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CURRENT OPINION

Frequency: The Overlooked Resistance Training Variable for Inducing Muscle Hypertrophy?

Scott J. Dankel[1] · Kevin T. Mattocks[1] · Matthew B. Jessee[1] · Samuel L. Buckner[1] · J. Grant Mouser[1] · Brittany R. Counts[1] · Gilberto C. Laurentino[1] · Jeremy P. Loenneke[1]

Abstract The principle of progressive overload must be adhered to for individuals to continually increase muscle size with resistance training. While the majority of trained individuals adhere to this principle by increasing the number of sets performed per exercise session, this does not appear to be an effective method for increasing muscle size once a given threshold is surpassed. Opposite the numerous studies examining differences in training loads and sets of exercise performed, a few studies have assessed the importance of training frequency with respect to muscle growth, none of which have tested very high frequencies of training (e.g., 7 days a week). The lack of studies examining such frequencies may be related to the American College of Sports Medicine recommendation that trained individuals use split routines allowing at least 48 h of rest between exercises that stress the same muscle groups. Given the attenuated muscle protein synthetic response to resistance exercise present in trained individuals, it can be hypothesized that increasing the training frequency would allow for more frequent elevations in muscle protein synthesis and more time spent in a positive net protein balance. We hypothesize that increasing the training frequency, as opposed to the training load or sets performed, may be a more appropriate strategy for trained individuals to progress a resistance exercise program aimed at increasing muscle size.

Key Points

Individuals are likely completing a volume of resistance exercise above that which is beneficial for muscle hypertrophy.

The muscle protein synthetic response to resistance exercise would seemingly favor higher frequencies of exercise.

Reducing the training volume and increasing the frequency may be beneficial for muscle hypertrophy.

1 Introduction

The American College of Sports Medicine recommends that individuals looking to increase muscle size perform two to four sets of exercise targeting each muscle group two to three times per week [1]. It is also recommended that individuals perform between 8 and 12 repetitions per set using a load corresponding to ≥70 % of the individual's one-repetition maximum (1RM) [1]. As individuals become trained and start to adapt to resistance exercise, an increased stress must be placed on the musculature to allow the possibility for further muscle growth. This principle of progressive overload can be adhered to by undertaking one or more of the following three modifications: (1) increasing the absolute training load performed for a set number of repetitions, (2) increasing the number of sets, and/or (3) increasing the frequency of exercise. It is well known that increases in muscle size are attenuated with training [2–5], with ~70 % of muscle growth proposed to occur within the first several weeks [6]. While part of the attenuated

✉ Jeremy P. Loenneke
jploenne@olemiss.edu

[1] Department of Health, Exercise Science, and Recreation Management, Kevser Ermin Applied Physiology Laboratory, The University of Mississippi, P.O. Box 1848, University, MS 38677, USA

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muscle growth can be attributed to individuals approaching their genetic potential (i.e., the finite amount of muscle they can accrue), it may also be partially due to an increased difficulty of providing a more effective stimulus. Herein we discuss the current literature examining different methods of progressive overload and explain why, in our opinion, increasing the training frequency may be the most effective way for trained individuals to progress a resistance training program aimed at increasing muscle size.

2 Increasing the Absolute Load

One strategy by which an individual can progress a muscle hypertrophy-focused training program is to increase the absolute training load that is lifted for a set number of repetitions (or maintain a constant absolute training load and perform more repetitions per set). However, increasing the absolute training load will become more difficult as strength gains are attenuated with continued training [7]. Once an individual can no longer increase the absolute training load while maintaining a similar repetition range, they must adhere to the principle of progressive overload to further increase muscle size. This can be done by either increasing the number of sets performed for each muscle group or increasing the frequency at which each muscle group is trained.

3 Increasing the Sets

Individuals can progress a resistance training program by increasing the number of sets performed for a given muscle group. While this is commonly referred to as exercise volume, the reporting of exercise volume has notable limitations in that it is entirely dependent on the absolute and relative load used. Briefly, muscle growth appears to be highly dependent on fatiguing the muscle, whereby the muscle is brought to a point at or near contractile failure to increase motor unit recruitment/activation [8]. Low-load protocols require substantially more repetitions to elicit contractile failure, thus requiring more volume to produce similar elevations in muscle protein synthesis [9, 10] and muscle hypertrophy [11]. Given that the level of effort to reach volitional failure, as opposed to fatigue per se, appears to be primarily driving muscle hypertrophy [8], we refer to 'sets of exercise' rather than 'exercise volume' to account for negligible differences in the reporting of exercise volume (i.e., lower loads require greater absolute volume to reach contractile failure [11]).

The American College of Sports Medicine recommends that more advanced lifters use split routines training one to three muscle groups per workout to allow for more sets per muscle group to be completed within a given training session [1]. In support of this recommendation, the majority of bodybuilders perform around four sets per exercise, while performing four different exercises targeting each muscle group, thus totaling 16 sets of exercise targeting a specific muscle group within a single training session [12]. While increasing the number of sets performed in a given session would adhere to the principle of progressive overload, there appears to be a point where no additive benefit (with respect to muscle hypertrophy) is seen from performing additional sets of exercise within a given training session. The point at which the anabolic response is maximized would also appear to be much lower than what is typically performed by trained individuals [12]. For example, one acute (short-term) study found no difference in muscle protein synthesis after performing three or six sets of resistance exercise [13], and this is supported by a training study illustrating similar increases in muscle size upon completing either four sets or eight sets per training session [14]. Although both of these studies were performed in untrained individuals [13, 14], similar increases in muscle size have been observed comparing one, two, or four sets of exercise per training session over 10 weeks in trained individuals [15].

Although a meta-analysis supports the efficacy of greater exercise volume [16], considerable heterogeneity was present in the studies included for analysis [17], and the only significant difference was observed when comparing one set with three sets. Even if a small difference exists between one and three sets of exercise, there is likely a threshold whereby increasing the sets of exercise performed per muscle group within a given training session does not necessarily provide greater muscle growth [18]. Specifically, this point of diminishing returns would likely be much lower than what is typically performed by trained individuals looking to increase muscle size (16 sets) [12]. This may be analogous to protein consumption where 10 g of protein may be better than 5 g for muscle growth, but consuming 80 g is not necessarily better for muscle growth than consuming 40 g [19]. For this reason, increasing the number of sets performed in a given training session may simply prolong fatigue without providing a greater increase in muscle size.

4 The Case for Frequency

Few studies have examined the efficacy of high-frequency training, which may be in part related to the American College of Sports Medicine's recommendation that individuals rest at least 48 h between training similar muscle groups [1]. This recommendation may also explain why 68 % of bodybuilders report only training a specific muscle

group once per week [12], and none of the 127 that were sampled reported training a specific muscle group more than twice per week [12]. It is also likely that the longer recovery periods are necessary to allow sufficient recovery from the previous bout of exercise, given that the average bodybuilder performs 16 sets of exercise targeting a specific muscle group within a given training session [12].

In response to resistance exercise, individuals undergo an elevated muscle protein synthetic response that lasts at least 24 [20], 36 [21], or 48 [22] h post-exercise. The magnitude and duration of the elevated protein synthetic response appears to be blunted in trained individuals [23]. Therefore, given that a relatively low number of sets (i.e., four sets to volitional failure) may be sufficient to elicit a large increase in protein synthesis for up to 24 h post-exercise [20], performing fewer sets may be more effective at reducing prolonged fatigue and allowing the same muscle group to be trained more frequently. The more repetitive stimuli would hypothetically result in a greater time spent in a net-positive protein balance, and it can therefore be hypothesized that trained individuals may see greater benefits in muscle growth by keeping the same number of sets performed per week but simply dispersing them over a greater number of training sessions (Fig. 1). This would allow for the avoidance of 'wasted sets' in terms of muscle hypertrophy, while also allowing for a hypothetical refractory period to pass before additional exercise is performed. While hypothetical, this refractory period may work in a similar manner to that of nutrition-induced muscle protein synthesis [24], whereby a certain time period must elapse before the muscle protein synthetic response from resistance exercise can be re-stimulated. However, this refractory period may be relatively short and may even be overcome within a 24-h window [25].

Increasing the training frequency may be somewhat less effective for untrained individuals given the longer duration for which muscle protein synthesis is elevated post-exercise (Fig. 2). Nonetheless, for trained individuals, it would likely be beneficial to progressively increase the training frequency from one to two times a week to two to three times a week in which the same muscle groups are stressed. As individuals become accustomed to training the same muscle group at higher frequencies, it may be beneficial to perform full-body routines daily, or every other day, depending on how individuals recover from exercise.

5 Previous Studies Assessing Training Frequency

A review paper demonstrated that the increase in muscle size per training session (~0.15 %) does not differ depending on whether high or low frequencies are employed [26]. Therefore, individuals who train more frequently would likely observe larger increases in muscle mass over the same time period given that more training sessions can be performed. However, this review [26] was not designed to examine the importance of training frequency as all other training variables were not held constant. Another recent meta-analysis concluded that volume-equated resistance training dispersed over two sessions per week was more effective than performing a larger volume in one session [27]; however, the analysis included insufficient studies to enable evaluation of training frequencies greater than twice per week. To our knowledge, only three studies have set out to directly assess the importance of training frequency while using a direct measure of muscle size. One study assessed trained individuals targeting the same muscle groups once versus three times per week [28] and noted a general trend toward greater muscle growth among those training three times a week. However, the results from this study were somewhat inconclusive as the only significant difference was noted in a muscle group that was not directly trained (i.e., biceps brachii). Another study assessing female athletes illustrated greater increases in muscle size when the total resistance training volume was split into two sessions per day as opposed to one [25]. It was likely that the group training twice a day avoided performing 'wasted sets' as described in Fig. 1 and was able to re-stimulate muscle protein synthesis after it quickly returned to baseline, as is the case in trained individuals. A similar study comparing the same training volume over one or two sessions per week found no differences in muscle size [29]; however, this study assessed untrained males, and may differ for reasons mentioned in Fig. 2. Despite two of these studies supporting our hypothesis, the vast majority of studies assessing training frequency have focused specifically on strength adaptations, whereas those providing a measure of muscle size have been limited to indirect measures of total lean mass (e.g., skinfold measurements, whole body dual-energy X-ray absorptiometry) [30–34].

6 Decreasing the Training Frequency

Although increasing the training frequency may provide greater muscle growth, it may be difficult to increase the training frequency beyond a certain point. We propose that once an individual has been training at a higher frequency for a sufficient duration (e.g., 16 weeks), it may then be beneficial to decrease the training frequency for a period of time (e.g., 24 weeks). A previous study [35] demonstrated that the muscle mass gained following 16 weeks of training (nine sets per session three times per week) was maintained after drastically reducing the exercise stimulus for an additional 32 weeks (three sets per session once per week).

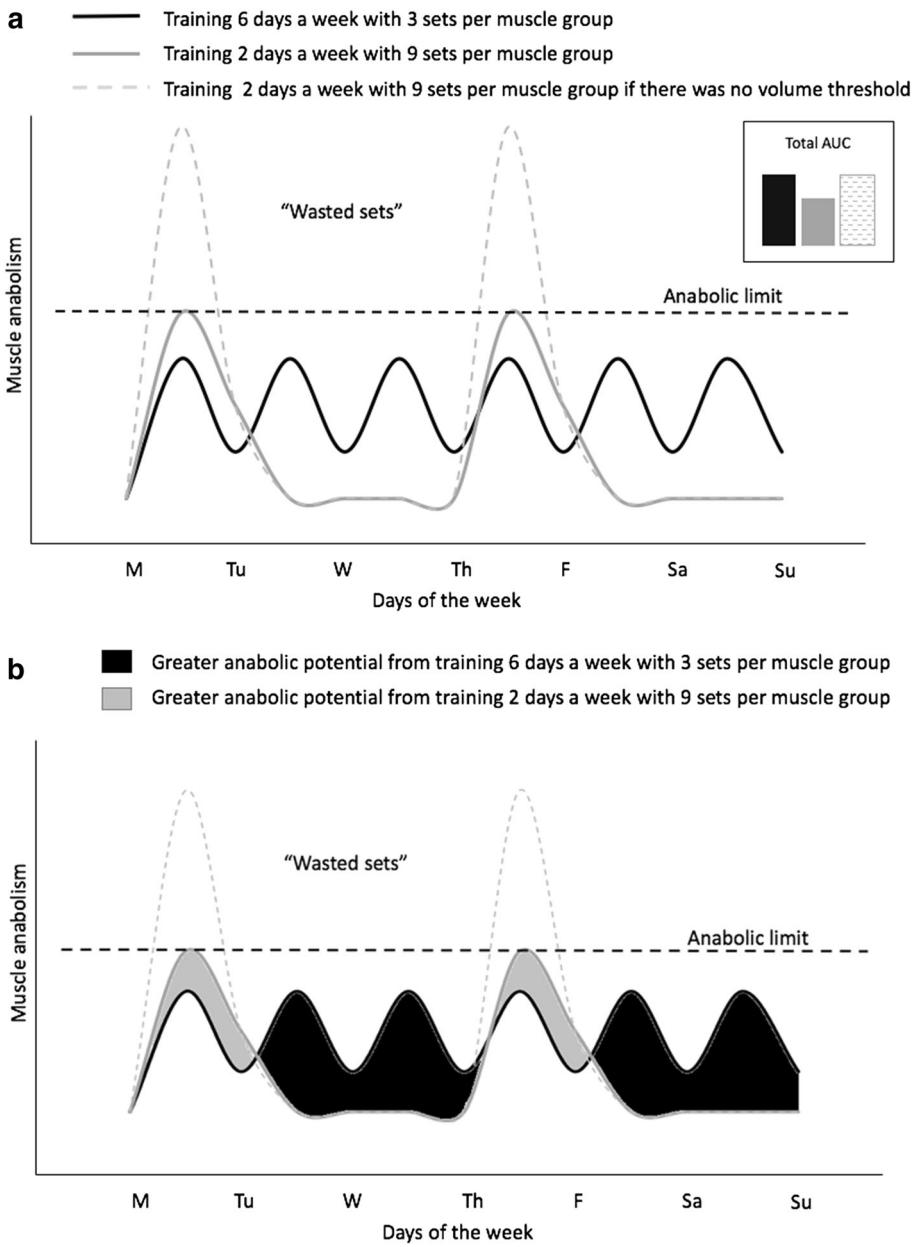

Fig. 1 **a** Hypothetical protein synthetic response to two different exercise protocols with the same number of sets performed per week. Performing fewer sets per session at a higher frequency will likely be sufficient for increasing muscle size while also limiting fatigue to allow for higher frequencies and thus more frequent stimulations of muscle protein synthesis. Performing more sets per session while using a lower training frequency may reduce the time spent in a positive net protein balance because the large number of sets performed within a given session may exceed the 'anabolic limit', resulting in wasted sets. Additionally, performing more sets within a given session requires greater recovery time, causing muscle protein synthesis to return to basal levels until re-stimulated again during another training session. **b** Demonstration of the greater anabolic potential during each protocol. *No shading* in the area *under the curve* illustrates a similar anabolic potential between both frequencies. The difference in the area *under the curve* between protocols can be attributed to the 'wasted sets' completed above the volume threshold during the twice-weekly protocol. *AUC* area under the curve

Therefore, once an individual increases the training frequency and hypothetically increases muscle mass over a period of time, he/she may then be able to reduce the training frequency while still maintaining the added muscle mass. While also hypothetical, this may allow for the down-regulation of metabolic brakes [36] and the re-sensitization of the muscle to the anabolic stimulus [37], whereby an individual may then benefit from increasing the training frequency again for reasons previously mentioned. Some support for this hypothesis may exist in that the rebounding of muscle hypertrophy following detraining is such that no differences were observed when comparing 24 weeks of continuous training with another group performing cycles of 6 weeks of training followed by 3 weeks of detraining [38]. Even if this hypothesis is correct, there would inevitably come a point where an individual can no longer increase muscle mass as he/she has reached his/her genetic ceiling.

7 Limitations of this Hypothesis

While increasing the training frequency would hypothetically allow for more frequent elevations in muscle protein synthesis, the body would likely adapt, forcing a further increase in training frequency to produce greater muscle growth. Even so, many trained individuals are not training the same muscle groups at high frequencies [12]; thus, this

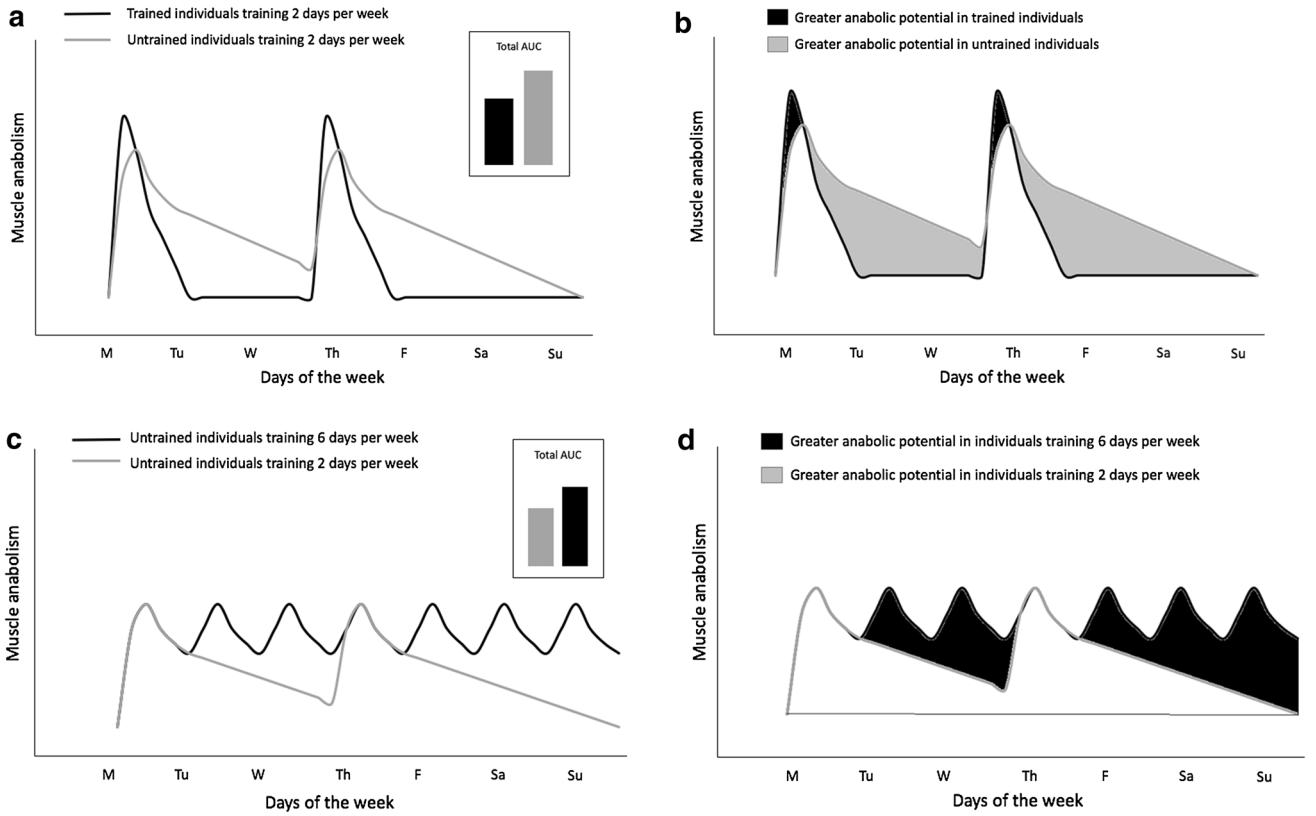

Fig. 2 Hypothetical depiction of muscle anabolism illustrating why increasing the training frequency may be more beneficial in trained individuals. **a** Trained and untrained individuals performing the same frequency of exercise. (**b**) Depiction of where the area under the curve favors trained or untrained individuals. *No shading* illustrates a similar anabolic potential between trained and untrained individuals. Notably, untrained individuals demonstrate longer durations in which the muscle is primed for anabolism. **c** Untrained individuals training the same muscle groups with different frequencies. **d** Depiction of where the area under the curve favors higher frequency. *No shading under the curve* illustrates similar anabolic potential between low and high frequencies. Increasing the training frequency is of less importance in untrained individuals because the muscle is still primed for greater anabolism as a result of the previous bout. *AUC* area under the curve

would likely be the most beneficial way to further progress a training program aimed at increasing muscle size. Additionally, this hypothesis is based largely on the muscle protein synthetic response to resistance exercise, which does not always correlate well with long-term changes in muscle size [39], nor does it take into account changes in muscle protein breakdown. Even so, acute changes in muscle protein synthesis would appear to be the primary driver of muscle growth from resistance training in humans [40, 41], and the lack of a correlation between muscle protein synthesis and muscle size may simply be due to the 'snapshot'-specific nature of how muscle protein synthesis is measured (i.e., muscle biopsies). Nonetheless, an increase in muscle size would need to occur through the accretion of new proteins, and would likely correlate well with muscle growth if measured over time [42], making the acute marker of muscle protein synthesis at least somewhat indicative of the efficacy of a resistance exercise protocol.

8 Future Research Questions

The hypothesis that increasing training frequency, rather than training load or sets performed, may be a more effective strategy for trained individuals to increase muscle size opens an avenue for future research to test whether increased training frequency does indeed result in greater muscle hypertrophy. Future studies may seek to compare two groups of trained individuals performing at markedly different training frequencies (e.g., 1 vs. 6 days per week) while equating the total number of sets performed to volitional failure. While this type of study design would oppose the recommendation of resting at least 48 h between exercises of the same muscle group [1], we have unpublished data suggesting that even three sets of exercise per day, for 21 straight days, elicited no signs of over-training in previously trained individuals. By using a direct measure of muscle size (e.g., ultrasound, magnetic

resonance imaging), the two groups can then be compared and any differences in muscle size could be attributed to differences in training frequencies. To test whether a muscle could then be re-sensitized to the anabolic stimulus, the high-frequency group could then be split into two groups, one of which continues training at a high frequency while the other reduces the frequency for a short period in an attempt to sensitize the muscle to the reintroduction of high-frequency training.

Future studies may also be designed to compare different exercise volumes to more closely detail the specific point at which the anabolic potential of a given training session has been reached. While a previous meta-analysis was only able to assess one set versus three sets [16], previous research in trained individuals found no difference between performing one, two, or four sets [15] of exercise within a single training session. Thus, the specific point at which performing more volume is not more advantageous for muscle growth has not been determined and may be exercise specific. For example, compound movements may require additional sets to fully activate the muscles of interest (e.g., bench press vs. triceps extensions).

9 Conclusion

While the majority of studies within the resistance training literature focus on increasing the sets of exercise to produce greater adaptations in muscle size, it is our opinion that it is likely more beneficial to increase the training frequency. Contrary to the American College of Sports Medicine recommendations that trained individuals use split routines to perform more sets of exercise within a given training session [1], we feel that trained individuals should train similar muscle groups more frequently while reducing the number of sets performed in a given training session. This hypothesis is made based on previous research demonstrating that (1) increasing the number of sets beyond a certain point has negligible effects on muscle hypertrophy given the relatively low volume that appears to maximally stimulate muscle protein synthesis; and (2) the duration of the time period when muscle protein synthesis is elevated in trained individuals appears to be shortened.

Compliance with Ethical Standards

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Conflict of interest Scott Dankel, Kevin Mattocks, Matthew Jessee, Samuel Buckner, J. Grant Mouser, Brittany Counts, Gilberto Laurentino, and Jeremy Loenneke have no conflicts of interest relevant to the content of this review.

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