Strength & Conditioning Research

TRAINING FOR HYPERTROPHY

SUMMARY

Relative load	It is very difficult at the present time to make any kind of definitive assessment whether the use of heavy loads (i.e. >65% of 1RM) is superior to the use of lighter loads (<65% of 1RM) for producing muscular hypertrophy in untrained individuals. While there is evidence that lighter loads are able to produce hypertrophy, it is possible that this degree of hypertrophy may be slightly less than that achievable with heavier loads.
Volume	Using multiple sets to achieve a higher volume of training appears to lead to greater hypertrophy than using either single sets or a smaller volume of training. However, the current literature is plagued by a lack of high quality studies with sufficient statistical power and this conclusion can only be drawn based on a meta-analysis of studies and based on a review of non-significant trends.
Muscular failure	It is very hard to make a definitive statement about the effect of training to muscular failure on hypertrophy because of the very small number of studies, However, it seems that hypertrophy might be greater when training to failure in comparison with training not-to-failure where other training variables are equated. Since some evidence suggests that training to failure may increase the risk of overtraining, alternating between periods of training to failure and not training to failure may be the best option.
Frequency	There appears to be a very limited trend towards a higher volume-matched frequency leading to greater hypertrophy in trained subjects. However, this conclusion is very tentative and further research is clearly needed in this area. On the other hand, in untrained subjects a higher volume-matched training frequency seems to have no effect or may even have a detrimental effect on hypertrophy.
Rest periods	Studies comparing short and long fixed rest periods have reported conflicting results. However, training volume was not always equated and the groups that used shorter rest periods often trained with lower volume, which makes them hard to compare. Studies comparing fixed with reducing rest periods have found that the duration of rest periods had no effect on muscular hypertrophy, even when volume was lower.
Range of motion	The research in this area is very limited but there is some evidence that training with a greater range-of-motion leads to greater hypertrophy than training with a smaller range-of-motion.
Repetition speed	Repetition speed appears to have little, if any, effect on hypertrophy. However, repetition speed may be important for other outcomes, such as speed and power.
Muscle action	It seems possible that eccentric muscle actions may lead to greater hypertrophy than concentric muscle actions but the literature is far from being conclusive.

FOREWORD BY JAMES FISHER

Chris Beardsley says...

For this collection of reviews, I was delighted when my friend James Fisher agreed to write a short foreword. James is a very well-known and highly respected sports scientist working in the areas of both strength and hypertrophy and he shares my keen interest in promoting the importance of long-term training studies for a better understanding of hypertrophy. I hasten to add that James and I don't always agree on the exact interpretation of the literature (in fact this is rarely the case!) but I find that because of our disagreements I learn more from reading what James has to say than I do from reading people with whom I agree. It was in this spirit of a desire to learn rather than a desire to be “right” that I asked James to contribute to this collection of reviews by writing a foreword.

James Fisher says…

The present piece represents a sound review of the body of literature surrounding resistance training for muscular hypertrophy.

What are the problems in the literature?

Unequivocally, this area of research is hindered with difficulties in comparing studies, whether that be differing methods of measuring hypertrophy, or the statistical analyses (which of course are further limited by under-powered research studies). A vast majority of research considering resistance training has utilized untrained participants, potentially to the bias of the scientist seeking significant values which make their research more attractive to publication.

Where should future research focus?

Further research should certainly consider trained participants, over longer duration interventions, as well as the inclusion of more realistic workouts (e.g. full body, or multiple exercises, as opposed to single exercises).

What is the most important training variable?

In my own review in 2013, and from the present piece it appears that intensity of effort, or training to muscular failure appears the most significant controllable variable; this is supported by the evidence and is logical in the sequential recruitment according to the well established size principle with the goal being maximal recruitment of motor units and thus muscle fibers.

What is the most important uncontrollable variable?

Of course the most significant, but uncontrollable variable, is that of our genetics; by understanding that we are not identical directs us on a path to seek our own individually prescriptive training routine. Other variables might affect growth to a varying degree; however limitations in the literature hinder definitive conclusions. A muscle does not recognize a difference between resistance types, and a maximal repetition is maximal whether it is a single repetition or the final repetition in a set.

How should we move forwards?

In my opinion, reviews of research such as this provide an excellent foundation which we should consider with intellectual analysis, addressing the application of the discussed principles honestly in our training and recording our progress as we try different methods.

INTRODUCTION

Chris Beardsley says…

Hypertrophy is one of the most sought-after outcomes that resistance-training programs are intended to achieve. However, in spite of the great interest in this area, relatively few long-term training studies have been performed to assess how the different variables within a resistance-training program can be manipulated to alter the amount of hypertrophy that occurs.

What are long-term studies important?

Most of the studies that are discussed in popular forums relating to hypertrophy are actually acute investigations of physiological variables. For example, studies are often performed to assess how different molecular signaling pathways are activated in response to different training protocols. Often, these are taken as evidence of the effectiveness of a particular protocol for achieving increases in muscular size. However, in reality, physiology is so complex that it is incredibly hard to be sure that such acute investigations will actually lead to meaningful changes over longer periods. A great reminder of this fact is the recent demise of the "hormone hypothesis" which stated that the level of the post-exercise anabolic hormone response was able to predict the amount of hypertrophy that occurred. For many years, researchers believed that if a workout led to a greater post-exercise anabolic hormone release, it would cause more hypertrophy. This led some strength and conditioning coaches to structure their programs around ways of increasing this post-exercise hormone response. However, recently, this has been found to be incorrect. There may certainly be some benefits of acute elevated hormone levels, but their overall importance for hypertrophy appears to be greatly over-exaggerated. This error underscores how dangerous it is to base our guidelines for resistance-training on acute studies and emphasizes the importance of knowing exactly what the long-term studies say.

What do long-term studies investigate?

Long-term studies tend to investigate how different training variables can be manipulated in order to alter the degree of hypertrophy that occurs. Training variables are those factors that can be altered within a resistance-training program in an effort to maximize hypertrophy. Such variables include relative load (i.e. percentage of 1RM), volume (i.e. number of sets and reps at a given load), whether muscular failure is reached, frequency (i.e. number of times per week), rest periods, range-of-motion, repetition speed (or duration), and muscle action (i.e. eccentric or concentric). Unlike the underlying mechanisms by which hypertrophy is thought to occur (mechanical loading, metabolic stress, and muscle damage), these factors can be very easily measured from one intervention to the next simply by altering programming and monitoring the results.

What is the point of reviewing long-term studies?

Given that many researchers have already performed reviews of the literature relating to hypertrophy, it is fair to ask what a limited review of the long-term studies can add. Importantly, few previous reviews have limited themselves to an exclusive discussion of the chronic, long-term training literature. Inevitably, this means that the conclusions of the reviews are colored by the acute literature, which as we noted above, leads to less reliable findings and could potentially cause coaches to make programming errors as the "hormone hypothesis" previously did.

What does this review add?

This particular review was performed in order to show what we know about how hypertrophy is affected by training variables. As you will see, our understanding is very much less complete than many would lead you to believe. In fact, amazing as it may seem, we actually know very little about how to structure a resistance-training program so that it causes significantly more hypertrophy than any other program.

What factors do have an effect?

Overall, it seems that the only factors for which we can make even the most tentative statements are: volume, range-of-motion and muscular failure. It seems that training with a higher volume, a greater range of motion and to muscular failure all seem to lead to greater hypertrophy. With a still smaller degree of confidence, we might also assert that a higher training frequency (in trained subjects only) and the use of eccentric muscle actions could also lead to greater hypertrophy. Finally, however, it is very difficult to see whether or how relative load, rest periods, and repetition speed affect the extent to which hypertrophy occurs following strength training programs.

Therefore, it seems logical that for developing muscle mass, training programs should focus on increasing volume (either in individual workouts or by increasing frequency), the use of full ranges of motion, and training to muscular failure where possible, acknowledging that recovery requirements may necessitate switching between periods of training to failure and not training to failure. Additionally, it is likely most beneficial to use exercises that involve an eccentric component as well as a concentric component.

CONTENTS

1. TRAINING FOR HYPERTROPHY

Relative load

Introduction

Whether heavy loads lead to greater hypertrophy than light loads is a matter of fierce debate, both in the ivory towers of sports science circles and on strength sports forums worldwide. Unfortunately, these debates often degenerate into unproductive arguments because of a lack of knowledge on one or both sides regarding the real extent of the currently available evidence from long-term training studies. This short review sets out the results of the available training studies and makes it clear how much we know (and how much we don't know).

What is the background?

When devising guidance or recommendations regarding resistance-training programs, strength and conditioning coaches generally refer to three different bands of relative load, typically described as heavy (1 – 5RM), moderate (6 – 15RM) and light (15RM+, which corresponds with <65% of 1RM). While the division between heavy and moderate relative loads is somewhat arbitrary, it is thought that the division between moderate and light loads represents a fundamental dividing line. Previous researchers and coaches have generally assumed that training with light loads of <65% of 1RM is less effective for hypertrophy than training with heavy loads, even in beginners. Perhaps surprisingly, although this is a commonly-held belief, the picture from the available training studies is not at all conclusive.

Why do we need to know what training studies say?

This review is necessary not because there is a lack of high-level analysis of the overall literature. After all, Brad Schoenfeld has provided exhaustive discussions of this area in at least two of his deservedly lauded review articles (Schoenfeld, 2010 and 2013). However, in my own discussions with strength and conditioning professionals and other researchers, I have noted that there is a lack of awareness of where evidence from the chronic (i.e. long-term) studies ends and where evidence from acute (i.e. very short-term) studies begins. While this might seem to some people to be a dry and unnecessary distinction, it is actually quite an important point. Chronic studies measuring hypertrophy do actually tell us how a training variable affects muscular size directly. They measure the size of the muscle before and after an intervention and, unless there is a severe flaw in the study, this gives us a firm foundation upon which to base recommendations. On the other hand, acute studies measure short-term physiological variables that are thought to correspond with greater muscular hypertrophy over the long-term. The problem with this is that the measurement is indirect and the human physiological system is extremely complex, leading to a very high risk of error.

Indeed, we are fortunate that we have all observed a very recent lesson in this respect, as the hormone hypothesis is now widely thought to be discredited. Formerly, evidence from acute studies suggested that we should build workouts around their ability to cause a significant rise in post-workout anabolic hormones. This is now believed to be unnecessary, or at least largely overrated (see Schoenfeld, 2013). Therefore, it seems prudent that we establish very clear statements regarding what is known about a subject firstly from the chronic literature, which can be regarded as strong evidence, and secondly from the acute literature, which should be regarded as weaker (but still very important) evidence. This review is intended to provide a summary of the chronic literature.

How does relative load affect hypertrophy?

In preparing this research summary, I am heavily indebted to the previously performed review by Schoenfeld (2013), and the reader is referred to that source for more detailed information. The following studies have assessed the differences in hypertrophy that result from using heavy vs. light loads in untrained populations. To my knowledge, no studies have been performed in trained populations (although Schoenfeld is currently working on a paper covering research from his laboratory in this respect).

Scheunke (2012) – the researchers recruited 34 untrained females for a 6-week program and allocated them into either slow-speed (6 – 10RM with 10-second concentric and 4-second eccentric, or 40 – 60% of 1RM), normal-speed-strength (6 – 10RM with 1-2-second concentric and 1-2-second eccentric or 80 – 85% of 1RM), normal-speed-endurance (20 – 30RM with 1-2-second concentric and 1-2-second eccentric or 40 – 60% of 1RM) or control groups. The subjects trained 2 days per week in week 1 and 3 days per week thereafter, performing leg presses, squats and knee extensions with 2 minutes inter-set rest periods. Before and after the 6-week period, the researchers took muscle fiber biopsies to assess fiber-type composition and muscular cross-sectional area. The normal-speed-strength increased type I and type IIA fiber area by 26.6 ± 22.7% and 32.9 ± 20.4%, respectively, both of which increases were significantly greater than the other groups. Moreover, the normal-speed-strength group increased type IIX fiber type area by 41.1 ± 32.7%, which was significantly greater than the control. This was the only significant difference in the change in type IIX fiber type between the groups.

Campos (2002) – the researchers recruited 32 untrained males for an 8-week resistance-training program and allocated them into a low-rep group (3 – 5RM for 4 sets of each exercise with 3 minutes of rest between sets and exercises), an intermediate-rep group (9 – 11RM for 3 sets with 2 minutes of rest), a high-rep group (20 – 28RM for 2 sets with 1 minutes rest), and a control group.

Relative load continued...

The subjects performed the leg press, squat, and knee extension 2 days per week for the first 4 weeks and 3 days per week for the second 4 weeks. The researchers took muscle biopsies before and after to assess muscular cross-sectional area and fiber-type composition. The researchers observed increases in the cross-sectional area of all 3 major fiber types (types I, IIA, and IIX) in the low-rep and intermediate-rep groups but they did not observe any significant increases in either the high-rep or control groups.

Holm (2008) – the researchers recruited 11 sedentary males for a 12-week intervention in which each subject trained 3 times per week, with one leg at 70% of 1RM (heavy load) and the other leg at 15.5% of 1RM (light load). Before and after the intervention, the researchers measured muscular cross-sectional area with magnetic resonance imaging (MRI) scans and also took muscle biopsies. They reported that quadriceps muscle cross-sectional area increased 8 ± 1% and 3 ± 1% in the heavy and light legs, respectively, and the difference between legs was significant.

Popov (2006) – the researchers recruited 18 young, physically active males for an 8-week intervention, in which they trained their leg extensor muscles 3 times per week. A heavy group worked at 80% of MVC and a light group worked at 50% of MVC. Before and after the intervention, the researchers measured muscular cross-sectional area using MRI scans. They found that the heavy group increased muscular cross-sectional area by 17% and the light group by 9%. However, this difference was not statistically significant.

Tanimoto (2008) – the researchers recruited 36 healthy but untrained young males who performed whole-body resistance training 2 times per week for 13 weeks using 3 sets each of the squat, chest press, lat-pull-down, abdominal bend, and back extension. The subjects were allocated into 3 groups: light (55 – 60% of 1RM with 3-second eccentric and concentric actions), heavy (80 – 90% of 1RM with 1-second concentric and eccentric actions and a 1-second pause) and a control. Before and after the intervention, the researchers measured muscle thickness using ultrasound. The researchers found that the increase in muscle thickness was similar in the light (6.8 ± 3.4% in a sum of six sites) and heavy groups (9.1 ± 4.2%). However, the heavy group displayed a non-significant trend to a larger increase than the light group.

Van Roie (2013) – the researchers compared the effects of high- and low-load resistance-training on muscle volume in 56 older adults performing an intervention of 12 weeks of leg press and leg extension training at either high (2 × 10–15 reps at 80% of 1RM, low (1 × 80–100 reps at 20% of 1RM), or low+ (1 × 60 reps at 20% of 1RM, followed by 1 × 10–20 reps at 40% of 1RM) relative loads. There was no significant difference in the increase in muscular volume between groups. The muscular volume of the upper leg increased significantly in the high (+3.2 ± 3.7%), low (+2.4 ± 2.7%), and low+ (+2.6 ± 3.8%) relative load groups. There was therefore a non-significant trend in favor of the higher relative load group.

Tanimoto (2006) – the researchers recruited 24 healthy but untrained young males who performed whole-body resistance training 3 times per week for 12 weeks with 3 sets of knee extension exercise. The subjects were allocated into 3 groups: light-slow (50% of 1RM with 3-second eccentric and concentric actions), light-normal (50% of 1RM with 1-second eccentric and concentric actions and a 1-second pause), and heavy (80% of 1RM with 1-second concentric and eccentric actions and a 1-second pause). Before and after the intervention, the researchers measured increases in cross-sectional area with MRI. The researchers found that the quadriceps cross-sectional area increased by 5.4 ± 3.7% in the light-slow group and by 4.3 ± 2.1% in the heavy group but there was no increase in the light-normal group. There was no significant difference between the increase in quadriceps cross-sectional area between the light-slow and the heavy groups.

Leger (2006) – the researchers recruited 25 healthy but untrained males for an 8-week intervention of resistance training followed by de-training. The subjects were allocated into one of two training groups (low reps or high reps) that were matched for age, height, weight, VO2-max and muscular strength and endurance. The subjects performed the same training protocol as described in Campos (2002) above and the researchers took CT scans to measure muscular cross-sectional area before and after the intervention. The researchers observed an increase in quadriceps cross-sectional area of approximately 10% in both groups with no significant differences between groups.

Mitchell (2012) – the researchers recruited 18 healthy but untrained young males for a 10-week study in which they performed single-leg resistance-training 3 times per week. The researchers randomly allocated each of the subjects' legs to 1 of 3 different training protocols that differed by volume and by relative load, as follows: 30% of 1RM x 3 sets, 80% of 1RM x 1 set, and 80% of 1RM x 3 sets. Before and after the intervention, the researchers measured muscle volume by MRI. The researchers reported that all 3 groups increased muscular volume significantly and similarly (30%-3 = 6.8 ± 1.8%, 80%-1 = 3.2 ± 0.8%, and 80%-3= 7.2 ± 1.9%), although there was a trend for the groups performing a greater number of sets to display non-significantly greater hypertrophy.

Relative load continued...

Ogasawara (2013) – the researchers recruited 9 young, untrained males for a 6-week, high-load-resistance-training program for the bench press using 75% of 1RM for 3 sets, 3 times per week, followed by a 12-month detraining period, followed by a 6-week, low-load-resistance-training program using 30% of 1RM for 4 sets, 3 times per week.

Before and after each 6-week intervention, the researchers measured the muscular cross-sectional area of the triceps brachii and pectorals major using MRI scans. They reported that in both interventions, the muscular cross-sectional area increased significantly for both muscles, with the high-load intervention increasing triceps brachii and pectorals major cross-sectional area by 11.9% and 17.6%, respectively, and the low-load intervention increasing the same muscles by 9.8% and 21.1%, respectively. However, there were no significant differences between groups.

What is the summary of findings?

In summary, this is not an easy set of studies to draw strong conclusions from. Moreover, we always need to remember that all of the above studies were performed in untrained subjects and not in trained individuals. However, the literature can be analyzed as follows:

Significant differences – The first 3 studies (i.e. Scheunke, 2012, Campos, 2002 and Holm, 2008) found significant differences between high- and low-relative load groups, with the high relative-load displayed greater increases in muscular hypertrophy than the low-relative load group.

Non-significant differences – The next 3 studies (i.e. Popov, 2006, Tanimoto, 2008, and Van Roie, 2013) reported marked non-significant differences between the high- and low-relative load groups, with the high relative-load displaying greater increases in muscular hypertrophy than the low-relative load group.

No differences – The final 4 studies (Tanimoto, 2006, Leger, 2006, Mitchell, 2012, and Ogasawara, 2013) found no differences.

This complete lack of agreement indicates that it is very difficult at the present time to make any kind of definitive assessment whether the use of heavy loads (i.e. >65% of 1RM) is superior to the use of lighter loads (<65% of 1RM) for producing muscular hypertrophy in untrained individuals.

What is the bottom line?

It is very difficult at the present time to make any kind of definitive assessment whether the use of heavy loads (i.e. >65% of 1RM) is superior to the use of lighter loads (<65% of 1RM) for producing muscular hypertrophy in untrained individuals. While there is some evidence that lighter loads are able to produce hypertrophy, it is possible that this degree of hypertrophy may be slightly less than that achievable with heavier loads.

What are the practical implications?

When working with untrained beginners, personal trainers may be able to produce significant hypertrophy using lighter loads (15RM+ or <65% of 1RM). Such hypertrophy may be similar or only slightly inferior to that achievable using heavier loads and this may allow for greater variety and an initially less-challenging task for the client.

Volume

Introduction

Along with training to failure, or the importance of heavy loads, the effect of training volume on hypertrophy is a highly contentious area for strength and conditioning professionals, bodybuilding coaches and personal trainers. Here is a summary of what we know…

What is the background?

Chronic training studies measuring the effect of different training variables on hypertrophy, including volume, are few and far between. Additionally, there are various problems associated with this area of literature, most notably that gains in hypertrophy are much smaller than gains in strength and that such gains tend to display a great deal of variability between subjects (e.g. Hubal, 2005). Moreover, trials tend to involve relatively few subjects over short durations. These factors indicate that the risk of type II error (failure to identify a significant difference) is high in chronic training studies investigating hypertrophy, as Krieger (2010) in fact noted in a recent meta-analysis. Krieger (2010) observed that there is a risk that if studies are consistently performed reporting no-significant effects as a result of a variable, this could lead to a false impression of the true effect of that factor, if those studies are deemed to be underpowered. This, therefore, was the basis for performing a meta-analysis, at the end of which he concluded that multiple sets are associated with 40% greater hypertrophy-related effect sizes than single sets, in both trained and untrained subjects. However, Fisher (2012) has offered a detailed critique of the meta-analysis by Krieger.

Fisher suggested that the meta-analysis did not control or analyze the training status of the individuals concerned, which as observed above might make a marked difference to the ability to gain muscle mass in the short-term. Fisher also proposed that different relative loads were used in the studies, ranging from 6 – 8RM through to 15 repetitions, although as we will see later on the topic of relative load, this might not be expected to make a substantial difference. On the technical side, Fisher also draws attention to the fact that there were wide ranges of measurement methods used in the studies, some of which have greater validity than others. Finally, Fisher concludes saying that "researchers should be careful of meta-analysis that provides a single statistic proving something that no empirical study within that meta-analysis is able to support". Indeed, it is important to note that only two of the eight studies in the meta-analysis support the use of multiple sets and only then in lower body training in untrained subjects. However, against this criticism, we must weigh the high risk of type II error when measuring hypertrophy, meaning that it is very easy to perform studies showing no effect.

What is the effect of volume on hypertrophy?

The following chronic training studies have explored the effects of different volumes of training in both untrained and trained individuals. This analysis is divided into two sections. The first section of eight studies covers those trials included in the meta-analysis by Krieger (2010). The second section covers those trials published since that date, which were not included in that meta-analysis.

Galvão (2005) performed a randomized trial in 28 community-dwelling men and women aged 65 – 78 years. The subjects were allocated to either a 1-set or a 3-set group and both groups performed progressive resistance training consisting of seven exercises targeting the major muscle groups of the upper and lower body on exercise machines two times per week for 20 weeks using an 8RM load. The researchers reported that there was no difference between groups in respect of the change in body composition.

Marzolini (2008) compared resistance training in 1-set or 3-set groups, when combined with aerobic training in 72 individuals with coronary artery disease, although only 53 subjects with a mean age of 61 ± 2 years completed the intervention. The 3-set group increased lean mass non-significantly more than the 1-set group.

McBride (2003) compared the effects of a 12-week resistance-training program in 1-set or 6-set groups of 28 untrained males and females, training twice a week, on lean body mass of the legs and arms measured by dual energy X-ray absorptiometry. The researchers found no significant differences in lean muscle mass gains for the legs or arms.

Munn (2005) compared the effects on arm circumference in the early phase of resistance training with 1 or 3 sets and with either fast or slow speeds. They found that 3 sets of training produced greater increases in strength than one set but no significant difference between the groups was found in respect of arm circumference, as measured by a tape measure.

Ostrowski (1997) investigated the effects of different volumes (1 set versus 3 sets) of resistance training on muscle size over a 10-week period in 27 males with 1 – 4 years weight-training experience, training 4 days a week. Ultrasound was used to measure the cross-sectional area of the rectus femoris as well as to measure the muscle thickness of the triceps brachii. The researchers reported that there were no significant between-group differences, although there were significant increases in cross-sectional area for the rectus femoris and in muscle thickness for the triceps brachii in each of the groups.

Volume continued...

Rønnestad (2007) compared the effects of single- and three-set resistance-training on hypertrophy in 21 untrained males, training 3 days per week for 11 weeks using 7 – 10RM loads. It was found that thigh cross-sectional area increased more in the three-set group than in the one-set group (16 vs. 8%) but there was no significant difference between groups in respect of upper trapezius muscle cross-sectional area.

Rhea (2002) compared 1-set and 3-set protocols of resistance-training in 16 recreationally trained young males, training 3 days per week for 12 weeks on the bench press and leg press using 4 – 8RM loads. However, neither group displayed significant changes in any of the body composition measures as a result of the training program.

Starkey (1996) assessed the effects of different volumes of resistance-training on muscle thickness in 10 healthy but untrained subjects training 3 times per week using either one set or three sets of bilateral knee extension and knee flexion exercises, which were performed to fatigue using 8 – 12 repetitions over a 14 week period. Before and after the intervention, the researchers assessed muscular thickness at various points along the leg using B-mode ultrasound. The researchers found increases in muscle thickness for both groups in the quadriceps muscles (in the medialis for the 3-set group and in the lateralis for the 1-set group) and in the hamstrings muscles at 40% and 60% from greater trochanter to lateral epicondyle of the tibia, for both 1-set and 3-sets groups.

Since the date of the most recent meta-analysis performed by Krieger, there have been at least three further studies performed exploring the effects of volume on hypertrophy, in various populations, as follows:

Bottaro (2011) compared the effects of resistance training volume on the adaptations of different muscle groups in untrained young males, randomly assigned into two groups who performed either 3 sets of knee extension and 1 set of elbow flexion or 1 set of knee extensions and 3 sets of elbow flexion, training 2 days per week for 12 weeks. The researchers found that muscle thickness of the elbow flexors increased significantly for both groups while changes in muscle thickness of the quadriceps were not significant for either group. They found that although there were no significant differences between the groups, there was a non-significant trend for the higher volume group to display a greater increase than the lower volume group in respect of the elbow flexors (7.2% for the 3-set group and 5.9% for the 1-set group).

Sooneste (2013) investigated the differential effects on hypertrophy of training both arms of the same subject in a crossover-like design with different training volumes (1 or 3 sets) in 8 sedentary, untrained young Japanese men. The subjects trained their elbow flexor muscles 2 times per week for 12 weeks using a seated dumbbell preacher curl with 80% of 1RM. The researchers reported that the 3-set protocol increased cross-sectional area significantly more than the 1 set protocol.

Radaelli (2013) compared the effects of low- and high-volume strength training on muscle thickness of the lower- and upper-body in 20 healthy, older women. The subjects were randomly assigned into two groups: low-volume and high-volume, where the low-volume group performed 1-set of each exercise, while the high-volume group performed 3-sets of each exercise, 2 times per week for 13 weeks. The researchers found that all muscle thickness measurements of the lower- and upper-body increased similarly in both groups. However, there was a non-significant trend for the total quadriceps muscle thickness to increase by more in the high-volume group than in the low-volume group (14.3 ± 4.1% versus 8.6 ± 2.0%).

What is the summary of findings?

In summary, out of all 11 studies assessing the difference between low- and high-volumes of training on hypertrophy, 3 have found statistically significant benefits of using a higher volume, 7 have found non-significant benefits of using a higher volume (which may or may not be because of a type II error), and 1 study has found no benefit at all of using a higher volume, although that study used perhaps the most unreliable measurement method of hypertrophy (arm circumference). In trained subjects, the only 2 studies that have been performed so far have found non-significant benefits of using a higher volume (which again may or may not be because of a type II error).

What is the bottom line?

In conclusion, using multiple sets to achieve a higher volume of training appears to lead to greater hypertrophy than using either single sets or a smaller volume of training. However, the current literature is plagued by a lack of high quality studies with sufficient statistical power and this conclusion can only be drawn based on a meta-analysis of studies and based on a review of non-significant trends.

What are the practical implications?

Training with multiple sets to achieve a higher volume of training appears to lead to greater hypertrophy, irrespective of training status and age. Additionally, there appears to be a dose-response to volume of training to a degree, although it is not clear at what point increasing doses cease to be increasingly effective. Finally, the law of diminishing returns seems to apply to hypertrophy training: in that the first set may be the most important and each successive set offers a steadily reducing stimulus. Therefore, for those who are short of time, fewer sets may be appropriate.

Muscular failure

Introduction

Despite great debate in the fitness industry regarding whether individuals should train to failure or not, researchers have not investigated this problem thoroughly. In fact, despite what many people believe, volume-matched, long-term training studies are very thin on the ground in respect of whether training to failure (or greater levels of fatigue) is to be preferred for strength and hypertrophy. Here is a summary of what we know…

What is the background?

Training to momentary muscular failure is a common concept in the fitness industry and most intermediate and advanced trainees have a good instinct for when they are approaching it during a set. Moreover, while many strength athletes do regularly go to failure in their training, a significant proportion, including some powerlifters and bodybuilders, do not always go to failure in a given workout. However, in the research literature exploring strength and hypertrophy gains following a period of training, it is very common for all sets to be performed to failure. There is therefore a discrepancy between what the research literature tells us and what a given trainee might be doing.

Additionally, as noted above, extremely few studies have compared volume-matched training protocols in which one group performed sets to failure while another group performed the same volume-matched program not to failure. Therefore, in this brief review, such studies are included as well as a few more that have explored the difference between volume-matched protocols with differing levels of fatigue. While this is not ideal, it does provide a fuller picture and based on the findings of Sundstrup (2012), which is discussed in more detail below, it is likely to be valid. Indeed, while some researchers and proponents of training to muscular failure have suggested that training to failure is necessary in order to recruit all motor units, the research does not completely support this view. Sundstrup (2012) explored the EMG activity of lateral raises during individual reps of 15RM loads performed to failure. They found that a plateau muscle activity was reached at 10 – 12 reps of the 15RM load, which they interpreted to mean that training to complete failure is not necessary to fully recruit the entire motor unit pool, at least in untrained individuals.

What is the effect of muscular failure on hypertrophy?

The following training studies have explored the effect on strength of groups performing exercises to muscular failure (or just greater degrees of fatigue) in comparison with other volume-matched groups performing the same exercises not to muscular failure (or lesser degrees of fatigue), using various different approaches:

Goto (2005) investigated the effects of failure within the context of a volume-equated scheme of resistance-training on quadriceps hypertrophy of the quadriceps. Although each training group performed 3 sets of 10RM on the lat pull-down and shoulder press, and 5 sets of 10RM on the bilateral knee extension, one group performed the exercises straight through with 1 minute of rest between sets and exercises, while another group took another 30 seconds of rest half-way through each set. The researchers found that the group that took the inter-set rest displayed less hypertrophy in comparison with the group who took no rest, indicating that muscular failure may well be an important modifying factor for muscular hypertrophy. However, the exact mechanism by which such superior results occur remains unclear.

Schott (1995) – the researchers compared the adaptations following two types of isometric strength training: short, intermittent contractions (lesser fatigue group) vs. longer, continuous contractions (greater fatigue group) at 70% of MVIC in which 7 subjects trained 3 times per week for 14 weeks. The right leg was trained using 4 sets of 10 bouts of 3-second contractions with a 2-second rest period between each contraction and 2 minutes inter-set rest periods. The left leg was trained using 4 sets of 30-second contractions with a 1-minute inter-set rest period. The researchers found that the increase in muscular cross-sectional area was significantly greater for the longer, continuous contractions than for the short, intermittent contractions.

What is the summary of findings?

Despite the great interest in this area and numerous proposals that muscular failure is critical for muscular strength and size gains by both lay people and researchers, there is in fact a paucity of literature. Only 2 studies have directly explored the effects of training to muscular failure or not in volume-matched trials and these have found beneficial results for training to muscular failure in comparison with training not-to-failure.

What is the bottom line?

In conclusion, it is very hard to make a definitive statement about the effect of muscular failure on hypertrophy because of the very small number of studies, However, seems that hypertrophy might be greater when training to failure in comparison with training not-to-failure where other training variables are equated.

What are the practical implications?

For strength athletes and bodybuilders, as well as everyone looking to increase hypertrophy for physique enhancement, there is some limited evidence that incorporating training to failure might lead to better gains in hypertrophy.

Frequency

Introduction

Along with training to muscular failure, using heavy or light loads, and training volume, the effect of training frequency on hypertrophy is a contentious area. Frequency most often comes up in the context of discussions about how many times a body part is trained per week. However, a big problem with manipulating training frequency is that volume tends to get altered at the same time. Fortunately, a small number of studies have investigated training frequency while keeping volume constant. Here is a summary of what we know…

What is the background?

Like volume, muscular failure and relative load, training frequency has traditionally been considered important for hypertrophy. However, matters are often confused on the gym floor because training frequency is often manipulated for the purposes of indirectly altering volume. The same issue is present in the literature. In many research studies investigating frequency, volume is not equated between the groups, leading to a greater total volume of training being performed by the high-frequency group. Since volume may well be a key factor in muscular hypertrophy, this is an important confounding factor for the study of training frequency. Nevertheless, a small number of volume-matched studies have been performed to assess the independent effect of frequency on hypertrophy, in both trained and untrained populations.

How does frequency affect hypertrophy in trained subjects?

The following chronic training studies have explored the effects of different volume-matched frequencies of training in trained subjects:

McLester (2000) performed a 12-week investigation involving trained subjects divided into two groups, one of which performed resistance training 1 day per week for 3 sets of each exercise at 80% of 1RM with 2 minutes of inter-set rest. The other group trained 3 days per week for 1 set of each exercise at 80% of 1RM. The number of sets was set in order to keep total volume constant. Neither group significantly increased lean body mass as a result of the training. The researchers found non-significantly greater increases in lean body mass as a result of training three times a week compared to once a week per muscle group, matched for total volume (8% and 1%, respectively).

Häkkinen and Kallinen (1994) performed a 6-week cross-over investigation involving trained female subjects. The subjects performed a sequence of two 3-week periods of resistance-training for the quadriceps, training three times a week. In one period, the subjects trained once on each training day and in the other period they trained using an identical volume over two sessions. Training once each training day, the subjects didn't display an increase in quadriceps cross-sectional area, but training twice each training day, they displayed significant increases in quadriceps cross-sectional area.

Hartmann (2007) performed a 3-week investigation into the effects of twice- and once-daily training sessions with similar training volumes in 10 nationally competitive male weightlifters on muscle cross-sectional area and performance measures. They reported no increases in muscular cross-sectional area in either group and no significant differences between groups. In fact, the once-daily group increased cross-sectional area to a non-significantly greater extent than the twice-daily group (3.2% versus 2.1%). However, the duration of the study was very short and the training status of the subjects was very high, suggesting that only tiny increases in muscular cross-sectional area would occur and, given that the sample size was very small, it would be impossible to detect such changes statistically.

What is the summary of findings?

In summary, if we exclude the Olympic weight-lifting study on the basis that the study design made it hard for any difference to be detected because of the very short study duration, small sample of subjects, and high training status of the subjects, there appears to be a limited trend towards a higher volume-matched frequency leading to greater hypertrophy in trained subjects. However, this conclusion is very tentative and further research is clearly needed in this area.

How does frequency affect hypertrophy in untrained subjects?

The following chronic training studies have explored the effects of different volume-matched frequencies of training in untrained subjects:

Calder (1994) performed a 20-week investigation in 30 young women in 3 groups who performed either whole-body training, upper-lower split training or no training (a control). The whole-body group performed 4 upper (5 sets of 6 – 10RM) and 3 lower body (5 sets of 10 – 12RM) resistance exercises in single sessions twice a week. The upper-lower split group did the upper body exercises on 2 days a week and the lower body exercises on 2 other days of the week. The researchers reported that trunk lean tissue mass increased in the whole body and upper-lower split groups by 3.4 and 2.7%, respectively, leg lean mass by 4.9% and 1.7%, and whole body lean mass by 4.1 and 2.6%, respectively. The leg lean mass increase was significant only in the whole body group.

Benton (2011) investigated the effects of 8 weeks of 3 versus 4 days per week of volume-matched resistance-training on body composition in middle-aged women.

Frequency continued...

The 3-day group completed 3 sets of 8 exercises arranged as a whole-body routine and the 4-day group completed 3 sets of 6 upper body exercises or 6 sets of 3 lower body exercises, arranged as an upper-lower split routine. Both groups of subjects performed 72 sets per week of 8 – 12 repetitions at 50 – 80% of 1RM. Although both groups displayed significant increases in lean mass (1.1 ± 0.3 kg), there were no significant differences between groups. However, the 3-day per week group displayed a non-significantly greater increase in lean mass than the 4-day per week group (3.1% versus 1.5%, respectively).

Candow and Burke (2007) investigated the effects of 6 weeks of 2 versus 3 days per week of volume-matched resistance-training on lean tissue mass in untrained subjects, who performed either 3 sets of 10 repetitions to fatigue twice a week or 2 sets of 10 repetitions three times a week. Although both groups increased lean tissue mass significantly, there were no significant or even any non-significant differences between groups (2.9 and 3.0% increases in lean mass for the lower and higher frequency groups, respectively).

Arazi and Asadi (2011) divided healthy but untrained males into four groups: one group performing one session of total-body resistance training (12 exercises, once a week), another group performing total-body resistance training divided into two sessions (6 exercises, twice a week), an upper-lower split group performing three sessions per week (4 exercises, three times a week), and a control group. All groups performed the same volume and number of exercises, which comprised the leg press, leg curl, leg extension, calf raise, lat pull-down, lat pull-row, bench press, pec fly, arm curl, dumbbell arm curl, triceps push-down, and dumbbell triceps extension. The total-body twice a week group and the upper-lower split group displayed significant improvements in thigh circumference while the total-body once a week group and the upper-lower split group displayed significant increases in arm circumference. While there were no significant differences between groups, there was a non-significant trend for the higher frequency groups to increase arm and thigh circumference to a greater extent than the low frequency group.

What is the summary of findings?

In summary, in untrained subjects a higher volume-matched training frequency seems to have no effect or may even have a detrimental effect on hypertrophy. Whether this difference between untrained and trained subjects is indeed an effect of training status or simply a function of there being conflicting results between studies is unclear.

What is the bottom line?

There appears to be a very limited trend towards a higher volume-matched frequency leading to greater hypertrophy in trained subjects. However, this conclusion is very tentative and further research is clearly needed in this area. On the other hand, in untrained subjects a higher volume-matched training frequency seems to have no effect or may even have a detrimental effect on hypertrophy.

What are the practical implications?

For trained individuals, increasing frequency may lead to slightly greater hypertrophy, whether in conjunction with increasing volume or simply by redistributing the same volume over a greater number of sessions. On the other hand, for untrained individuals, increasing frequency may not be as effective for hypertrophy and sticking to a more traditional number of sessions (e.g. three times per week) may be the best course of action.

Rest periods

Introduction

Many training variables seem to have an important effect on the extent to which a resistance-training protocol can cause hypertrophy. Such variables include volume, relative load, range of motion, exercise selection, whether or not the exercise is taken to failure, repetition speed, and inter-set rest period duration. However, while some of these variables have been extensively researched in long-term studies (e.g. volume), other areas, including inter-set rest period duration, have not. To bring you up to speed with where the research is at when it comes to how inter-set rest periods affect strength and size gains, here's a brief review of the long-term studies that are currently available.

How does rest period affect gains in hypertrophy?

The effect of rest period duration on gains in muscular strength and size has been reviewed previously (see De Salles, 2009). However, at the time that review was written, there were no studies that had studied the long-term effects of rest period duration on muscular size gains! Consequently, conclusions drawn for muscular hypertrophy in that review were based on acute studies of hormones and metabolites. Since then, two studies have been performed, as follows:

Ahtiainen (2005) – The researchers explored the effects of rest period duration on the hormonal and neuromuscular adaptations following a 6-month period of resistance-training. The researchers recruited 13 recreationally resistance-trained male subjects. The study was divided into two separate 3-month training periods in a crossover design. In one 3-month period, the subjects performed a training protocol using a short rest (2 minutes) and in the other they used a long rest (5 minutes). Before and after the interventions, the researchers measured hormonal concentrations as well as maximal isometric leg extension torque, unilateral leg press 1RM, and muscle cross-sectional area of the quadriceps femoris using magnetic resonance imaging (MRI) scans. The training protocol involved leg presses and squats with 10RM sets and were matched for volume (i.e. load x sets x reps) but were different in respect of the relative load used and the rest period durations. The researchers observed significant increases in quadriceps muscle cross-sectional area (4%) over the 6-month strength-training period. However, both 3-month training periods resulted in similar gains in muscle mass but no statistically significant changes were observed in hormone concentrations.

Buresh (2009) – The researchers wanted to compare the effects of short (1 minute) and long (2.5 minutes) rest periods on strength and muscular cross-sectional area during a 10-week training period. They recruited 12 untrained male subjects who performed a training routine of 3 sets using a load that led to failure on the third set of each exercise, including the squat and bench press exercises. The researchers found that arm cross-sectional area increased more with long rest periods (12.3 ±7.2%) than with short rest periods (5.1 ± 2.9%) but they did not notice any significant differences in respect of leg muscle cross-sectional area.

What is the summary of findings?

These studies found conflicting results. Ahtiainen (2005) found no differences in muscular hypertrophy when short (2 minutes) vs. long (4 minutes) rest periods were used in a volume-matched program of resistance-training. On the other hand, Buresh (2009) found that hypertrophy was greater when using long (2.5 minutes) versus short (1 minute) rest periods when volume was dictated by muscular failure and therefore lower in the short-rest group. The differences between these studies may again arise because of the failure of the short-rest period in the latter study to achieve sufficient training volume. Slightly longer rest periods than 1 minute (e.g. 90 – 120 seconds) may therefore be preferable in order to maintain optimal workloads while maintaining some metabolic stress, which is thought to be beneficial for hypertrophy based on acute studies (Schoenfeld, 2013). However, the exact duration of rest period that leads to the optimal recovery of strength between sets is outside the scope of this review. Moreover, persisting working with short rest periods may lead to beneficial adaptations which permit higher volumes while using short rests, as the next sections will demonstrate. Therefore, it remains difficult to assess whether rest period has any significant effect on hypertrophy irrespective of volume based on the current long-term studies. It seems appropriate to recommend that individuals seeking hypertrophy do not prejudice training volume too much by reducing rest periods to the point where it is difficult to perform as much work as they would otherwise be able to with longer rest periods.

How does reducing rest periods affect hypertrophy?

A rather interesting couple of studies have been initiated since the review by De Salles et al. in 2009, which involve the use of reducing rest periods over the sequence of resistance-training sets.

De Souza (2010) – The researchers compared the effect on strength and hypertrophy of 8 weeks of resistance-training using either (1) constant rest intervals, or (2) decreasing rest intervals. They recruited 20 young, recreationally-trained subjects and allocated them to one or other of the training groups, who performed resistance-training including the bench press and squat exercises. In the first 2 weeks of training, the subjects performed 3 sets of 10 – 12RM with 2-minute rests.

Rest periods continued...

In the following 6 weeks of training, the subjects performed 4 sets of 8 – 10RM and while the constant-rest group rested 2-minutes between sets, the decreasing-rest group rested with progressively shorter rests (2 minutes decreasing to 30 seconds) over the 6 weeks of training. Before and after the intervention, the researchers measured 1RM bench press and squat, as well as isokinetic peak knee extension and flexion torque and muscular cross-sectional area.. The researchers found that total training volume of the bench press and squat were significantly lower for the decreasing-rest group compared to the constant-rest group (bench press 9.4% lower, and squat 13.9% lower). However, they found that there were no significant differences in the arm or thigh cross-sectional area increases (arm 13.8 vs. 14.5%, thigh 16.6 vs. 16.3%) between the two training groups.

Souza-Junior (2011) – The researchers compared the effect on strength and hypertrophy of 8 weeks of resistance-training and creatine supplementation using either (1) constant rest intervals, or (2) decreasing rest intervals. They recruited 22 young, recreationally-trained males and allocated them to one or other of the training groups, who performed resistance-training including the bench press and squat exercises. In the first 2 weeks of training, the subjects all performed exercises with 2-minute rests. In the following 6 weeks of training, while the constant-rest group rested 2-minutes between sets, the decreasing-rest group rested with progressively shorter rests (2 minutes decreasing to 30 seconds) over the 6 weeks of training. Before and after the intervention, the researchers measured 1RM bench press and squat, as well as isokinetic peak knee extension and flexion torque and arm and thigh muscular cross-sectional area. The researchers found that total training volume of the bench press and squat were significantly lower for the decreasing-rest group compared to the constant-rest group. The researchers found that both groups displayed significant increases in arm and thigh muscular cross-sectional area but there were no significant differences between groups for either variable.

What is the summary of findings?

These two studies comparing fixed with reducing rest periods found identical results, which were that the duration of rest periods had no effect on muscular hypertrophy. However, the period of time was quite short for measuring hypertrophy differences (6 weeks for the 2 different protocols). Similarly, Ahtiainen (2005) found no differences in muscular hypertrophy when short (2 minutes) vs. long (4 minutes) rest periods were used but this study differed in that a volume-matched program was used. On the other hand, Buresh (2009) found that hypertrophy was greater when using long (2.5 minutes) versus short (1 minute) rest periods when volume was dictated by muscular failure and therefore lower in the short-rest group. Exactly why Buresh (2009) found different results to these two studies is unclear but again may relate to the progressive adaptations achieved by steadily decreasing rest periods rather than maintaining short rest periods from the outset.

What is the bottom line?

Studies comparing short and long fixed rest periods have reported conflicting results in respect of hypertrophy. However, training volume was not always equated and the groups that used shorter rest periods often trained with lower volume, which makes them hard to compare. Studies comparing fixed with reducing rest periods have found that the duration of rest periods had no effect on muscular hypertrophy, even when volume was lower.

What are the practical implications?

While the research is extremely limited and very conflicting, it seems wise that when using constant rest periods, care should be taken not to reduce volume at the expense of using short rest periods, as this may lead to sub-optimal volume, which appears to be a relevant training variable for hypertrophy.

Range of motion

Introduction

Most lifters instinctively know that larger range of motion (ROM) translates to greater gains in strength and hypertrophy, most of the time. However, surprisingly, it is not until recently that research has demonstrated this to be the case. Here is a brief review of how ROM during resistance-training exercises affects gains in strength and size.

How does ROM affect gains in hypertrophy?

The following studies have compared increases in hypertrophy between two or more different groups as a result of a chronic (i.e. long-term) training intervention. As you will note, there are far fewer studies in this area, as a result of the greater difficulty in measuring muscular cross-sectional area than strength.

Raastad (2008, conference proceedings) – The researchers reported that they compared the effects of parallel and quarter back squats over a 12-week period and found that the full back squats produced higher increases in quadriceps muscle cross-sectional area than quarter back squats.

Pinto (2012) – The researchers compared partial ROM vs. full ROM upper-body resistance training on strength. They recruited 40 young males with no resistance-training experience and allocated them randomly to one of three groups: full ROM, partial ROM, and a control. The subjects in the training groups performed a preacher curl exercise, 2 days per week for 10 weeks in a periodized program. The full ROM group performed the exercise with full ROM (0 to 130 degrees, where 0 degrees is full elbow extension) ROM and the partial ROM group performed the exercise with partial ROM (50 to 100 degrees) ROM. Before and after the intervention, the researchers measured the muscle thickness of the elbow flexors using ultrasound. The researchers found that both the full ROM and partial ROM groups significantly increased muscle thickness by 9.52% and 7.37%, respectively. However, the difference in hypertrophy between the two groups was not significant.

Bloomquist (2013) – The researchers compared the effects of short ROM and long ROM squat training on thigh muscle cross-sectional area. They recruited 24 young male subjects with little experience of resistance-training and allocated them to either a short ROM squat group or a long ROM squat group. Both groups performed a periodized program that included both sets to failure and sets not to failure for 3 – 4 sets of 3 – 10 reps. The short ROM squat group performed the squat from 0 – 60 degrees of knee flexion (0 degrees being full knee extension) while the long ROM squat group performed the squat from 0 – 120 degrees of knee flexion. The researchers found that the long ROM squat group increased front thigh muscle cross-sectional area at all measured sites while the short ROM squat group increased front thigh muscle cross-sectional area only at the two most proximal sites. However, the increases in the long ROM group were significantly greater at all front thigh sites than in the short ROM group. Additionally, the researchers found that the long ROM squat group increased back thigh muscle cross-sectional area at the second most proximal site whereas the short ROM squat group did not.

McMahon (2013) – The researchers compared the effects of training and detraining using long and short ROMs. They recruited 26 recreationally active subjects and allocated them to either a long ROM group, a short ROM group, or a control group. Both training groups performed 8 weeks of resistance-training and 4 weeks detraining, involving isoinertial resistance training with either a short muscle length (0 – 50 degrees knee flexion) or with a long muscle length (0 – 90 degrees knee flexion), 3 times per week at 80% of 1RM using the squat, leg press and leg extension. Before and after, the researchers measured anatomical cross-sectional area of the vastus lateralis at 25%, 50%, 75% of femur length. The researchers found that vastus lateralis anatomical cross-sectional area increased significantly following training at all sites in both training groups. They also noted a trend for the long ROM group to display greater relative gains in vastus lateralis anatomical cross-sectional area compared to the short ROM group at all sites. However, the difference between groups was only significant at the end of the 8-week training intervention at 75% of femur length, with the long ROM group displaying a 59 ± 15% increase compared to the short ROM group showing only a 16 ± 10% increase.

What is the summary of findings?

In summary, Pinto (2012) found that there was no significant difference in muscle thickness as a result of full ROM and partial ROM training of the elbow flexors, although they did observe a trend towards increased hypertrophy in the full ROM group. On the other hand, Bloomquist (2013), McMahon (2013) and Raastad (2008, conference proceedings) each reported that a long ROM group displayed greater hypertrophy of the thigh muscles than a short ROM group following squat training.

What is the bottom line?

The research in this area is very limited but there is some evidence that a greater ROM leads to greater hypertrophy than a smaller ROM.

What are the practical implications?

It seems likely that full ROM exercises lead to the greatest gains in hypertrophy and should therefore be preferred in the first instance, unless the exercise is being altered to focus on a different muscle group (e.g. partial bench press for the triceps).

Repetition speed

Introduction

Repetition speed is less frequently discussed than the more contentious topics of training to muscular failure, using heavy or light loads, high versus low training volume, and high versus low training frequency. However, the use of explosive repetitions and the use of slow, controlled tempos both have their stalwart supporters. Some strength and conditioning coaches recommend using fast bar speeds. Others suggest that by slowing down the repetition and extending its duration, "time-under-tension" can be increased, which has been proposed to lead to greater hypertrophy. A small number of studies have investigated the effect of repetition speed on hypertrophy.

What is the background?

Various researchers as well as strength and conditioning coaches have proposed that repetition speed may be important for hypertrophy. In essence, there are two ways in which a weight can be lifted: (1) with maximal velocity, and (2) with a controlled, sub-maximal tempo. Of course, within the second category, a variety of different lifting tempos could be used, ranging from very slow (even SuperSlow) to very fast.

A number of studies have compared the resulting hypertrophy between groups that used fast and slow repetition speeds. Some researchers and strength and conditioning coaches who subscribe to the view that longer repetition speeds are superior for hypertrophy have suggested that a better term would be "repetition duration" in order to emphasize the importance of the "time-under-tension" aspect. However, it is important to recognize that, emphasis aside, the two variables are inherently very strongly and inversely correlated. For most conventional resistance-training exercises, the distance over which the weight travels is essentially fixed by anthropometry and therefore when repetition duration is reduced, repetition speed must be increased proportionally and vice versa.

What is the effect of repetition speed on hypertrophy?

At least six studies have been performed comparing the effect of repetition velocity or repetition duration on the rate of hypertrophy in untrained subjects. To my knowledge, no studies have been performed in trained populations.

Tanimoto and Ishii (2006) compared slow and fast repetitions in a 12-week knee extension exercise intervention comprising 3 sets, 3 times a week. The slow repetition group lifted with a 3-second eccentric and concentric action and a 1-second pause but no relaxation using a 50% of 1RM load, while the fast repetition group lifted with a 1-second eccentric and concentric action and a 1-second relaxation but no pause, using an 80% of 1RM load. Both of these groups improved muscular cross-sectional area significantly and while there was no significant difference between groups, the slow repetition group displayed a small non-significantly greater increase (5.4 ± 3.7% versus 4.3 ± 2.1%).

Tanimoto (2008) performed a similar study but with five exercises (squat, chest press, latissimus dorsi pull-down, abdominal bend, and back extension). Both of these groups improved total body muscular cross-sectional area significantly and while there was no significant difference between groups, the fast repetition group displayed a non-significantly greater increase (9.1 ± 4.2% versus 6.8 ± 3.4%).

Neils (2005) compared conventional (2-second concentric and 4-second eccentric contractions) and SuperSlow (10-second concentric and 5-second eccentric contractions) resistance-training over an 8-week intervention, training 3 days per week. The SuperSlow group used 50% of 1RM and the conventional group used 80% of 1RM. While there were no significant changes in lean body mass in either group, in the SuperSlow group, lean body mass increased by 0.3kg while in the conventional group it reduced by 0.2kg.

Keeler (2001) performed a similar study that nevertheless reported contrasting results. They compared the effects of traditional Nautilus-type (2-second concentric and 4-second eccentric contractions) or SuperSlow (10-second concentric and 5-second eccentric contractions) resistance-training on body composition in sedentary women, training 3 times per week for 10 weeks. There were no significant differences in respect of lean body mass gains between the groups, although the traditional group displayed a non-significantly greater increase than the SuperSlow group (+0.5kg versus -0.4kg).

Young and Bilby (1993) compared the effect of repetition speed in a 7.5-week trial in which subjects performed 4 sets of 8 – 12RM with the half squat exercise, 3 times per week with either fast or slow repetitions. The fast-repetition group performed a controlled eccentric phase followed by an explosive concentric phase while the slow-repetition group performed both concentric and eccentric phases in a slow and controlled manner. Muscle thickness was measured with ultrasound and while both groups displayed a significant increase in several parts of the leg musculature, there were no significant differences between the groups. For the sum of all measurements, muscle thickness increased by non-significantly more in the fast-repetition group than in the slow-repetition group (3.9% versus 3.2%).

Repetition speed continued...

Nogueira (2009) compared the effects of 10 weeks of either traditional slow and heavy resistance-training or fast and light power training on the rate of hypertrophy in elderly males, training twice a week, during 10 weeks. The two groups performed the same volume of work comprising 3 sets of 8 repetitions of the same exercises with relative loads of 40 – 60% of 1RM. It was found that muscle thickness as measured by ultrasound increased significantly in both groups in the biceps brachii but only increased significantly in the power training group in the rectus femoris. The increase in muscle thickness of the biceps brachii was greater in the power training group than in the resistance-training group.

What is the summary of findings?

In summary, only one out of the six studies found a significant effect of repetition speed on hypertrophy. That study reported that a fast repetition speed was superior for hypertrophy than a slow repetition speed in elderly males. Whether this is applicable to younger populations is unclear. Of the remaining five studies, three reported a non-significant effect that a fast repetition speed was superior for hypertrophy than a slow repetition speed in various populations of untrained subjects while two studies reported the opposite effect. It is therefore likely that repetition speed is not a strong modifying factor of hypertrophy in untrained individuals. If it has any effect at all, it is likely that a fast repetition speed is marginally superior to a slow repetition speed. Whether different effects would be observed in trained subjects is unknown from the literature at the present time.

What is the bottom line?

The research in this area suggests that repetition speed has little, if any, effect on hypertrophy. However, repetition speed may be important for other outcomes, such as speed and power.

What are the practical implications?

Personal trainers may recommend slower, more controlled repetitions for achieving hypertrophy with their clients if they wish, as repetition speed seems to have little effect in untrained subjects for body composition goals. Individuals may make use of either fast or slow repetition speeds for the purposes of hypertrophy, depending on their personal preferences and other goals. However, for strength and power gains, a faster speed may be necessary.

Muscle action

Introduction

Many strength and conditioning coaches have previously recommended using eccentric muscle actions for enhancing hypertrophy. But how much support is there for this claim? Fortunately, a small number of studies have directly compared the effects of eccentric-only with concentric-only training on hypertrophy. Here is a summary of what we know…

What is the background?

Although some strength and conditioning coaches have recommended using eccentric-only muscle actions for maximizing hypertrophic gains, and even though eccentric-only training is common in rehabilitation circles, few lifters actually make use of eccentric-only training for bodybuilding. However, there are a number of theoretical bases upon which eccentric-only training might lead to superior results to concentric-only or stretch-shortening cycle training, as follows:

- Eccentric muscle actions are thought to lead to greater exercise-induced muscle damage than concentric muscle actions. Exercise-induced muscle damage may be one mechanism by which hypertrophy is stimulated (see Schoenfeld, 2010). However, whether this factor is as important as has previously been reported is a matter of debate at present (see further Schoenfeld, 2012).
- Eccentric-only training involves a lower energy cost for the same amount of mechanical tension (e.g. Peñailillo, 2013). In this way, lifters are able to perform a greater volume of work while taxing their work capacity to the same degree.
- Eccentric-only training enables lifters to move a larger amount of weight than during concentric-only or stretch-shortening cycle muscle actions with the same percentage of 1RM (e.g. Flanagan, 2013, and Moir, 2013), which may lead to greater mechanical tension for the same relative load.
- Eccentric muscle actions appear to preferentially target the fast-twitch muscle fibers (e.g. Hortobagyi, 2000, and Hortobagyi, 1996), which have greater capacity for growth.

Since these large differences between eccentric and concentric muscle actions exist, researchers have often been unable to control other key variables, such as volume and relative load. Often in studies, the same absolute load is used, which means that the relative load is lower in the eccentric condition (as muscles are stronger eccentrically than concentrically). Alternatively, where the same relative load is used, the researchers often use the same set/rep scheme, which means that the volume of work performed is higher in the eccentric condition (as muscles are stronger eccentrically than concentrically). These mismatches between the variables make it difficult to compare the effects of eccentric-only and concentric-only resistance-training programs. Therefore, it is important when comparing studies to note whether the relative loads and volumes were matched.

What is the effect of muscle action on hypertrophy?

At least 15 studies have been performed comparing the effect of eccentric and concentric muscle actions on the rate of hypertrophy in mainly untrained subjects, as shown below, although one or two studies in the list were performed in trained populations.

Vikne (2006) investigated the effects of 12 weeks of either concentric or eccentric training of the elbow flexors using a bespoke elbow flexion training machine in 17 resistance-trained males. The subjects trained 2 – 3 times per week with varying loads. The exercise sessions alternated between maximum or medium loads. The maximum load was based on a repetition maximum (4 – 8RM) while the medium training load was set to 85 – 90% of the maximum load. Over a 2-week period of training, each subject completed 3 workouts with the maximum load and 2 workouts with the medium load. Inter-set rest periods were 3 – 6 minutes. In the eccentric condition, the subjects lowered the weight over 3 – 4 seconds while the concentric condition, the subjects used maximum effort. The number of sets was increased from 3 – 5 over the intervention. Therefore, the relative loads used were similar across the two conditions but it is likely that the volumes were not matched. Before and after the intervention, the researchers measured muscular cross-sectional area using a CT scan. The researchers reported that the mean anatomical elbow-flexor cross-sectional area did not change in the concentric group (+3%) but increased significantly in the eccentric group (11%).

Higbie (1996) investigated the effects of 10 weeks of unilateral concentric or eccentric isokinetic training at 60 degrees/s on quadriceps cross-sectional area in 54 untrained female subjects, as measured by magnetic resonance imaging (MRI) scans. The subjects trained 3 days per week for 10 weeks with 3 sets of 10 reps and 3-minute inter-set rest periods. The isokinetic efforts were performed maximally and therefore it is likely that the relative load was similar but that the volume was different, although these variables were not directly measured by the researchers. Using the MRI scans, the researchers measured 7 slices of the quadriceps from 20 – 80% of femur length and they reported that the mean increases in quadriceps cross-sectional area for the eccentric and concentric groups ranged from 6.0 – 7.8% and 3.5 – 8.6%, respectively.

Muscle action continued...

For the sum of the all 7 slices, mean increases in quadriceps cross-sectional area increased by 6.6 and 5.0% in the eccentric and concentric groups, respectively. The increase was significantly greater in the eccentric condition than in concentric condition.

Komi and Buskirk (1972) investigated the effects of eccentric or concentric training in 31 untrained male subjects. The subjects performed 6 maximal isokinetic elbow flexion contractions with either eccentric or concentric muscle actions, 4 times per week for 7 weeks. Before and after the intervention, the researchers measured the girth of the upper right and left arms. They reported that the eccentric-only group increased right upper arm girth by a greater amount than the concentric-only group (0.57 ± 0.68cm versus 0.09 ± 0.04cm). The increase in the eccentric-only group was significant while the increase in the concentric-only group was not significant.

Seger (1998) investigated the effects of 10 weeks of either eccentric or concentric isokinetic training at 90 degrees/s on knee extensor muscular adaptations in 10 moderately-trained male physical education students. Since isokinetic efforts were used, it is likely that the relative load was similar but that the volume was different. The researchers found that the cross-sectional area of the quadriceps increased by around 3 – 4% in both groups but only reached statistical significance in the eccentric training group.

Farthing (2003) investigated the effects of isokinetic concentric and eccentric training of the elbow flexors at two different velocities (180 and 30 degrees/s) in 36 subjects (13 male and 23 female) with little experience of resistance-training. The subjects trained their elbow flexors using an isokinetic dynamometer 3 times per week for 8 weeks at a set velocity (either 180 or 30 degrees/s) for 2 – 6 sets of 8 reps with maximal effort with 1 minute of intra-set rest. The researchers measured muscular cross-sectional area before and after the intervention using ultrasound. The researchers reported that the eccentric fast training condition resulted in greater muscle thickness change (13 ± 2.5%) than the concentric slow (5.3 ± 1.5%) and concentric fast (2.6 ± 0.7%) conditions, and non-significantly greater muscle thickness change than the eccentric slow training condition (7.8 ± 1.3%).

Hortobagyi (1996) investigated whether maximal eccentric-only training would lead to greater gains in muscle size than concentric-only training. They therefore recruited 15 untrained subjects who performed 36 sessions of isokinetic concentric-only or eccentric-only unilateral knee extension resistance-training for a 12-week period. The researchers reported that type I fiber areas did not change significantly in either group but type II fiber area increased approximately 10 times more in the eccentric-only training group compared to the concentric-only training group.

Hortobagyi (2000) investigated the effects of 3 weeks of knee immobilization followed by 12 weeks of retraining with eccentric-only, concentric-only or stretch-shortening cycle muscle actions in 48 untrained males and females. The subjects performed 12 weeks of maximum effort isokinetic concentric-only or eccentric-only or stretch-shortening cycle quadriceps knee extension training of the left leg at 60 degrees/s. The subjects performed 4 – 6 sets of 8 – 12 repetitions with a 1-minute inter-set rest period. The researchers reported that immobilization reduced type I, IIa and IIx muscle fibre areas by 13, 10 and 10%, respectively. They reported that hypertrophy of type I, IIa and IIx fibers was 10, 16 and 16% after eccentric-only training but only 4, 5 and 5% after concentric-only training. They reported that increases in type IIa and IIx fibers were greater than the increases in type I fibers after eccentric training.

Ben-Sira (1995) investigated the effects of eccentric-only, concentric-only, conventional and supra-maximal eccentric-only resistance training on thigh girth in 60 untrained young female students. The subjects performed knee extension exercise 2 times per week for 8 weeks. The subjects in the conventional group performed 3 sets of 10 bilateral reps with 65% of 1RM. The supra-maximal eccentric-only group performed the eccentric phase only of 3 sets of unilateral 5 reps with 130% of 1RM. Therefore, these two groups were work-matched although it is unclear whether they were matched in terms of relative load. The concentric-only and eccentric-only groups performed only the concentric or eccentric phases of 3 sets of 10 bilateral reps with 65% of 1RM. These groups were work matched with each other but were not matched in terms of relative load. The researchers found no meaningful changes in thigh girth and changes ranged from -0.7 - +0.5% over the four training groups.

Reeves (2009) investigated the effects of bilateral eccentric-only and conventional leg press and knee extension resistance-training in 19 untrained older adults. The subjects were divided into two groups who both trained 3 times per week for 14 weeks at 80% of the muscle-action specific 5RM, performing 2 sets of 10 repetitions. Thus, the relative load was matched between the two groups. However, the training volume was not matched between the two groups, although the researchers did not discern any significant differences between groups in this respect. Before and after the intervention, the researchers measured vastus lateralis muscle thickness using ultrasonography. The researchers reported that muscle thickness increased to a similar extent in both groups (by 12 ± 13% in the concentric group and by 11 ± 10% in the eccentric group).

Muscle action continued...

Nickols-Richardson (2007) investigated the effects of 5 months of either unilateral concentric or eccentric isokinetic resistance-training in young female subjects. The training intervention was performed 3 days per week and comprised 1 – 5 sets of 6 reps of isokinetic knee and elbow extension and flexion at 60 degrees/s with 1 minute of intra-set rest. Before and after the intervention, the researchers measured body composition using dual-energy X-ray absorptiometry scans. They found that the concentric group gained 0.6kg (1.5%) of lean mass, while the eccentric group gained 0.7kg (1.7%). While these increases were significant, there were no differences in the increase in lean mass between the two groups.

Blazevich (2007) investigated the effect of 10 weeks of either concentric-only or eccentric-only slow speed (30 degrees/s) isokinetic knee extensor training on muscular adaptations in 21 men and women. The subjects performed 4 – 6 sets of 6 maximal knee extension reps with a 1-minute inter-set rest period 3 times a week on an isokinetic dynamometer at 30 degree/s, using either concentric-only or eccentric-only muscle actions. The isokinetic efforts were performed maximally and therefore it is likely that the relative load was similar but that the volume was different, although these variables were not directly measured by the researchers. Before and after the intervention, the researchers measured muscle volume, anatomical cross-sectional area and physiological cross-sectional area using magnetic resonance imaging (MRI) scans as well as muscle thickness using ultrasound. The researchers found that both groups increased muscular size but they reported no differences between groups. Since the researchers did not report any values for the groups separately, it is unclear whether there was a non-significant trend for one of the groups to increase muscular size by more than the other group.

Smith (1995) investigated the effects of 20 weeks of either concentric-only or eccentric-only unilateral knee extension resistance-training in 10 young males and females on strength and hypertrophy. All subjects trained using both types of loading protocol, one for each leg. The training program involved a heavier load for the eccentric group but it was not clear whether this represented the same relative load as for the concentric group. Before and after the intervention, the researchers measured muscle cross-sectional area near the knee and hip using computed tomography (CT) scans. The researchers found significant increases in muscle cross-sectional area occurred near the hip for both the eccentric-only and concentric-only conditions but there were no significant differences between the two conditions (4.0% versus 4.6%).

Jones (1987) compared the increases in the size of the quadriceps muscle following 12 weeks of either eccentric-only or concentric-only unilateral knee extension resistance-training in 6 young males and females. The training was performed 3 times per week and comprised 4 sets with a 6RM load, representing around 80% of 1RM for each muscle action. A 1-minute inter-set rest period was provided. The researchers noted that the load used for the eccentric condition was around 145% of the load used in the concentric condition. Before and after the intervention, the researchers measured the quadriceps cross-sectional area with mid-thigh X-ray computerized tomography (CT) scans. The researchers reported that the changes quadriceps cross-sectional area were not significantly different between the eccentric-only and concentric-only training groups (3.5% versus 5.7%).

Franchi (2014) investigated the effects of 10 weeks of either concentric or eccentric resistance-training in 12 young males on vastus lateralis volume, as measured by magnetic resonance imaging (MRI) scans. The subjects performed 4 sets leg presses for 8 – 10 repetitions with 80% of either concentric or eccentric 1RM. Thus the relative load was matched between the two studies. However, the load and volume used in the eccentric-only group was 1.2-fold greater than in the concentric-only group. The researchers reported that the increases in muscular volume were similar in both groups, although there was a trend towards a greater increase in the concentric group compared to the eccentric group (8% versus 6%).

Mayhew (1995) investigated the effects of concentric and eccentric training on hypertrophy in 20 untrained male and female subjects. The subjects performed either concentric or eccentric isokinetic contractions at 30 degrees/s of the quadriceps muscles for 5 sets of 10 repetitions at 90% of maximal concentric power, 3 times per week for 4 weeks. Therefore, in this study, training volume was equated but the relative load used in each condition differed – the proportion of eccentric-1RM in the eccentric condition was lower than the proportion of concentric-1RM in the concentric condition. Before and after the intervention, the researchers measured the fiber area of the type I and type II fibers. The researchers found that with the same load, performing concentric contractions led to significantly greater type II muscle hypertrophy than training with eccentric contractions (25.7% versus 18.0%) and also displayed a trend towards greater type I hypertrophy (14.3% versus 12.3%).

What is the summary of findings?

Most of the studies used the same relative load but different volumes of training. In most of these cases, the eccentric-training groups used greater volumes because their relative loads were greater. However, there were also many differences between the studies, with some using isokinetic training methods and others using conventional loading protocols.

Muscle action continued...

There was no clear-cut difference between eccentric-only training and concentric-only training at either the significant or non-significant levels. However, there was a strong trend for eccentric-only training to display greater hypertrophy. Out of the 15 studies, 7 found a significantly beneficial effect of eccentric-only training while 1 found a significantly beneficial effect of concentric-only training. Of the 7 studies that reported non-significant effects, the results of 4 studies displayed either no differences, or were unreported. The remaining 3 studies that reported non-significant effects displayed a beneficial trend in favour of concentric-only training. Nevertheless, a previous review and meta-analysis concluded that eccentric-only training does in fact lead to greater hypertrophy than concentric-only training (Roig, 2009). As may well be the case with training volume, it could therefore be the case that the presence of type II errors prevents the individual studies from observing the underlying effects. However, in contrast to training volume, the studies comparing eccentric and concentric muscle actions have found conflicting results at the non-significant level.

What is the bottom line?

It seems possible that eccentric muscle actions may lead to greater hypertrophy than concentric muscle actions but the literature is far from being conclusive.

What are the practical implications?

For strength athletes, bodybuilders and physique athletes Eccentric-only training may lead to slightly greater hypertrophy than concentric-only training. Individuals seeking hypertrophy should make use of eccentric muscle actions in their programming to maximize increases in muscular size.