sets. There were no significant differences between groups in changes in 1-RM strength or biceps thickness, although isometric strength only improved in the highest volume group. While there were no significant differences in changes in bicep thickness, the magnitude of the percentage gain tended to favor the moderate group over the other groups (9.5% versus 4.3% or 5.4%). Judging by the individual data, it appears there were more high responders in the moderate group, as well as less non-responders.

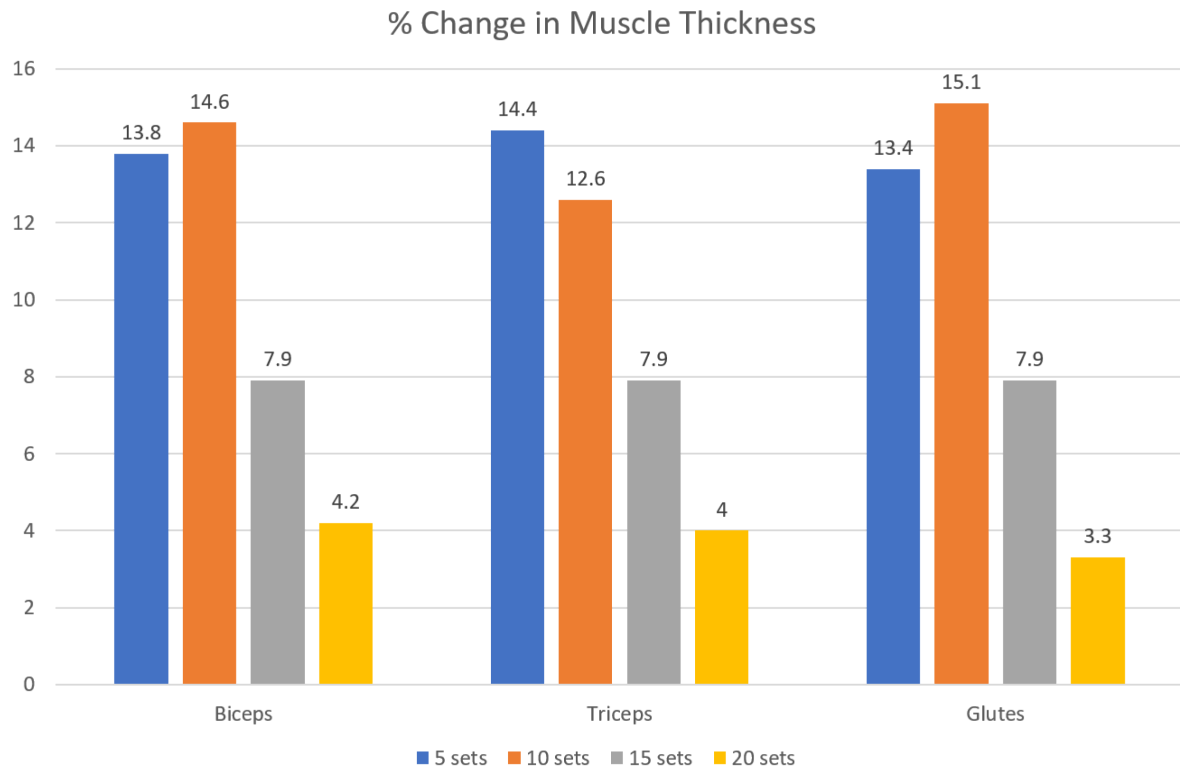


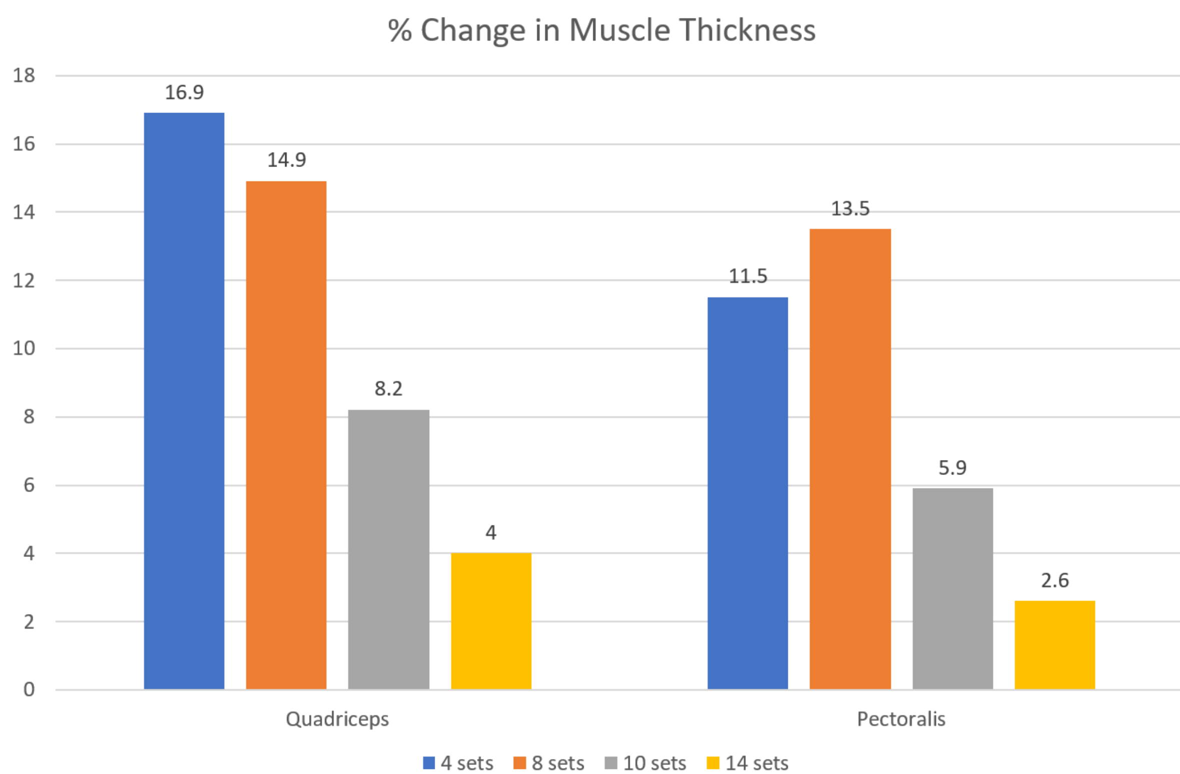
One limitation of this study was that subjects were allowed to train outside of the study. While the researchers asked the subjects not to do any sort of pulling or bicep movements, and while the subjects did record their own training journals outside the study to ensure this wasn't happening, it can't be ruled out that they may have been doing some other pulling or bicep work. Another limitation is the short duration of the study (6 weeks); it is the shortest study among all the dose-response studies on volume. It is possible that longer durations could show differences; for example, one study found no significant difference in hypertrophy between 12 and 4 weekly sets after 6 weeks, but did show a difference after 20 weeks. A third limitation is that the groups used different frequencies; the low volume group trained biceps once per week, while the other two groups trained biceps twice per week. While frequency does not appear to impact hypertrophy much on a volume equated basis, it may impact hypertrophy when weekly training volumes become high as I pointed out earlier in this article.

- Ostrowski and colleagues examined the effects of 1, 2, or 4 sets per exercise on hypertrophy in trained subjects. The study lasted for 10 weeks. Subjects did 7-12 reps to failure per set, with 3 minute rests between sets. Each exercise was performed once per week. Triceps were trained twice per week, as pressing movements were performed on one day, and isolation movements were performed on another day. Only triceps and quadriceps hypertrophy were assessed. Quadriceps training volume did not exceed 12 total weekly sets since they were only trained once per week. However, triceps weekly volume, when counting pressing movements, was 7, 14, and 28 for the low, moderate, and high volume groups, respectively. There were no significant differences in changes in triceps thickness between the groups, although the percentage gains and effect sizes favored the groups doing 14 and 28 weekly sets. In fact, percentage gains and effect sizes for 14-28 weekly sets were about twice that of 7 weekly sets. There was little difference between 14 and 28, however.

	7 weekly sets	**14 weekly sets**	**28 weekly sets**
1-RM Bench	+4.01% 0.29	+4.96% 0.43	+1.93% 0.15
Tricep Thickness	+2.27% 0.25	+4.65% 0.4	+4.76% 0.5

- In a very well-designed study, Barbalho and colleagues examined the effects of four different volume levels over a period of 6 months in trained young women. The women had an average training experience of over 3 years. Subjects did approximately 5, 10, 15, or 20 sets per muscle group per training session (chest and quadriceps ended up being 4, 8, 10, and 14). The subjects trained each muscle group once per week. Sets per exercise ranged from 1-2 in the lowest volume group to 6-7 in the highest volume group. Repetition ranges were periodized, varying between 4-6 RM, 6-8 RM, 10-12 RM, and 12-15 RM over the entire study. Rest intervals were also periodized, varying between 30-60 seconds for 12-15 RM, 3-4 minutes for 4-6 RM, 1-2 minutes for 10-12 RM, and 2-3 minutes for 6-8 RM. The 5-set and 10-set group showed significantly greater improvements in muscle thickness compared to the 15-set and 20-set groups. The 15-set group also showed greater improvements in muscle thickness than the 20-set group.



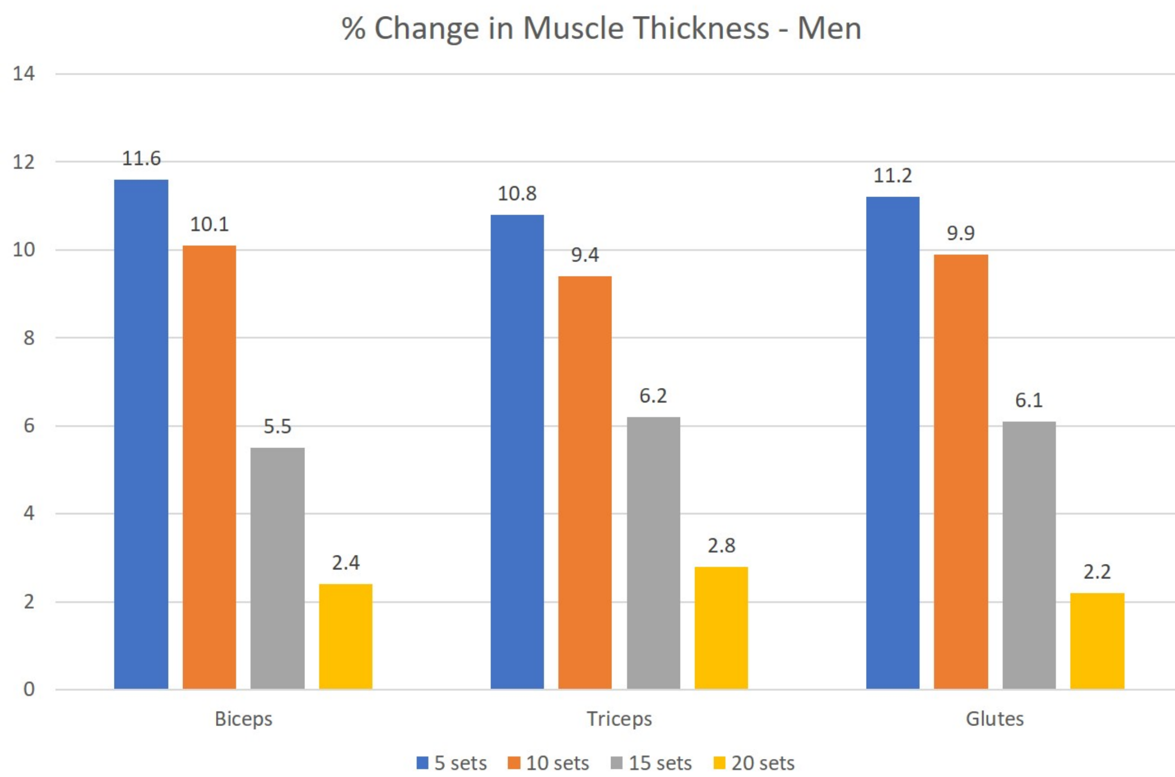


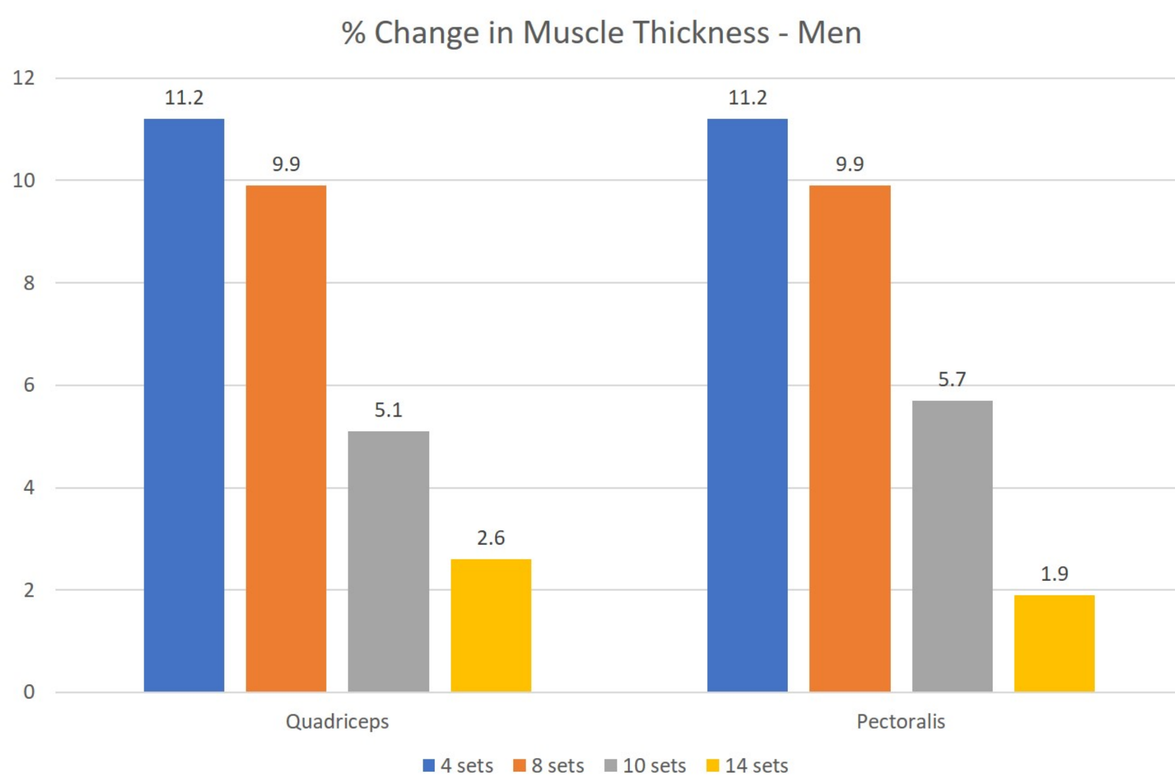
While this study was well designed, it is not without its limitations. First, the training frequency was only once per week; this study tends to support the concept of an inverted U hypothesis for a single training session, as session volumes of more than 10 tended to result in less hypertrophy. Results could have been different with higher frequencies but equivalent weekly volumes (and thus lower per-session volumes). Second, the results for quadriceps are different from what was observed by Ostrowski and colleagues (who also trained quads only once per week). Ostrowski observed 12 sets of quadriceps in a single session resulted in twice the percentage gains as 3 sets, and anywhere from one to 2.5 times the percentage gains as 6 sets.

	3 weekly sets (7 for triceps)	6 weekly sets (14 for triceps)	12 weekly sets (28 for triceps)
Tricep Thickness	+2.27% 0.25	+4.65% 0.4	+4.76% 0.5
Rectus Femoris Cross-Sectional Area	+6.77% 0.30	+5% 0.29	+13.14% 0.78
Rectus Femoris Thickness	+3.03% 0.27	+1.05% 0.14	+6.35% 0.73

A third limitation is the dramatic difference in hypertrophy between 8 and 10 sets for quadriceps and pectoralis. The percentage gains for 10 sets were around half that for 8 sets. It would seem unlikely that such a small difference in sets would make such a large difference in hypertrophy. This may be more a product of sampling variance, and illustrates why one should never draw strong conclusions from any single study. It is better to consider a study as a small piece of a larger overall puzzle, and see how that study fits. A fourth consideration, put forth in the discussion section by the authors themselves, is that their results might differ from other studies because they feel their subjects trained to "true" failure. This seems as a very unlikely reason, as there is no discernible difference in hypertrophy whether sets are taken to true failure or stopped a rep or two short of failure.

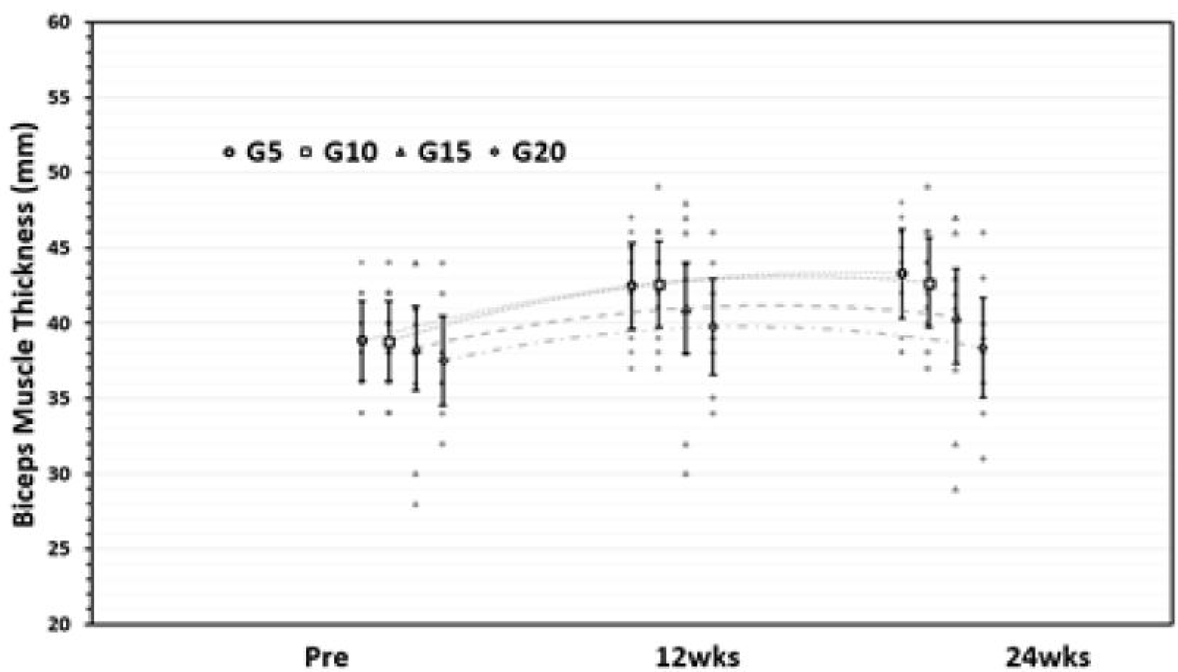
- Barbalho and colleagues carried out a second study with trained males that was identical in design to the study on females discussed in the previous bullet. The pattern of results was similar.

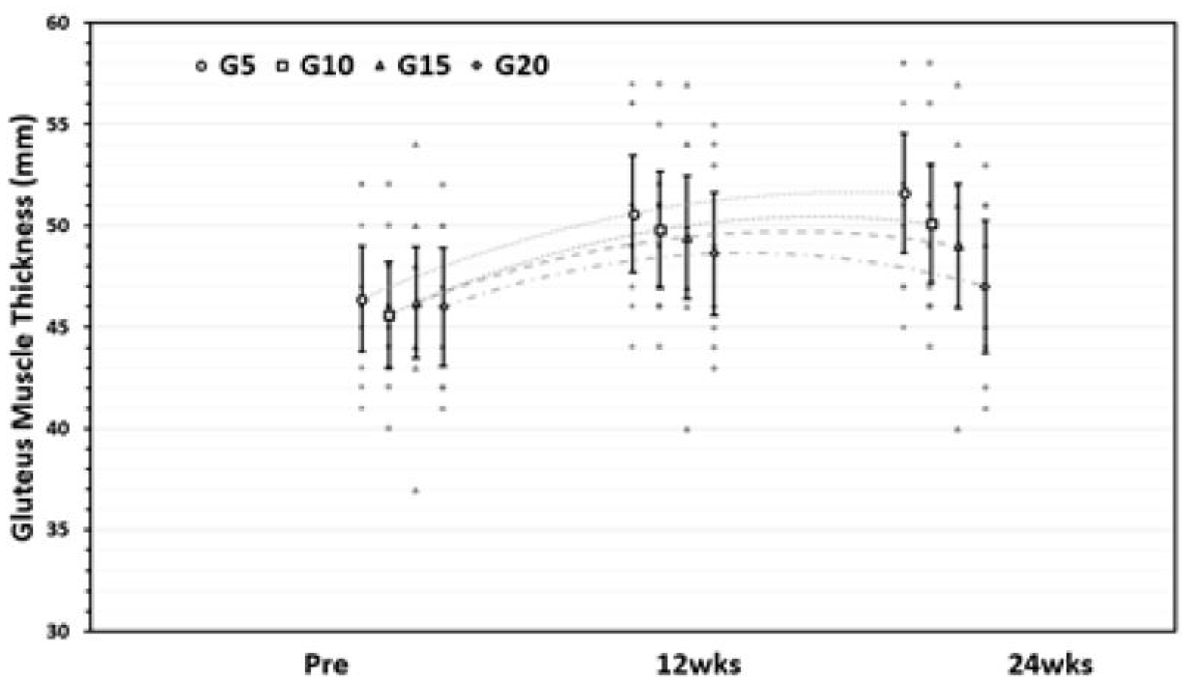


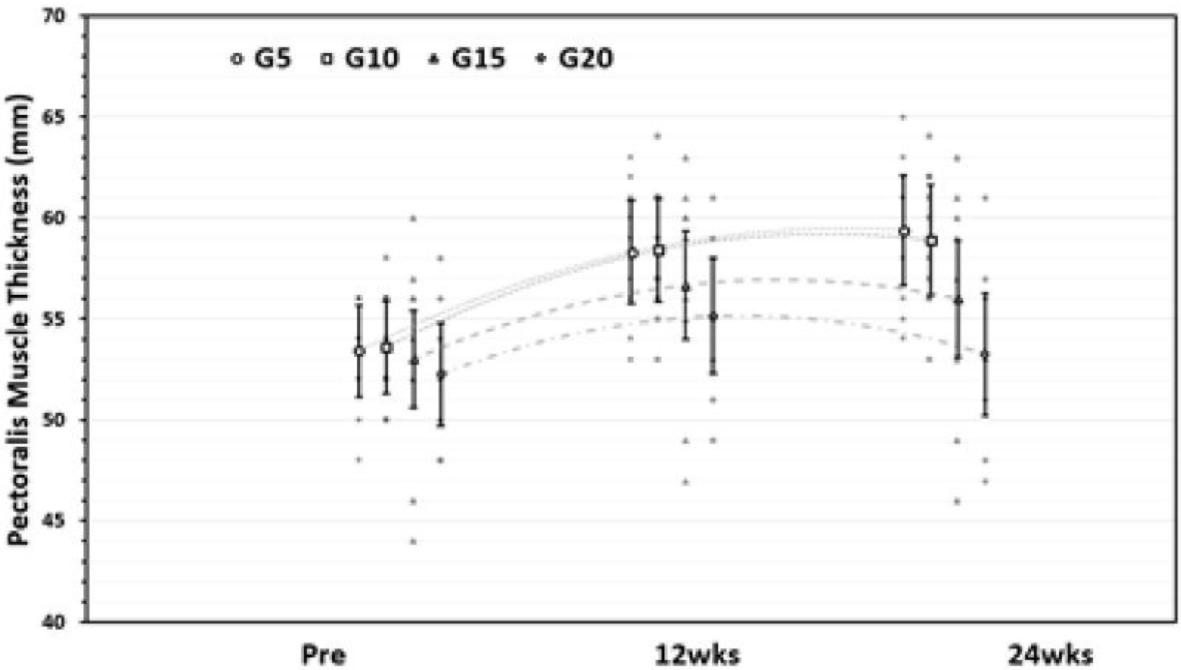


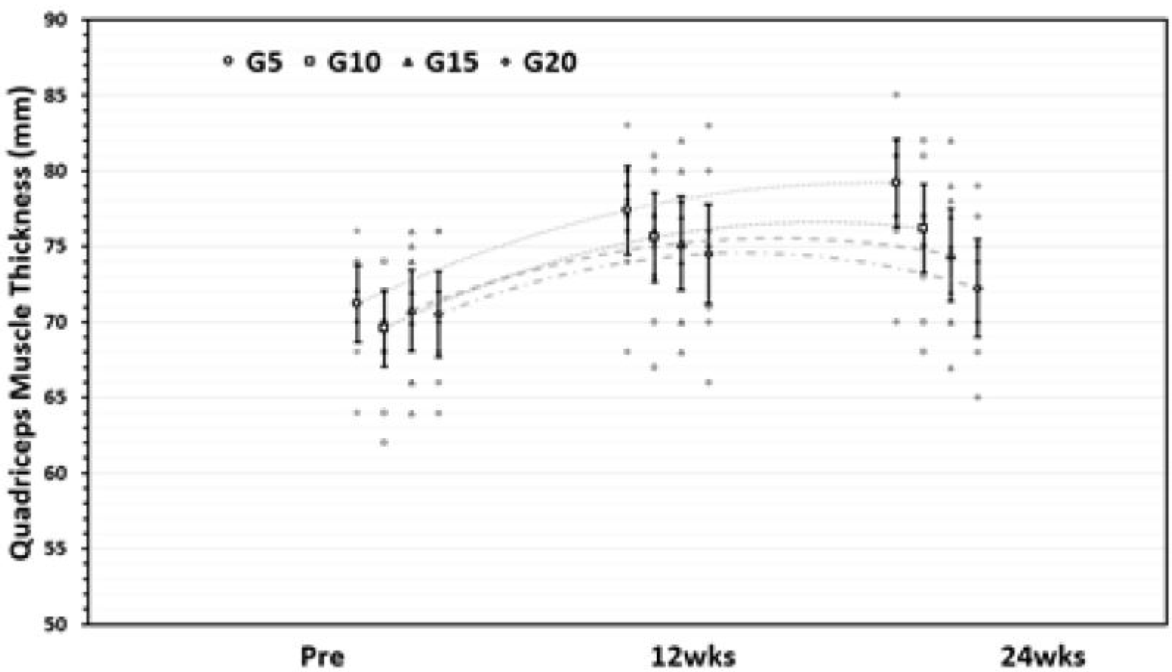
Since the study design was identical to the study on women, the limitations are identical as well. In fact, the authors failed to discuss the once-per-week muscle group frequency as a limitation; they claimed the study supported a max weekly volume of 5-10 sets. However, due to the low frequency, this study is more supportive of a max per-session volume of 5-10 sets, which is in line with the meta-regression results earlier. Also, like the study on women, this study showed a large drop-off in quad and pec gains moving from 8 to 10 sets. Again, it seems unlikely that such a small variation in volume would cause such a large dropoff. Finally, the authors again state that their results might differ from other studies because their subjects trained to "true" failure, but this is an unlikely explanation.

One interesting observation from this study is how the subjects made most of their gains in the first 12 weeks, and then plateaued after that. The two highest volume groups, in fact, experienced regression during the last half of the study.



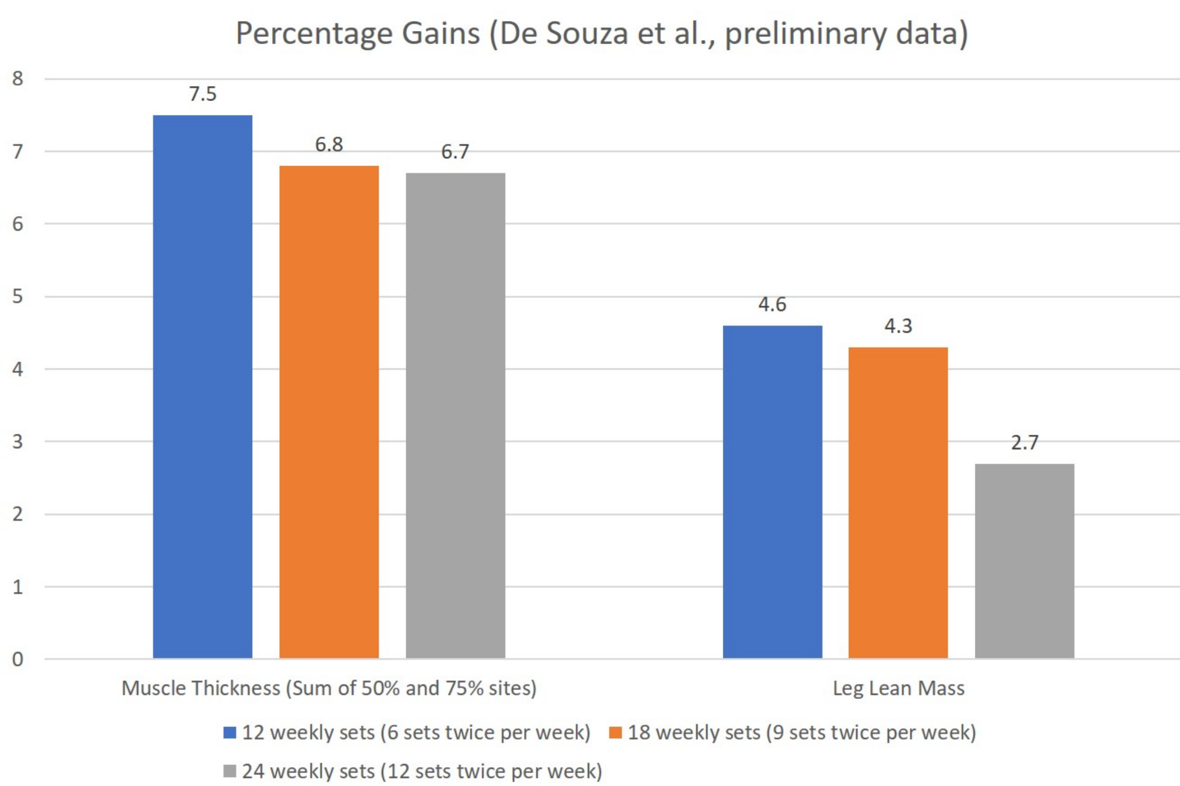






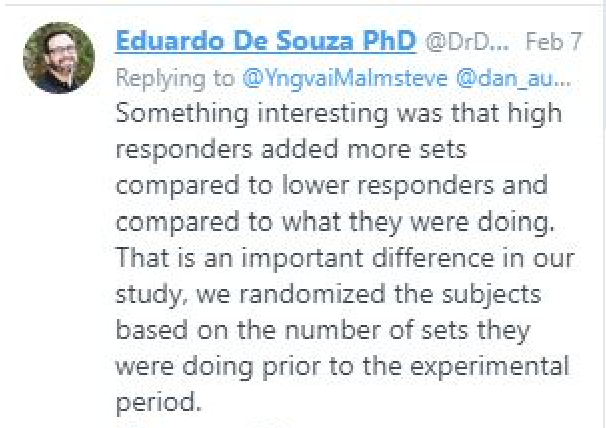
This data suggests that, when experienced trainees are put on a new training program (at least one structured similarly to this study), most gains will occur within the first 12 weeks, and then plateau. The data also suggests that perhaps the highest volume groups were experiencing an overtrained state in the final 12 weeks. This has potential implications for individuals that practice volume cycling, and **suggests that high volume cycles should not exceed periods of 8-12 weeks**.

- Dr. Eduardo De Souza recently tweeted preliminary outcomes from a volume study that his group has completed. While we will need to await full publication of the study to thoroughly evaluate it, we can discuss some of the preliminary data, and I will update this article as more info comes out. The study was performed on highly trained subjects who could squat approximately twice their body weight and had 11% body fat on average. Subjects did 12, 18, or 24 weekly sets on the quadriceps. Training was performed twice per week; thus, per-session volume was 6, 9, and 12 sets. Subjects did squats and leg press with 2 minute rests between sets and 3 minutes between exercises. Here are the percentage gains in the sum of muscle thicknesses and also leg lean mass for each group; De Souza has not reported the P values, but judging by the data he posted, there were likely no significant differences between groups.



The results are in line with our meta-analysis dose-response curve where gains seem to level off or decrease beyond 6-10 sets per training session. I've updated the dose-response curve to include data from this study; the curve barely changed at all with the addition of this data.

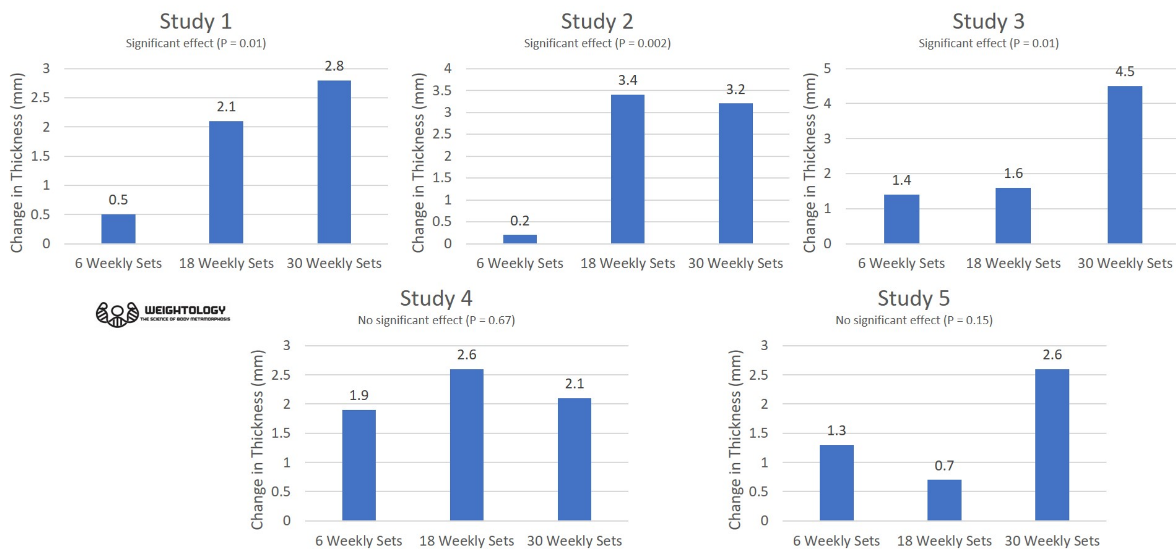
Another interesting aspect of this study is that the researchers randomized subjects based on the number of sets they were doing prior to the experimental period. While the details of this aren't available, it appears that the high-responders in this study were people who increased their volume relative to what they were doing prior to the study, while the low-responders were people who stayed the same or decreased their volume.



This tends to agree with the responder/non-responder analysis from the volume study by Schoenfeld et al. that I discussed earlier, where there were more high responders in the highest volume groups (and the volumes were so high, they were likely an increase over what subjects had been previously doing). This would suggest that **individuals who have plateaued on low-to-moderate volume programs may benefit from an increase in volume**. It also has important implications for the outcomes of research studies**, as the type of program the subjects were using prior to the study may impact the gains observed in the study.** This becomes a potential confounder when looking at group averages in studies on resistance training volume.

Why are there differences in the outcomes of these dose-response studies? Two show a benefit to very high weekly volumes (both of which had very similar study designs), while three do not. There are a number of potential explanations for this:

- **Random chance**. As I have written about here, you can get different results in training volume studies due to random chance alone, even if study designs are identical (which in this case, they are not). This is especially true when you have small sample sizes (most resistance training studies don't have more than 9-20 per group), and you're measuring something that shows tremendous variance from one person to the next, like hypertrophy. In that article, I did a statistical simulation of 5 different studies that sampled from populations that showed a graded dose-response effect of volume on hypertrophy. The studies all had different outcomes, as you can see in this set of charts:



Thus, it's possible that one factor behind the different results of these studies are due to random chance, or a combination of random chance and different study designs. This is why meta-analysis and meta-regression become important.

- **Short vs. Long Rest Intervals**. The two studies showing a graded dose-response relationship up to very high volumes involved short rest intervals of around 90 seconds (although Raedaelli's rest intervals were as high as 2 minutes). Of the studies that showed a plateau, the De Souza study used rest intervals of 2-3 minutes, and two other studies involved long rest intervals of 3 minutes. The Barbalho study used a mix of rest intervals. As I discuss in the guide on rest intervals, longer rest intervals usually result in more hypertrophy than short rest intervals for the same number of sets. This appears to primarily occur with compound movements, and central fatigue is the likely mechanism. The use of short rest intervals on compound movements may inhibit recruitment of high threshold motor units (which have the most capacity for hypertrophy) due to central fatigue. When you train with short rest intervals, you have to do more sets to make up for this. It should be noted that the two studies showing a benefit of very high volumes (Raedaelli and Schoenfeld) used 90 second - 2 minute rest intervals and whole body workouts. Thus, central fatigue was likely very high, and thus more sets were likely necessary and this may explain why a benefit was observed for more than 10 sets per session. Contrast that with most of the other volume studies, which used split routines and longer rest intervals. This would likely result in less central fatigue, and thus you would see a plateau in the response at a lower volume. Therefore, it's possible that the benefits of very high volumes (>10 sets per session) are limited to whole-body training interventions with short rest intervals. Obviously more data is needed here.

- **Lower vs. Higher Frequency**. When examining these studies, the following pattern emerges:
  - Once per week: Hypertrophy plateaus or regresses beyond 10 weekly sets
  - Twice per week: Hypertrophy plateaus or regresses beyond 14-18 weekly sets
  - Three times per week: Hypertrophy continues to increase up to 30-45 weekly sets

  This falls in line with the concept of a maximum effective volume threshold per training session. Based on these studies, it appears to be roughly around 10 sets per session, in agreement with the meta-regression performed earlier. Now, the two studies using a frequency of three times per week suggested a higher threshold of 15 sets per session for some muscle groups. This could be due to random variance (remember that the theoretical peak of 10 sets is based on averages). It could also be due to the use of shorter rest intervals and whole-body workouts as mentioned earlier. A third possibility is that, with increased training frequency, you improve your recovery ability and your capacity to tolerate higher volumes within a single training session.

- **Previous Training Programs**. As discussed earlier, the training program a subject is on prior to participating in a study may impact the subject's response to the study. A subject who has already been training with high volumes may not have the same response as an subject who had been training previously with low volumes. Differences among studies may relate to the types of programs subjects were on before embarking on the training, and which groups they were randomized to. Unfortunately, most studies do not examine individual responses or what types of training programs subjects were utilizing previously. Only the upcoming De Souza paper appears to be directly addressing this question.

It is also possible that the differences between studies could be due to a combination of some or all of these factors.

The Theoretical Case for Volume Cycling

As mentioned earlier, the Schoenfeld volume paper showed an increasing number of responders with increasing volume. Similarly, the De Souza study showed that the responders were primarily individuals who increased their training volume relative to what they were doing before. A third study by Bamman et al. showed that only 16% of the young subjects were non-responders at a volume of 27 weekly sets on quads. All together, this data would suggest that increasing set volume is an effective means to stimulate hypertrophy, especially if someone has reached a plateau and is not responding.

However, there is a limit to how much you can increase volume to achieve further gains. As suggested by the inverted U hypothesis, at some point gains will plateau or regress if volume becomes too high. Thus, at high training volumes, increasing volume is no longer an option once a plateau has been reached. In this situation, dramatically decreasing volume is likely the best option. This would theoretically have the following effects:

- It would allow cumulative fatigue to dissipate, resulting in the expression of new strength gains that may have been masked during the cumulative fatigue of the high volume period.
- It would allow for the maintenance of the new size gains, while simultaneously re-sensitizing the muscle to a future volume stimulus.

The amount of set volume needed to maintain size is much smaller than the amount of volume needed to increase size:

- In a study I reviewed here at Weightology, cutting volume from 24 weekly sets (3 times per week) to 8 weekly sets (2 times per week) for 8 weeks resulted in a maintenance of size gains in untrained men.
- In this study by Bickel et al., untrained subjects did 27 weekly sets to near failure on legs (3 exercises for 3 sets each, 3 times per week). Training went on for 16 weeks. This was followed by two different reduced training periods that lasted for 32 weeks. One group reduced volume by 1/3 (to 9 weekly sets), where training was reduced to only once per week. The other group reduced volume to 1/9 (3 weekly sets), where frequency was reduced to only once per week and set volume was reduced to one per exercise. The 1/9 volume condition maintained size in the young but not old subjects. Muscle size

continued to increase in the young, but not old, subjects of the 1/3 volume group for 16 weeks, and then remained steady for another 16 weeks. Both conditions resulted in a maintenance of strength, if not slight improvement during the reduced volume phase.

- In a study on elderly men, subjects performed 9 weekly sets on legs (3 sets of leg extensions, 3 times per week) for 12 weeks. This was followed by a 12 week reduced training period where frequency was reduced to once per week (1/3 total weekly volume). Size and strength were maintained on the reduced volume.
- In a study I reviewed here at Weightology, lean mass was retained during 2 weeks of no training.

The concept of re-sensitizing a muscle to training is supported in a study I reviewed here at Weightology. In that study, subjects who took 3-week breaks from training experienced decreases in muscle size during those 3-week periods. However, when they returned to training, they gained muscle at a faster rate than subjects who had been training continuously until they caught up with those subjects. This indicates that the muscles of the subjects who took time off were sensitized to the training stimulus due to detraining, and experienced rapid regain (also often called "muscle memory"). But what would have happened if, rather than completely taking time off, the subjects simply had done a period of reduced training volume? We don't know, but we can speculate that perhaps the subjects might have maintained their size, and then when returning to full volume, might have increased at a faster rate than the subjects training at constant volume. However, this is purely speculative, and unfortunately there is no research that has examined this directly. There is at least some theoretical basis for it, though. Once the body adapts to a stimulus, you must provide more stimulus (volume in this case) to continue to produce adaptation. However, you cannot continue to increase the stimulus indefinitely. At some point, you need to make your body more responsive to the stimulus again, and the only way to do that is to reduce (but not eliminate) the stimulus. This will allow for maintenance of adaptations, while allowing the body to recover and become primed for a future increase in the stimulus.

It's also possible that gains may continue for a period of time during a reduction in training volume. In the study by Bickel and colleagues that I mentioned earlier, subjects continued to gain size when they cut volume from 27 weekly sets to 9 weekly sets (but not 3 weekly sets). Now, this study was on untrained subjects, but it at least raises the possibility of continued gains during the initial periods of volume reduction.

Given this limited data, we can hypothesize that volume cycling may be beneficial to maximizing hypertrophy over time. Set volume is increased over time until a maximum effective stimulus is achieved. You stay at this volume until performance plateaus, and then dramatically reduce volume for a period of time. You then start the cycle again. This approach is similar to the approach of cycling between minimum effective volume and maximum recoverable volume recommended by Mike Israetel and Renaissance Periodization. One primary difference from their method is that you use performance as a gauge as to when to stop a high volume cycle, rather than having a preplanned number of weeks.

Here's how a hypothetical cycle might progress:

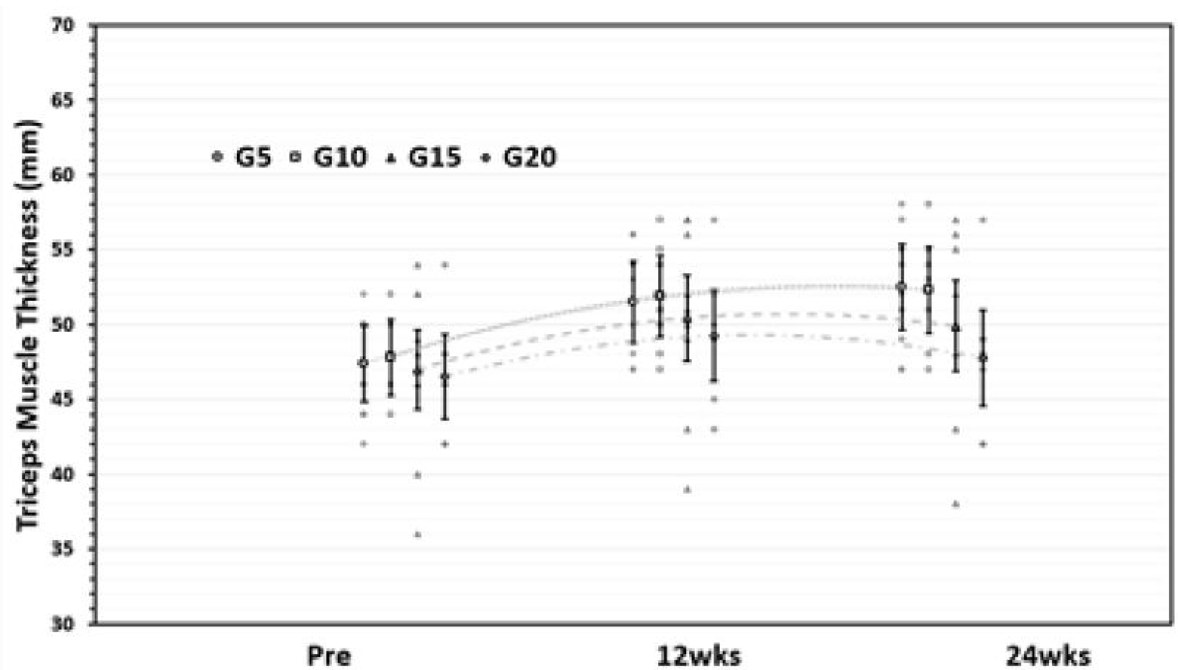
1. Begin with a low training volume (2 sets per muscle group per session, 3 days per week for 6 weekly sets).
2. Add a set per muscle group or per exercise over time (such as once per week, or per session as long as you don't experience next-day soreness).
3. Continue adding sets until you hit 8-10 sets per muscle group per session. Stay at this volume as long as training performance is improving (such as first set performance or overall training load volume across all sets).
4. Once progress stagnates, reduce volume back to near the volume is step 1. You may continue to notice strength improvements during this time as cumulative fatigue dissipates.
5. Continue training at low volume for a period of time to allow your muscles to re-sensitize themselves to a new volume stimulus. The amount of time will likely depend upon how you feel and how your gym performance is doing. If gym performance starts to regress during the low volume period, increase volume a bit.
6. Repeat step #2 and ramp volume back up again. Continue cycling between periods of low, medium, and high volume.

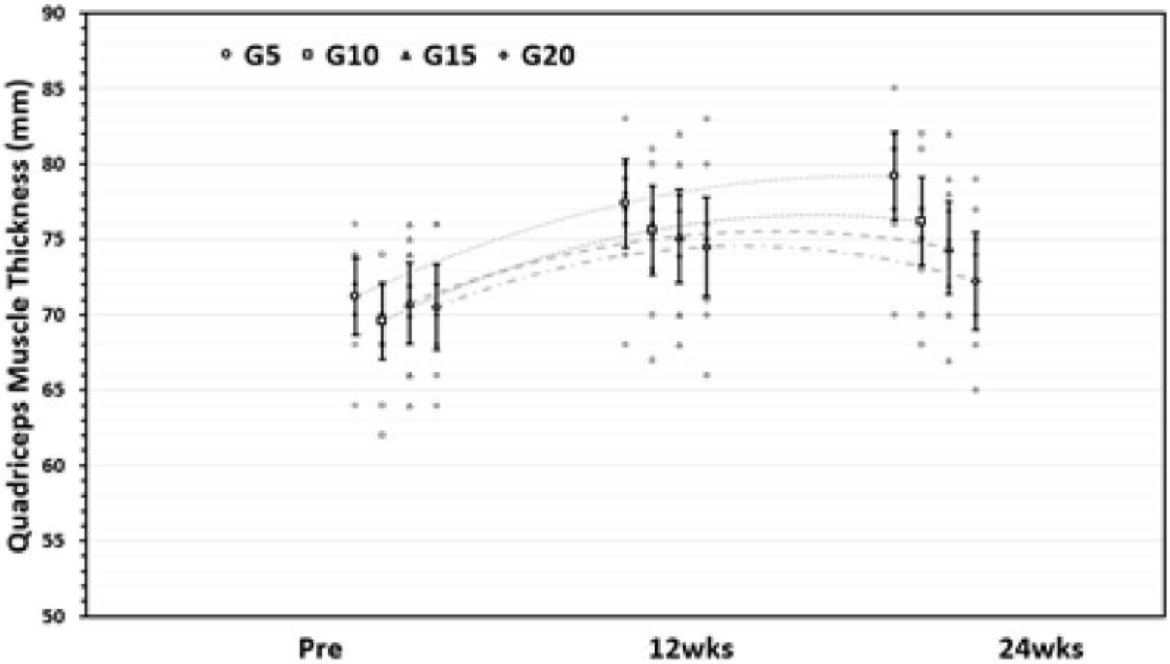
This process can be used in the context of body part specialization (discussed later in this article). Perform a volume ramp with one or two muscle groups, while keeping all other muscle groups on low volume maintenance. Once the high volume cycle is finished for those one or two muscle groups, return those muscle groups to low volume, and then begin a volume ramp for one or two other muscle groups.

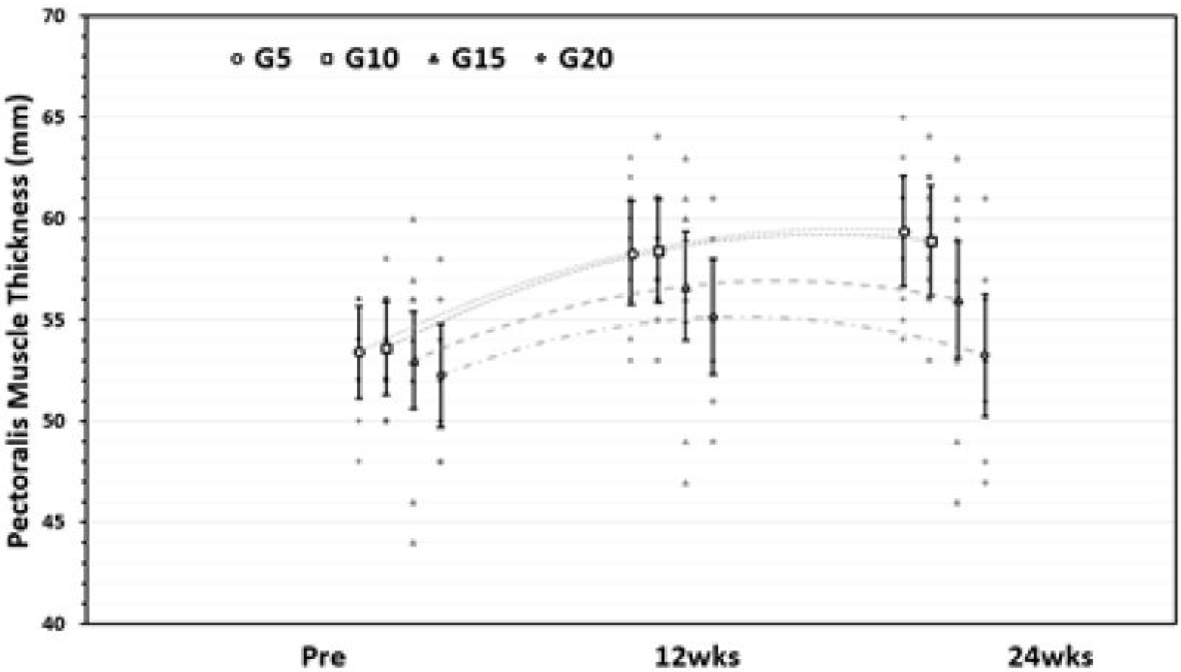
Bear in mind that this is all speculative and hypothetical. We need more research examining the impacts of varying set volume over time.

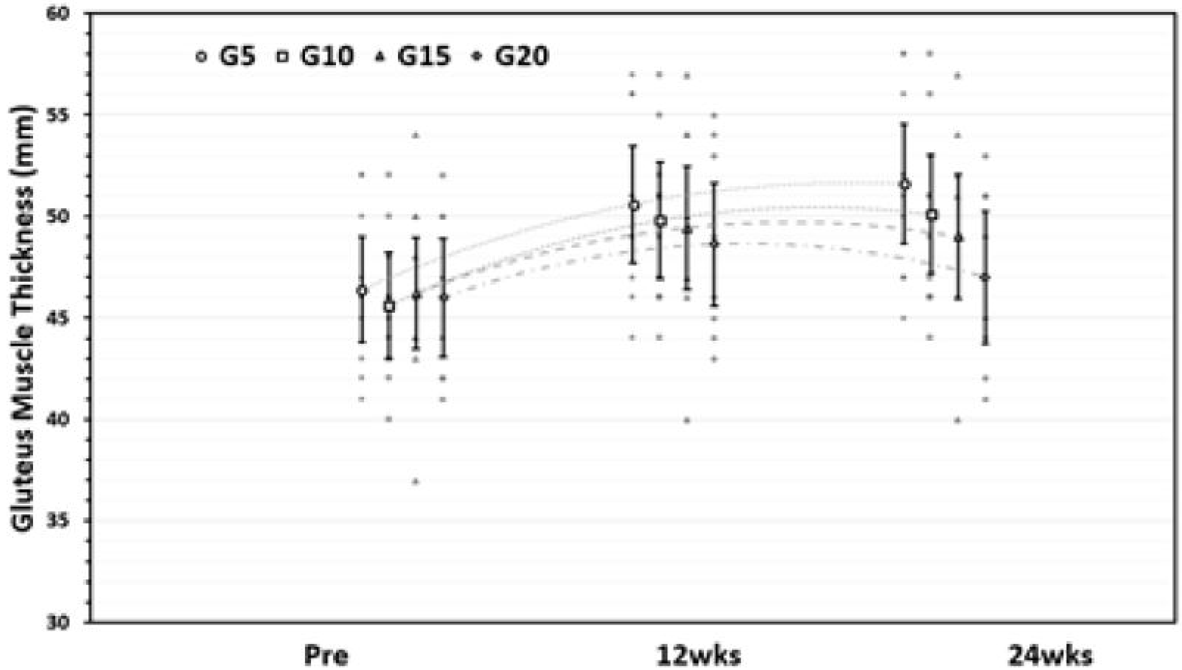
Volume Cycling Via Alterations in Frequency

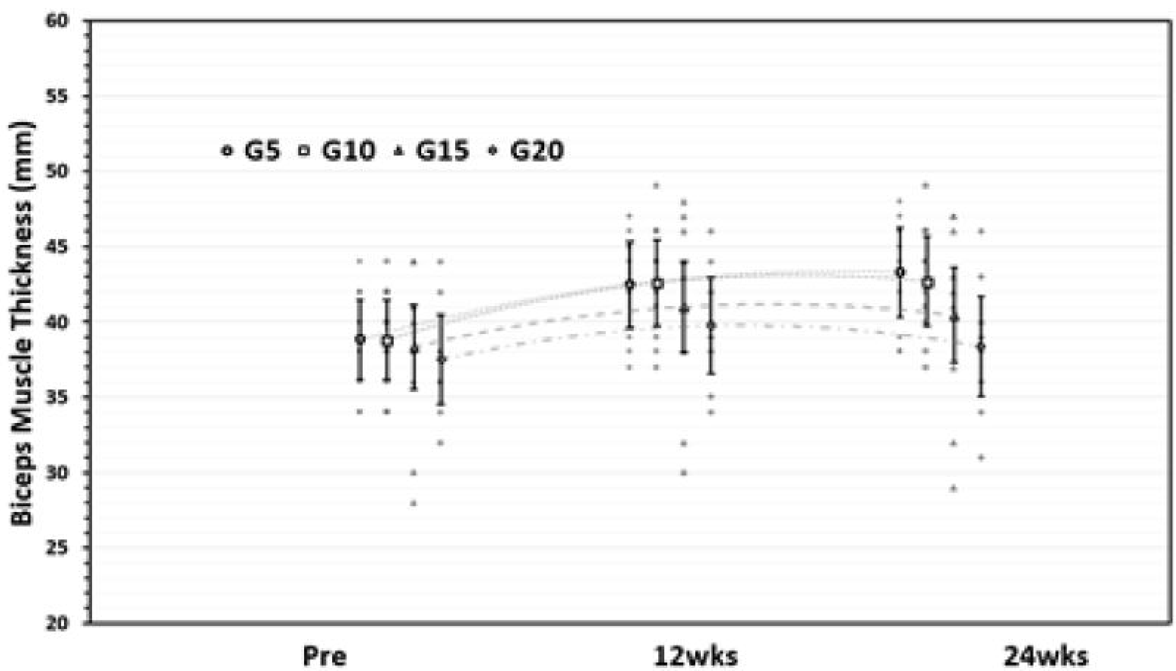
Increasing weekly volume by adding training days represents an alternative to adding sets within a training session. Let's look again at the study by Barbalho and colleagues on trained men. The groups that experienced the best gains (5 and 10 sets within a session) started to plateau after 12 weeks.




G5 G10 G15 G20
Quadriceps Muscle Thickness (mm)
90
85
80
75
70
65
60
55
50
Pre
12wks
24wks

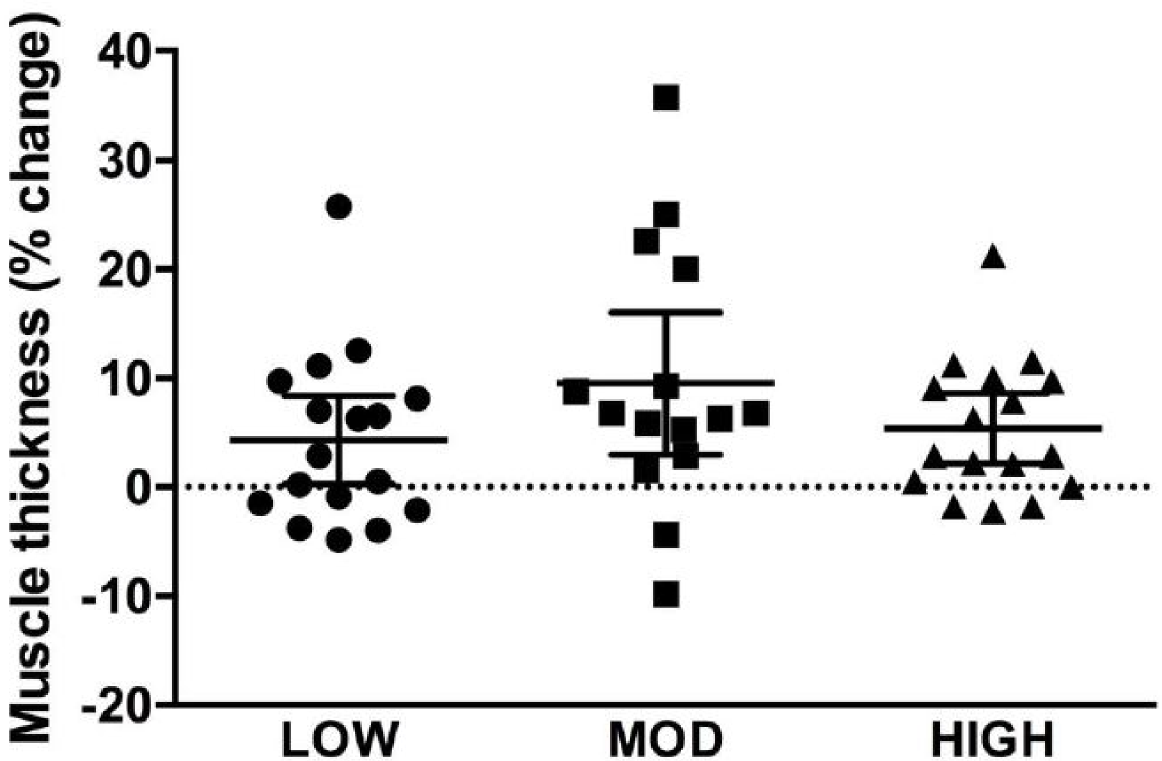

G5 G10 G15 G20
Pectoralis Muscle Thickness (mm)
70
65
60
55
50
45
40
Pre
12wks
24wks



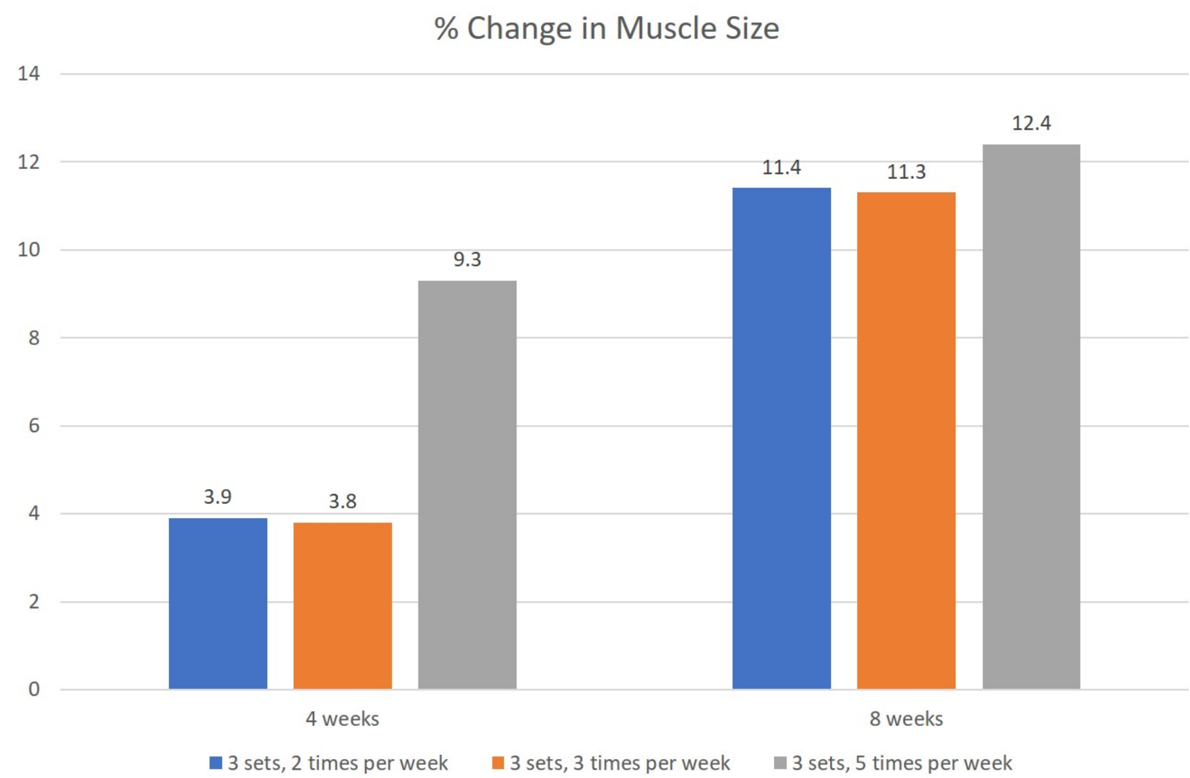


These groups were at the theoretical maximum limit in terms of per-session volume, so increasing volume by adding sets is not the answer to help continue gains beyond 12 weeks. However, since the frequency was only once per week, training frequency could be increased to twice a week. This would essentially double the weekly volume, without going over the maximum per-session limit. For example, the 5-set group would now be doing 10 sets per week (5 sets, twice per week).

Theoretically, increasing volume by adding frequency would increase gains. Unfortunately, there is very limited research as to the effects of using a higher frequency as a tool to increase volume. One study where this did occur was the study by Heaselgrave and colleagues which was discussed earlier. The lowest volume group did 9 sets on biceps, once per week, while the moderate volume group did 9 sets on biceps, twice per week. While not statistically significant, the increase in frequency tended to show an improvement in hypertrophy, with a doubling of the percentage change (9.5 versus 4.3%).



Unfortunately this was the only study performed on trained subjects. Barcelos and colleagues compared 3 sets of leg extensions performed 2, 3, or 5 times per week (6, 9, and 15 weekly sets) in untrained subjects. While changes in muscle size tended to be the greatest in the highest weekly volume group after 4 weeks, the other groups caught up so that by the end of 8 weeks, changes in muscle size were similar.

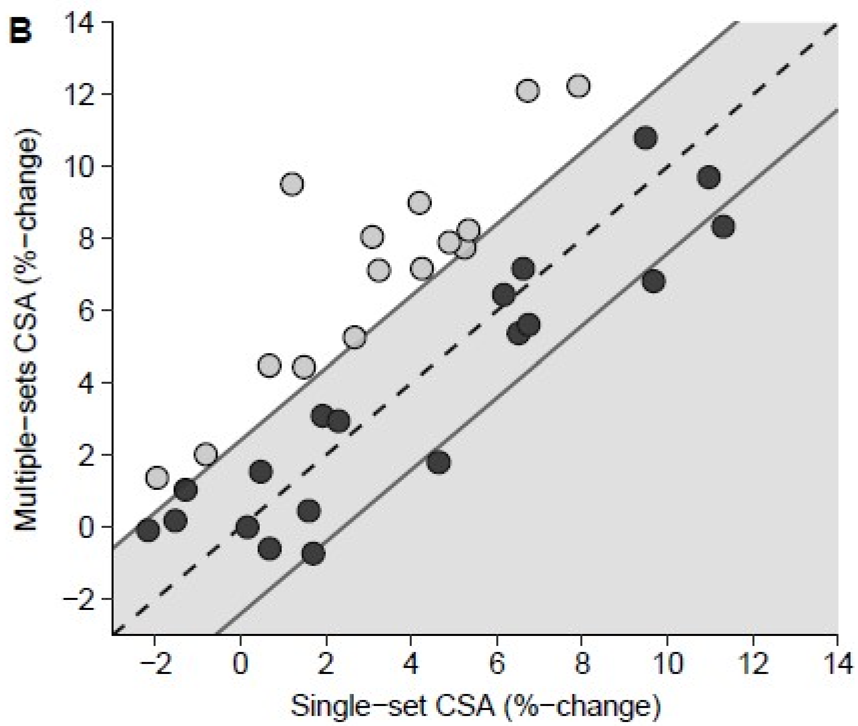


This study supports the concept discussed earlier that beginners are not very responsive to increases in volume, at least if the length of the training program is sufficient (8+ weeks). Thus, low volume, lower frequency programs are sufficient for this population. Remember, though, that this is based on average responses...individual data from this same study by Barcelos showed about a third of beginners benefited from an increase in frequency, another third benefited from a decrease in frequency, and a third showed no additional benefit to either one. Thus, with 2/3 of the subjects showing either a benefit or neutral effect of lower frequency, beginners are best erring on the side of low volume and frequency for their hypertrophy programs.

For experienced individuals, a method of volume cycling using frequency could start off with 5 sets once per week, and then progress to 5 sets twice per week after 6-12 weeks or a plateau is experienced. After another 6-12 weeks or a plateau, frequency is increased again to three times per week (15 weekly sets). A final overreaching phase could then be undertaken with 5 sets performed 4 times per week (20 weekly sets). Then frequency can be reduced back to 1-2 times per week to begin another volume cycle.

The Genetics of the Volume Response

While volume may be a tool to help turn non-responders into responders, especially in trained subjects, there are still limitations to its ability to induce a response. The evidence suggests that how people respond to volume is genetically determined. In this study, beginning lifters performed single leg press and single leg extensions. One leg was trained with low volume (1 set per exercise or 2 total sets for quadriceps), and the other with moderate volume (3 sets per exercise or 6 total sets for quadriceps). Since this was a ***within-subject design***, it removes the effect of genetic variability, and allows a scientist to isolate the effect of volume. The response to low volume was correlated to the response with high volume, with a correlation coefficient of 0.75 (1 is a perfect correlation).



In other words, subjects who were good responders to low volume also tended to be good responders to high volume. Subjects who were poor responders to low volume also tended to be poor responders to high volume (even if the response was improved). This suggests that genetics are the ultimate dictator of how much muscle you'll gain, regardless of your training volume. Some people will grow a lot no matter what type of training they do, and some people won't grow much no matter what type of training they do. While increasing volume may help with your response, it is unlikely that increasing volume will turn you from a hardgainer into an easy gainer. Rather, it is more likely you'll just turn into less of a hardgainer. That's not to say you won't get improvement from increasing volume if you are a hardgainer. If you look at the above graph, there were certain individuals who had a much better response with more sets (such as one individual who went from a 2% change in muscle size with 2 sets per session to nearly a 10% change in muscle size with 6 sets per session).

In this same study, the researchers found that the subjects who responded the best to higher volume had a greater accumulation of total RNA in their muscles. This was indicative of greater creation of ribosomes, which serve as the site for protein synthesis.

Counting Sets: The Direct Vs. Indirect Problem

You'll notice that, in all of this, a set of direct isolation work (like a biceps curl) is treated as a set count of 1, and indirect work (like a row) is also treated as a set count of 1. The question is whether counting direct and indirect movements as 1:1 in terms of sets is valid. Unfortunately, there's no research to guide us to the "real" ratio (assuming there is one). It should be noted that, at least in untrained subjects, the addition of isolation movements doesn't add much to changes in muscle size. This would tend to support the 1:1 relationship, at least in untrained subjects. In other research, it was shown that subjects tended to recover faster from single joint lifts compared to multijoint lifts, suggesting that, if anything, isolation movements may be less stressful than compound movements and possibly benefit from more volume and frequency. However, other data suggests that recovery from single joint exercise may be slower than multijoint exercise, which would tend to support the idea that a set of compound movements shouldn't be counted as "1 set" for muscles like triceps. Also, muscle activity in supporting muscle groups (like triceps in a bench press) may not be maximal compared to a single joint movement, which would tend to question the 1:1 counting method.

Overall, it is not clear whether counting direct and indirect volume as 1:1 is the best method. Nevertheless, there is very little data to suggest any other method, and anything else (like counting each compound movement as a "half set") is based purely on speculation. Thus, until the data clearly shows otherwise, it is likely best to use the 1:1 counting method.

The Practical Limitations of Very High Volumes: A Personal Experiment

Even if the data does support more hypertrophy with volumes up to 27-45 weekly sets, and even if one can tolerate such training, one must consider the practical limitations of trying to train with such volumes, especially in regards to time.

In the high volume training study performed by Schoenfeld, me, and others, the average training time per session for the highest volume group was 68 minutes. The subjects performed 7 exercises, for 5 sets each, for a total of 35 sets per session. However, it's important to note that this time frame of 68 minutes may not be realistic when applied to someone training in a regular gym. In a resistance training study, you have research assistants pushing you along, and also helping to get weights set up for you. There's also no waiting for equipment.

Contrast that with a real-life gym situation, where you don't have anyone hurrying you along from one exercise to the next, and no one is setting up your weights for you. I decided to try an experiment to see how long my training sessions would be, if I tried to do 5 sets per exercise so that I was achieving around 30 weekly sets for most muscle groups. I started out at 1 set per exercise, and would slowly add sets over a number of weeks to allow my body to adapt to ever increasing volume, and to help minimize any soreness. When I got to 5 sets per exercise, I was doing the following in a whole body workout (all sets had 90 seconds rest between them):

- 5 sets hack squat
- 5 sets incline dumbbell press (30 degree incline, neutral grip)
- 5 sets leg extension
- 5 sets machine flye
- 5 sets skullcrushers
- 5 sets machine row
- 5 sets dumbbell curl

This session (35 work sets total), including warmups, took me about 1 hour and 50 minutes to complete. Thus, this is a fairly long workout, longer than what I like to do personally (I don't like to exceed 90 minutes). At three times per week, this would be about 6 hours per week of training. Keep in mind that doesn't even achieve a full 30 sets per muscle group for all muscle groups. Back only amounts to 15 weekly sets. There is no calf work, hamstring work, or direct shoulder work.

Now, one difference between my experiment and the Schoenfeld study is that I utilized a number of isolation exercises. Nevertheless, there is a fairly large difference between my experience and the study. My own experience is probably more relevant to what would happen in real life, as people generally don't have others pushing them along or setting up weights for them.

This brings up the idea that, for most people, achieving very high volumes for most muscle groups is going to be unrealistic, especially if you're using free weights where it takes time to set up. Thus, the most realistic way to achieve high volumes is through the use of specialization, focusing on 1-2 muscle groups while training everything else in the low to moderate volume range.

Tying It All Together

In science, there is something called a "convergence of evidence", also known as "consilience." This is where, when multiple sources of evidence are in agreement, the conclusion can be strong even if the conclusion from any one particular piece of evidence is not strong. In this case, we have lines of evidence from protein synthesis data, anabolic signaling data, satellite cell data, and meta-analytic data, all clustering around a conclusion that ***more volume is better for hypertrophy, up to around 8 sets per training session in experienced subjects***. High weekly volumes (20+ weekly sets) only work with higher frequencies of 3+ days per week, as the per-session maximum volume threshold is exceeded with lower frequencies. Here's an overview of how all the evidence converges. You can see how every line of evidence points to a similar conclusion.

WEIGHTOLOGY THE SCIENCE OF BODY METAMORPHOSIS	Number of Sets Per Muscle Group for Largest Response
Protein Synthesis	3 > 1 in a single session (Burd et al., 2010) 6 > 3 in a single session (Kumar et al., 2012) 12 is only slightly better than 8 in a single session (Damas et al., 2019) 10 non-significantly > 5, and 10 > 20 in a single session (rodent data; Ogasawara et al., 2017) ***Conclusion: Multiple sets better than single sets in a single session; response may peak around 6-10 sets, with a plateau somewhere between 8 and 12 and regression at high volumes of 20+***
Anabolic Signaling	10 > 5 in a single session (Ahtiainen et al., 2015) 3 > 1 in a single session (Burd et al., 2010) 5 > 3 in a single session(Terzis et al., 2010) 6 > 2 in a single session (Hammarström et al., 2019) ***Conclusion: More sets (up to 10 in a single session) are better; no data on upper limit***
Satellite Cells	6 sets, 3 times per week > 2 sets, 3 times per week (Hanssen et al., 2013) ***Conclusion: Up to 6 sets per session, or 18 weekly sets at a frequency of 3 times per week, are better than 2 sets per session, or 6 weekly sets at a frequency of 3 times per week*** ***No data on upper limit***
Hypertrophy (Meta-Analyses)	1x per week frequency: Up to 10 weekly sets; more is associated with plateau or regression 2x per week frequency: 10-19 weekly sets; more is associated with plateau or regression 3x per week frequency: 21+ weekly sets, no data on upper limit Quadratic regression suggests peak hypertrophy at around 8 sets per muscle, per training session in experienced subjects Linear regression on untrained subjects suggests very little benefit from increased volume ***Conclusion: Peak hypertrophy is associated with around 8 sets per muscle group per training session on average in trained subjects. Frequency can be used to achieve high weekly volumes. 2-3 sets per session is sufficient for beginners.*** ***At training frequencies of 2 or 3 days per week, 10-20 weekly sets give the most "bang for the buck" in terms of hypertrophy achieved versus time investment*** ***Individual responses may vary from these averages***
Upper Limit	There appears to be an upper limit of around 8-10 sets per muscle group per session before a plateau or regression occurs. A variety of factors, such as rest intervals, training history, and genetics may impact this upper limit. It should also be remembered that this upper limit will vary from one person to the next.

OVERALL CONCLUSIONS:

- **PEAK HYPERTROPHY IS ASSOCIATED WITH SET VOLUMES OF AROUND 8 HARD SETS PER TRAINING SESSION IN EXPERIENCED SUBJECTS. 2-3 SETS ARE SUFFICIENT FOR BEGINNERS.**
- **THERE IS AN INTERACTION BETWEEN FREQUENCY AND VOLUME; HIGHER WEEKLY VOLUMES (20-45 WEEKLY SETS) ONLY APPEAR TO WORK WITH HIGHER FREQUENCIES (3+ DAYS PER WEEK), LIKELY DUE TO THE LIMIT IN "EFFECTIVE" SETS THAT CAN BE DONE IN A SINGLE SESSION.**
- **WITH A TRAINING FREQUENCY OF 2 OR 3 DAYS PER WEEK, THERE IS MORE BENEFIT MOVING FROM SINGLE DIGIT WEEKLY SETS TO 10-20 WEEKLY SETS, AND LESS BENEFIT WHEN MOVING EVEN HIGHER TO 20+ WEEKLY SETS. THIS WOULD SUGGEST THE BEST "BANG FOR THE BUCK" COMES FROM WEEKLY VOLUMES IN THE 10-20 RANGE IN TERMS OF THE HYPERTROPHY VS. TIME INVESTMENT TRADEOFF WHEN TRAINING EACH MUSCLE GROUP 2-3 DAYS PER WEEK.**

Now, there are a number of limitations to these conclusions:

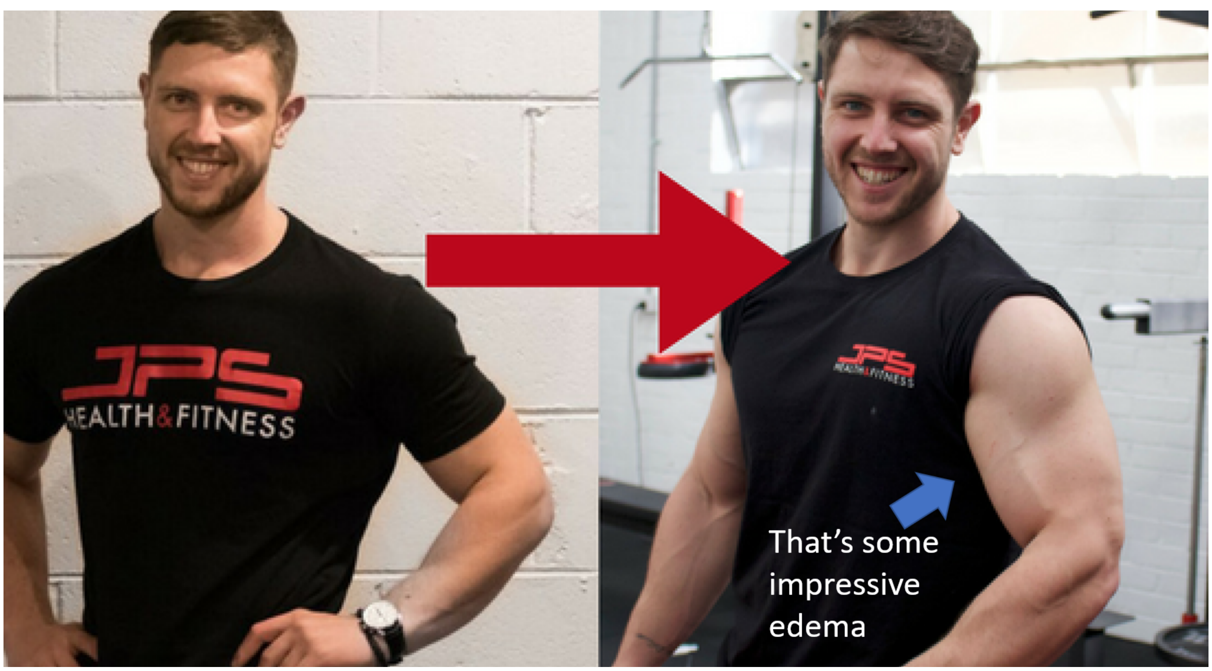
- This is based on average responses. **Individual responses to differences in volume can vary from the overall average dramatically, and thus volume needs will vary from one person to the next.**
- There may be some benefits to cycling volume (similar to the Renaissance Periodization method) and having volume "re-sensitization" periods, but this is speculative and the data is limited at this point.

- **These results only apply to set volumes involving moderate to high repetition ranges (approximately 8 reps or more) to failure or near failure.**
- There is insufficient data to tell us how volume needs might vary based on factors such as age, training status, etc. Age may be a particularly relevant factor here, as recovery time may increase with age. It should be noted that the studies involving 21+ weekly sets all involved young subjects in their 20's. Older individuals may not be able to tolerate such volumes.
- There is insufficient data to tell us how volume needs might vary between different muscle groups (such as upper versus lower body), if they need to vary at all. Currently most of the data suggests there is no benefit, but more research is needed.
- There is insufficient data to tell us how volume needs might vary between different types of exercises (like compound versus isolation, or exercises that load a muscle under stretch versus ones that don't). It's possible that some exercises may need less volume; for example, exercises that load a muscle under stretch (like an overhead dumbbell triceps extension) are more damaging to muscle tissue than exercises that don't (like a hip thrust), so it might be easier to "overdo" it in terms of volume with the loaded stretch exercises.
- **Weekly set volumes of 21+ are very high, and are going to be more than many individuals can tolerate or have time for.** Remember that significant gains are achieved with low to moderate volumes**. You must consider the needs of an individual, including schedule, volume tolerance, recovery ability, available time to train, importance of achieving maximal hypertrophy, injury history, etc.**
- It cannot be ruled out that individuals training with low to moderate volumes may eventually achieve the same gains as higher volumes, but over a much longer time frame. However, there is no research examining this.
- Depending upon an individual's available time to train, it may be difficult for someone to achieve 21+ weekly sets for most major muscle groups, even if he/she can tolerate the volume. In situations like these, it may be best to focus on a couple individual muscle groups, training them with very high volume, and using a maintenance volume on the other muscle groups. Then, after a period of 2-4 months, switch to emphasizing some different muscle groups. This is a strategy that has been recommended by Bryan Krahn,
- Most training studies only last 8-12 weeks. It's possible that, if you're training with 21+ weekly sets for a muscle group, you may not tolerate such volumes

for longer periods of time (although the study by Raedelli and colleagues lasted for 6 months and involved weekly volumes of 30-45 sets for the arms). This is where the needs of the individual have to be considered, including many factors mentioned before (training history, injury history, how close sets are being performed to failure, types of exercises being used, etc).

- **Conclusions in science are always tentative.** The conclusions of this review may change as more data is accumulated (this review has already undergone three major revisions as new data has come in!).

It's interesting to note, anecdotally, that some top trainers in the industry use specialization routines and weekly set volumes of 30-40 to achieve maximum hypertrophy in target muscle groups. Bret Contreras often programs 30-40 weekly sets for glutes in his clients, and Bryan Krahn has mentioned using specialization and 30-40 weekly sets to maximize hypertrophy in a particular muscle group. My friend Jacob Schepis also embarked on his own 10-month high volume arm specialization routine, where biceps and triceps each got about 30 weekly sets (about 15 direct and 15 indirect). Here is visible evidence of his results (and this is in a well trained individual!):



Practical Application: A Moderate Volume Example

So how might you apply this information to structuring a training program for maximizing hypertrophy? Here's one example of how you might structure a program that uses the best "bang for your buck" range of 10-20 weekly sets per muscle group. This particular example is a 4-day upper/lower split; most muscle groups are trained via combination of compound and isolation movements. Total weekly set volume is 16 for most muscle groups. Sets per training session are around 8. Sets are stopped around 1-2 reps short of failure to allow for better recovery, and repetitions and exercises are varied to help reduce joint stress.

Lower Body A			Lower Body B		
	Exercise	Sets*reps @RPE		Exercise	Sets*reps @RPE
LEG PUSH COMPOUND	Barbell Back Squat	4*10-12 @8-9	LEG PUSH COMPOUND	Leg Press	4*10-12 @8-9
HIP COMPOUND	Barbell Hip Thrust	4*10-12 @8-9	HIP COMPOUND	Romanian Deadlift	4*10-12 @8-9
QUAD ISO	Leg Extension	4*10-15 @8-9	QUAD ISO	Sissy Squat	4*15-20 @8-9
HAM ISO	Lying Leg Curl	4*10-15 @8-9	HAM ISO	Standing Leg Curl	4*10-15 @8-9
CALVES	Standing Calf Raise	6*10-15 @8-9	CALVES	Calf Press on Leg Press Machine	6*10-15 @8-9
Upper Body A			Upper Body B		
	Exercise	Sets*reps @RPE		Exercise	Sets*reps @RPE
HORIZONTAL PUSH	Barbell Bench Press	4*10-12 @8-9	HORIZONTAL PUSH	Incline Dumbbell Bench Press	4*10-12 @8-9
VERTICAL PULL	Medium Width Pronated or Neutral Grip Pullups (Weighted if necessary)	4*10-12 @8-9	VERTICAL PULL	Close Grip Lat Pulldown	4*10-12 @8-9
CHEST ISO	Machine Flye	4*12-20 @8-9	CHEST ISO	Cable Crossover	4*15-20 @8-9
TRICEP ISO	Dumbbell Triceps Overhead Extension	4*12-20 @8-9	TRICEP ISO	Tricep Pushdown	4*12-20 @8-9
HORIZONTAL PULL	One Arm Dumbbell Row	4*12-20 @8-9	HORIZONTAL PULL	Cable Row	4*12-20 @8-9
BICEP ISO	Dumbbell Bicep Curl	4*10-12 @8-9	BICEP ISO	Cable Curl	4*10-12 @8-9
DELT ISO	Dumbbell Lateral Raise	4*15-20 @9-10	DELT COMPOUND	Upright Cable Row	4*12-15 @8-9

Practical Application: High Volume Arm Specialization Example

In this example, upper body is trained three times per week (one day is a dedicated arm day) and lower body twice per week. Total arm volume is approximately 26 sets for triceps and 32 sets for biceps (counting both indirect and direct movements). Other muscle groups are in the 12-18 range. Sets per training session does not exceed 10 per muscle group.

Upper Body Monday/Friday			Arms Wednesday		
	Exercise	Sets*reps @RPE		Exercise	Sets*reps @RPE
HORIZONTAL PUSH	Bench Press Variation	4*10-12 @8-9	TRICEPS	Rope Pushdown	5*12-20 @8-9
VERTICAL PULL	Pullup or pulldown variation	4*10-12 @8-9	BICEPS	High Cable Curl	4*12-20 @8-9
CHEST ISO	Machine Flye or Cable Crossover	4*12-20 @8-9	TRICEPS	Skullcrusher	5*12-20 @8-9
TRICEP ISO	Dumbbell Triceps Overhead Extension	4*12-20 @8-9	BICEPS	Low Cable Curl	4*12-20 @8-9
HORIZONTAL PULL	Row Variation	4*12-20 @8-9			
BICEP ISO	Dumbbell Bicep Curl	4*10-12 @8-9			
DELT ISO	Dumbbell Lateral Raise	4*15-20 @9-10			
Lower Body Tuesday			Lower Body Thursday		
	Exercise	Sets*reps @RPE		Exercise	Sets*reps @RPE
LEG PUSH COMPOUND	Barbell Back Squat	4*10-12 @8-9	LEG PUSH COMPOUND	Leg Press	4*10-12 @8-9
HIP COMPOUND	Barbell Hip Thrust	4*10-12 @8-9	HIP COMPOUND	Romanian Deadlift	4*10-12 @8-9
QUAD ISO	Leg Extension	4*10-15 @8-9	QUAD ISO	Sissy Squat	4*15-20 @8-9
HAM ISO	Lying Leg Curl	4*10-15 @8-9	HAM ISO	Standing Leg Curl	4*10-15 @8-9
CALVES	Standing Calf Raise	6*10-15 @8-9	CALVES	Calf Press on Leg Press Machine	6*10-15 @8-9

Wrapping It Up

Well, that about does it for the most thorough review on training volume and hypertrophy that you'll find anywhere. You can be sure that this will be updated as new research becomes available. Conclusions in science are always tentative, and based on the best available evidence at the moment. **In the case of set volume and hypertrophy, more is better up to around 8 hard sets per training session in experienced subjects, while 2-3 sets per session are sufficient for beginners.** High weekly volumes (20+ weekly sets) give best results when split into frequencies of at least 3 days per week. Of course, this is based on averages, and individuals may respond very differently to changes in volume compared to the average. It's also important to point out that **10-20 weekly sets give you the best bang for your buck in terms of hypertrophy relative to the time investment when hitting each muscle 2-3 days per week**. If you're looking to do some very high volume training, s**pecialization is the most realistic method of achieving high weekly volumes for a particular muscle group**. Also, regardless of how you program volume, **the needs of the individual must be considered.**

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