Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Physiology

Training for strength and hypertrophy: an evidence-based approach

Robert W Morton[1], Lauren Colenso-Semple[2] and Stuart M Phillips[1]

Resistance exercise training (RET)-induced increases in voluntary 1RM strength are greater if the RET is performed with higher loads and replication (or close) of the strength test. In contrast, RET-induced muscular hypertrophy is primarily mediated by intensity of effort, which is achieved by performing RET to volitional fatigue and with an internal focus on contracting a muscle throughout the exercise range of motion. In addition, RET-induced muscular hypertrophy is augmented by increasing training volume, but with diminishing returns. Other training variables such as volume-load, inter-set rest, and time under tension have negligible effects on RET-induced changes in muscle size or strength. We conclude that an uncomplicated, evidence-based approach to optimizing RET-induced changes in muscle size and strength follows the FITT principle: frequency, intensity (effort), type, and time.

Addresses
[1] Department of Kinesiology, McMaster University, Hamilton, Canada
[2] Performance and Physique Enhancement Laboratory, University of South Florida, Tampa, USA

Corresponding author: Phillips, Stuart M (phillis@mcmaster.ca)

Current Opinion in Physiology 2019, **10**:90–95

This review comes from a themed issue on **Exercise physiology**

Edited by **Harry B Rossiter** and **Brian Glancy**

For a complete overview see the Issue and the Editorial

Available online 17th April 2019

https://doi.org/10.1016/j.cophys.2019.04.006

Introduction

Skeletal muscle strength is important to human health, as is evidenced by the inclusion of a recommendation to practice strengthening activities in all national physical activity guidelines. In addition, muscle strength and size are often core components of athletic performance. Therefore, the aim of this review is to provide evidenced-based recommendations on resistance exercise training (RET) variables that impact RET-induced changes in muscle strength and size (hypertrophy).

Evidence-based training for muscular strength

Strength is measured in a variety of ways but most commonly as a voluntary isotonic (unchanging force throughout a range of motion) maximal lift: the so-called one repetition maximum (1RM). Other forms might include 3–10 repetitions to fatigue: 3–10RM. Tests may also include isometric (unchanging range of motion), isokinetic (unchanging speed of contraction throughout a range of motion), or power-based tests that include an element of velocity.

Load

RET-induced increases in 1RM are optimized when performing RET with nearer-to-maximal loads (e.g. >85 %1RM) [1,2,3••,4,5]. However, when muscular strength is evaluated using an unpracticed test (i.e. an outcome that is not performed in the RET protocol: isometric dynamometry), RET of any form is effective at increasing strength and heavier loads are not superior [2,3••,5,6,7••,8]. Moreover, periodic practice/training of a 1RM test nullifies, or at least diminishes, the difference in RET-induced 1RM strength between heavier-load and lighter-load RET indicating that a large part of the strength differences is practice-related, which may be facilitated by various neuromuscular adaptations [9]. Evidently, RET-induced changes in muscular strength are primarily determined by load (heavier being better) and training specificity (close replication of the test) [4,7••].

Volume

Weekly training volume (repetitions × sets) can be altered directly by manipulating the number of sets per session [10–13], the number of repetitions per set (e.g. by training to volitional fatigue or not) [14•,15,16], or the number of training sessions per week [17–19]; however, weekly training volume is also indirectly altered by manipulating load [5,6,9,20–22] or time under tension [23]. Regardless, increased volume (or volume-load [load × repetitions × sets]) does not, beyond a certain point, necessarily augment RET-induced changes in muscular strength [5,7••,9–13,14•,15–19,21,22,24,25]. In fact, it seems that performing excessive weekly training volume results in a plateau or inferior changes in RET-induced strength (>15 sets per muscle group per week) [12,13], which is likely due to insufficient recovery. A definitive study by Mattocks *et al.* [7••] compared individuals that performed five 1RM tests (i.e. five repetitions) per session to a traditional RET regime (four sets of 8–12 repetitions per session) and found that, after eight weeks of RET and a 10-fold difference in volume and volume-load, 1RM strength increased similarly between conditions. Evidently, specificity of the RET regime supersedes any effect of increased volume or volume-load on

RET-induced changes in 1RM [5,7••,9–13,14•,15–19,21,22,24,25].

Training frequency

Increasing the number of weekly training sessions (i.e. increasing training frequency/decreasing the rest between sessions) is a viable way to increase volume and volume-load as an alternative to increasing the number of sets or repetitions per session [17–19]. However, both when volume is unmatched [17–19] and matched [25,26•,27–30], higher training frequencies do not independently improve RET-induced changes in muscular strength.

Rest

A recent systematic review concluded that increasing inter-set rest durations does not result in superior changes in RET-induced muscular strength; however, the authors concluded by hypothesizing increasing inter-set rest to two to five minutes may be advantageous in resistance-trained individuals [31]. Indeed, it is apparent that this thesis is dependent on the strength assessment and training status of participants (e.g. 1RM testing resistance-trained young men [32] versus isometric dynamometry testing in comparatively untrained older women [33]); so, even if longer rest intervals are advantageous in trained populations, the benefits are evidently marginal [31] and contingent on training status and specificity [32,33].

Other variables

There are a number of RET variables that could be manipulated in effort to augment RET-induced muscular strength, but most appear to be inconsequential. For example, performing RET at different times of the day [34], with different times under tension [23], with or without autonomy over training schedules [35], with or without blood flow occlusion [36], or on or avoiding consecutive days [37] has little-to-no effect on RET-induced changes in muscular strength. However, it may be that multi-joint exercises (e.g. squats) are more effective than single-joint exercises (e.g. knee extensions) [38] and that periodized programs are more efficacious than non-periodized programs [39], but those results are seemingly influenced by training specificity.

Practical and evidence-based recommendations to augment RET-induced strength

RET-induced changes in muscular strength are primarily mediated by load [1,2,3••,4,5] and training specificity [4,7••]. Accordingly, as recommended by both the American College of Sports Medicine (ACSM) [40] and National Strength and Conditioning Association (NSCA) [41], recent evidence suggests that RET-induced changes in 1RM strength are greater when participants perform regular strength assessments with near-maximal loads (>85 %1RM) [1,2,3••,4,5]. In addition, recent evidence suggests that increasing inter-set rest (>2 min) [31,32] and moderating weekly training volume (<15 sets/muscle group/week) [12,13] may improve RET-induced muscular strength in resistance-trained individuals. Otherwise, though not the focus of this review, increased protein intake up to at least 1.6 g/kg of body mass/day may provide a small but statistically significant benefit on RET-induced muscular strength as detailed elsewhere [42]. In conclusion, RET-induced muscular strength is primarily mediated by load and specificity, though dietary protein intake, volume, and inter-set rest warrant consideration with increased training experience (Figure 1).

Evidence-based training for muscular hypertrophy

Muscular hypertrophy describes the expansion of proteins within a given muscle fiber and subsequent enlargement of the fiber cross-sectional area and the muscle as a whole. As a process, hypertrophy is multifactorial including changes in muscle protein turnover, satellite cells, genetics, and multiple molecular regulatory processes. Indeed, the molecular mechanisms that may underpin RET-induced skeletal muscle hypertrophy are beyond the scope of this review; thus, we direct the reader elsewhere if interested [43].

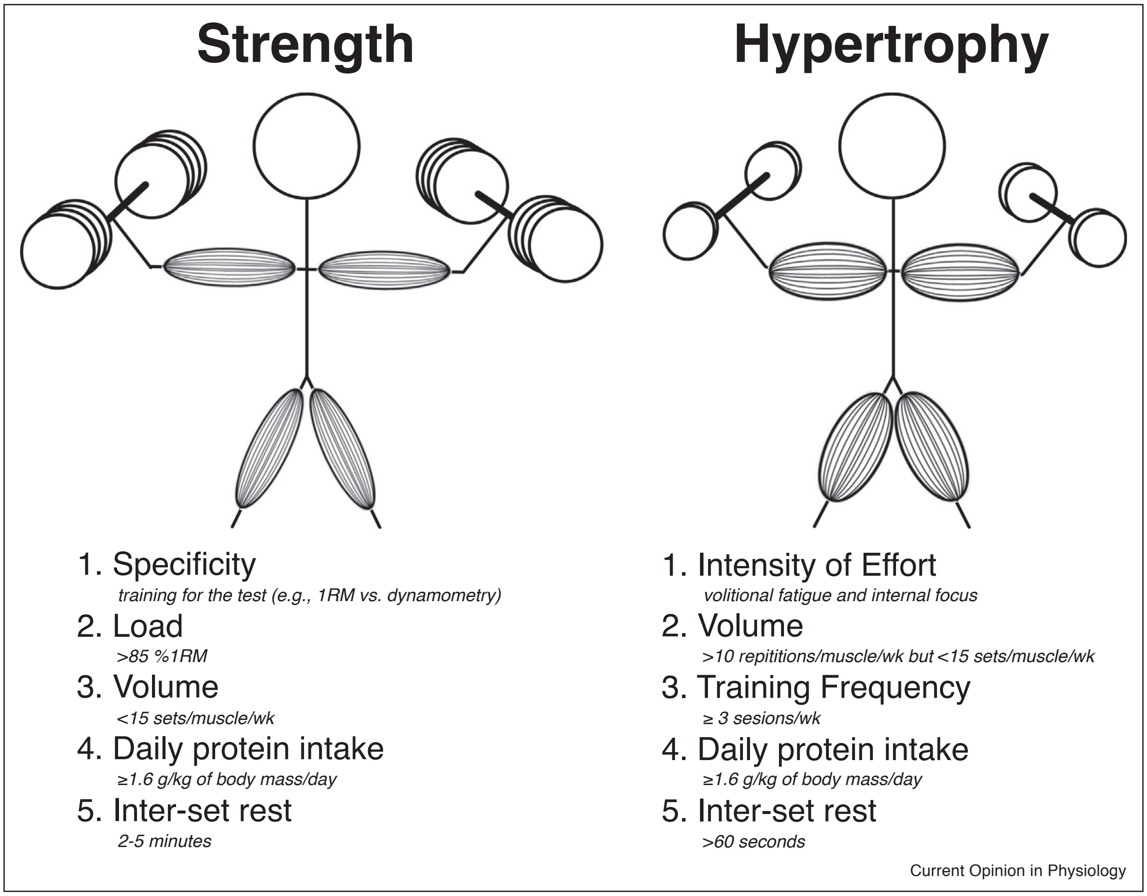
Load

A recent meta-analysis (21 studies) [2] and numerous publications since [1,5,8,16,20–22,44] showed that heavier loads are not necessary for RET-induced muscular hypertrophy. Indeed, muscular hypertrophy is similar between lower-load (~30–50 %1RM) and higher-load (>70 %1RM) RET when loads are lifted to the point of volitional fatigue [1,2,3••,5,8,16,20–22,44]; thus, load does not mediate RET-induced muscular hypertrophy.

Volume

Some have proposed that there is a dose–response relationship between volume (repetitions × sets) and RET-induced muscular hypertrophy [45]. In contrast, recent data have revealed that increasing volume or volume-load by manipulating the number of sets per session [11,12], number of repetitions per set [14•,15,16], number of sessions per week [17,19], or load lifted per repetition [3••,5,9,20–22] does not result in superior RET-induced muscular hypertrophy. However, supplementing a group of participants that were not performing RET to volitional fatigue with additional volume can match the RET-induced muscle hypertrophy of a group of participants that were performing RET to volitional fatigue [14•]. Thus, though second to performing RET to volitional fatigue, volume may have a small effect on RET-induced muscular hypertrophy in untrained populations. Otherwise, studies in resistance-trained individuals have found superior increases in muscle size with increased

Figure 1



Resistance exercise training variables alongside evidence-based recommendations to increase RET-induced increases in muscle strength and size.

training volumes [10,18] but only up to ∼15 sets per muscle group per week [12,13]. Moreover, even in untrained populations, optimal RET-induced muscular hypertrophy is contingent on performing a sufficient number of contractions (>10 repetitions per muscle per week) [7••]. In conclusion, volume appears to be an ostensible mediator of RET-induced muscular hypertrophy in resistance-trained individuals [10,18], and it is clear that individuals should perform well over 10 repetitions/muscle/week [7••] but less than 15 sets/muscle/week [12,13] to amass a weekly training volume that is necessary for RET-induced muscular hypertrophy.

Training frequency

Evidently, there is no measurable benefit of increased training frequency on RET-induced muscular hypertrophy when volume is equated [25,26•,27–30,46]. However, when higher-training frequency conditions are not volume-matched to lower-training frequency conditions there appears to be a modest benefit of performing RET three times per week versus one time per week on RET-induced muscular hypertrophy [26•]. Indeed, the majority of RET-induced muscular hypertrophy appears to occur with a single session of RET per week, but increased training frequency (i.e. decreased rest between sessions) as a means to increase training volume may augment RET-induced muscular hypertrophy with diminishing returns [26•].

Rest

A recent systematic review (six studies) posited that RET-induced muscle hypertrophy may be improved by increasing inter-set rest upwards of 60 s [47]. However, similar to the effect of increased rest on changes in 1RM strength, the benefit of increased inter-set rest on RET-induced muscular hypertrophy appears to be contingent on increased training status [32,47].

Other variables

The time of day [34], velocity of contraction [23], single-joint versus multi-joint resistance exercise [38], days of recovery between training sessions [37], occlusion of blood flow [5,36], and autonomy over RET variables [35] appear to confer little-to-no benefit on RET-induced muscular hypertrophy. However, a recent meta-analysis (15 studies) found a small benefit of performing eccentric-only versus concentric-only RET on changes in muscle size, which warrants consideration to include eccentric muscle actions throughout each repetition [48].

Intensity of effort

Recently, with load, volume, number of repetitions, and training to volitional fatigue matched between conditions, Schoenfeld *et al.* [49••] demonstrated that focusing on maximally contracting a muscle group throughout the exercise's range of motion (i.e. increased internal focus) results in superior RET-induced increases in muscle thickness compared with simply moving the load through the exercise's range of motion (i.e. external focus). Indeed, the thesis that internal focus mediates RET-induced muscular hypertrophy is anecdotally supported in bodybuilding practice, and provides a reasonable hypothesis for explaining the results from the no-load RET study by Counts *et al.* [3••]. Intensity of effort can be modulated by increasing load [1], volume-load [7••], training frequency [26•], inter-set rest [47], time under tension [23], blood flow occlusion [5,36], mode of contraction [48], or otherwise; but, it is implicit when RET is performed to volitional fatigue and with increased internal focus. Therefore, as previously hypothesized [50], maximizing RET-induced muscular hypertrophy is chiefly determined by intensity of effort and not by categorical manipulation of specific RET variables [1,2,5,8,16,20–22,44]).

Practical and evidence-based recommendations to augment RET-induced hypertrophy

In contrast with RET guidelines from the ACSM [40] and NSCA [41], RET-induced muscular hypertrophy is not confined to performing RET with heavy loads since lighter loads lifted to volitional fatigue result in similar hypertrophy [1,2,3••,9,20–22,44]. Instead, we propose that the most potent regulator of RET-induced muscular hypertrophy is intensity of effort, which is sufficient when performing RET with increased internal focus [3••,49••] or to volitional fatigue [1,2,5,8,16,20–22,44]. Additionally, though more efficacious in resistance-trained individuals, it appears that RET-induced muscular hypertrophy can be slightly improved with additional volume [10,18], rest [47], training frequency (via increased volume) [26•], and daily protein intake [42]. Thus, to enhance RET-induced muscular hypertrophy, RET should be performed with high intensity of effort (i.e. the practice, likely not exclusively, of lifting to or near volitional fatigue with increased internal focus) along with adequate volume (i.e. >10 repetitions per muscle group per week [7••,10,18] but <15 sets per muscle group per week [12,13]), training frequency (at least three training sessions per week [26•]), inter-set rest (>60 s [47]), and daily protein intake (≥1.6 g/kg of body mass/day) [42] (Figure 1).

Sex-based differences

By comparison to men, there is far less work done in women on their respective responses to RET. Absolute RET-induced changes in muscle strength and mass are greater in men versus women, but the relative changes in each are remarkably similar when men and women are compared [51]. Interestingly, this axiom holds true despite an almost 10-fold difference in circulating testosterone between men and women [52]. Moreover, the research we present above includes and is, despite a much smaller volume of work, consistent with research performed in women. That is, in women there is little-to-no influence of load [8,22], volume [11,12], velocity of contraction [23], or inter-set rest duration [33] on RET-induced changes in muscle strength and/or mass, and the efficacy of protein supplementation to support these gains while small is apparently no different in women [42]. In addition, we do not find evidence to support that performing RET to volitional fatigue is the only driver of RET-induced muscular hypertrophy in women [14•]. Therefore, though untrained men have higher strength and muscle mass before RET [53], which may be related to biomechanical differences between sexes, women have a similar propensity for RET-induced changes in muscle mass and strength [51] and are not differentially affected by specific RET-related variables [8,11,12,14•,22,23,33,42].

Conclusion

RET-induced increases in skeletal muscle mass and strength are largely independent of sex and specific RET variables. Unless an individual is trying to selectively improve 1RM strength (e.g. powerlifting or sport-related performance) or muscular hypertrophy (e.g. bodybuilding or other esthetically oriented sport), it is prudent to recommend that any RET regime performed regularly and with a high degree of effort is a sufficient stimulus for increasing muscle mass and strength. Nonetheless, RET-induced changes in muscular strength are chiefly determined by load and the specificity of training (i.e. practicing the strength test used as the outcome: 1RM test). Accordingly, to optimize RET-induced increases in 1RM, the evidence-based recommendations are to perform the specific test (e.g. a 1RM) with or near maximal loads (>85 %1RM). In contrast, the principal mediator of RET-induced muscular hypertrophy is intensity of effort, which is implicit when RET is performed to volitional fatigue or with increased internal focus (i.e. maximally contracting a muscle group throughout the range of motion). In addition, there appears to be a window of volume that is necessary (>10 repetitions and <15 sets per muscle group per week) for RET-induced muscular hypertrophy, and increased training frequency, inter-set rest, and eccentric contractions are relevant considerations for continued improvements in resistance-trained individuals. Indeed, once regular performance of RET is accomplished, the efficacy of any particular RET variable to augment RET-induced muscular hypertrophy is diminished in comparison to intensity of effort during any given RET session. Therefore, the evidence-based recommendations to a greater level of RET-induced muscular hypertrophy are first to prioritize performing the RET with heightened intensity of effort (volitional fatigue and internal focus), and secondarily to include a sufficient number of repetitions (>10 per muscle group per week), volume (<15 sets per muscle group per week), training frequency (three sessions per week), inter-set rest (>60 s), and daily protein intake (≥1.6 g per kg of body weight per day).

Funding

RWM was supported by a Natural Sciences and Engineering Research Council of Canada (NSERC) Fellowship during the completion of this work. SMP is supported by funding from the Canada Research Chairs program and holds grants from NSERC and the Canadian Institutes of Health Research (CIHR) and wishes to acknowledge those sources of support. Otherwise, this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest statement

Nothing declared.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Lasevicius T, Ugrinowitsch C, Schoenfeld BJ *et al.*: **Effects of different intensities of resistance training with equated volume load on muscle strength and hypertrophy**. *Eur J Sport Sci* 2018, **18**:772-780.

2. Schoenfeld BJ, Grgic J, Ogborn D, Krieger JW: **Strength and hypertrophy adaptations between low- vs. high-load resistance training: a systematic review and meta-analysis**. *J Strength Cond Res* 2017, **31**:3508-3523.

3. •• Counts BR, Buckner SL, Dankel SJ *et al.*: **The acute and chronic effects of "NO LOAD" resistance training**. *Physiol Behav* 2016, **164**:345-352.
This study demonstrated equal hypertrophy between biceps curls with no load versus 70 %1RM, which is convincing illustration of the lack of effect that load and volume-load have on RET-induced muscular hypertrophy.

4. Gentil P, Del Vecchio FB, Paoli A *et al.*: **Isokinetic dynamometry and 1RM tests produce conflicting results for assessing alterations in muscle strength**. *J Hum Kinet* 2017, **56**:19-27.

5. Jessee MB, Buckner SL, Mouser JG *et al.*: **Muscle adaptations to high-load training and very low-load training with and without blood flow restriction**. *Front Physiol* 2018, **9**:1448.

6. Fisher JP, Steele J: **Heavier and lighter load resistance training to momentary failure produce similar increases in strength with differing degrees of discomfort**. *Muscle Nerve* 2017, **56**:797-803.

7. •• Mattocks KT, Buckner SL, Jessee MB *et al.*: **Practicing the test produces strength equivalent to higher volume training**. *Med Sci Sports Exerc* 2017, **49**:1945-1954.
This study compared performing traditional RET (8–12 repetitions, four sets, twice per week) to just performing five attempts at a 1RM twice per week (i.e. a total of 10 repetitions per week) and found similar changes in 1RM strength but dissimilar changes in muscle thickness. Accordingly, this study is an impressive demonstration that RET-induced changes in 1RM strength are a function of specificity/practice and a strong representation that increased volume is necessary if near-maximal loads are to be used during RET.

8. Cholewa J, Rossi FE *et al.*: **The effects of moderate- versus high-load training on body composition, muscle growth, and performance in college aged females**. *J Strength Cond Res* 2018:32.

9. Morton RW, Oikawa SY, Wavell CG *et al.*: **Neither load nor systemic hormones determine resistance training-mediated hypertrophy or strength gains in resistance-trained young men**. *J Appl Physiol (1985)* 2016, **121**:129-138.

10. Schoenfeld BJ, Contreras B, Krieger J *et al.*: **Resistance training volume enhances muscle hypertrophy but not strength in trained men**. *Med Sci Sports Exerc* 2019, **51**:94-103.

11. Cunha PM, Nunes JP, Tomeleri CM *et al.*: **Resistance training performed with single and multiple sets induces similar improvements in muscular strength, muscle mass, muscle quality, and IGF-1 in older women: a randomized controlled trial**. *J Strength Cond Res* 2018 http://dx.doi.org/10.1519/JSC.0000000000002847. Epub ahead of print.

12. Barbalho M, Coswig VS, Steele J *et al.*: **Evidence for an upper threshold for resistance training volume in trained women**. *Med Sci Sports Exerc* 2018, **1**.

13. Amirthalingam T, Mavros Y, Wilson GC *et al.*: **Effects of a modified German volume training program on muscular hypertrophy and strength**. *J Strength Cond Res* 2017, **31**:3109-3119.

14. • Martorelli S, Cadore EL, Izquierdo M *et al.*: **Strength training with repetitions to failure does not provide additional strength and muscle hypertrophy gains in young women**. *Eur J Transl Myol* 2017, **27**:6339.
This study demonstrated that training to volitional fatigue results in superior increases in RET-induced muscular hypertrophy, but also performing 'supplementary' sets to volume-match a non-volitional fatigue condition to the volitional fatigue condition results in similar RET-induced muscular hypertrophy. Thus, this study is a strong case for the efficacy of increasing volume during moderate-load RET.

15. Sampson JA, Groeller H: **Is repetition failure critical for the development of muscle hypertrophy and strength?** *Scand J Med Sci Sports* 2016, **26**:375-383.

16. Nobrega SR, Ugrinowitsch C, Pintanel L *et al.*: **Effect of resistance training to muscle failure vs. volitional interruption at high- and low-intensities on muscle mass and strength**. *J Strength Cond Res* 2018, **32**:162-169.

17. Damas F, Barcelos C, Nobrega SR *et al.*: **Individual muscle hypertrophy and strength responses to high vs. low resistance training frequencies**. *J Strength Cond Res* 2018, **33**:897-901.

18. Heaselgrave SR, Blacker J, Smeuninx B *et al.*: **Dose-response relationship of weekly resistance-training volume and frequency on muscular adaptations in trained men**. *Int J Sports Physiol Perform* 2019:1-9.

19. Barcelos C, Damas F, Nobrega SR *et al.*: **High-frequency resistance training does not promote greater muscular adaptations compared to low frequencies in young untrained men**. *Eur J Sport Sci* 2018, **18**:1077-1082.

20. Vargas S, Petro JL, Romance R *et al.*: **Comparison of changes in lean body mass with a strength- versus muscle endurance-based resistance training program**. *Eur J Appl Physiol* 2019, **119**:933-940.

21. Stefanaki DGA, Dzulkarnain A, Gray SR: **Comparing the effects of low and high load resistance exercise to failure on adaptive responses to resistance exercise in young women**. *J Sports Sci* 2019:1-6.

22. Franco CMC, Carneiro MADS, Alves LTH *et al.*: **Lower-load is more effective than higher-load resistance training in increasing muscle mass in young women**. *J Strength Cond Res* 2019 http://dx.doi.org/10.1519/JSC.0000000000002970. Epub ahead of print.

23. Carlson L, Jonker B, Westcott WL *et al.*: **Neither repetition duration nor number of muscle actions affect strength increases, body composition, muscle size, or fasted blood glucose in trained males and females**. *Appl Physiol Nutr Metab* 2019, **44**:200-207.

24. Davies T, Orr R, Halaki M, Hackett D: **Erratum to: effect of training leading to repetition failure on muscular strength: a systematic review and meta-analysis**. *Sports Med* 2016, **46**:605-610.

25. Colquhoun RJ, Gai CM, Aguilar D *et al.*: **Training volume, not frequency, indicative of maximal strength adaptations to resistance training**. *J Strength Cond Res* 2018, **32**:1207-1213.

26. • Schoenfeld BJ, Grgic J, Krieger J: **How many times per week should a muscle be trained to maximize muscle hypertrophy? A systematic review and meta-analysis of studies examining the effects of resistance training frequency**. *J Sports Sci* 2018:1-10.

This meta-analysis shows that when volume is equated, increased training frequency does not result in superior RET-induced muscular hypertrophy; however, with a meta-regression on studies that were not volume-matched, this meta-analysis identified a modest benefit of performing three or more weekly RET sessions compared to just one.

27. Saric J, Lisica D, Orlic I *et al.*: **Resistance training frequencies of 3 and 6 times per week produce similar muscular adaptations in resistance-trained men**. *J Strength Cond Res* 2018 http://dx.doi.org/10.1519/JSC.0000000000002909. Epub ahead of print.

28. Brigatto FA, Braz TV, Zanini T *et al.*: **Effect of resistance training frequency on neuromuscular performance and muscle morphology after eight weeks in trained men**. *J Strength Cond Res* 2018 http://dx.doi.org/10.1519/JSC.0000000000002563. Epub ahead of print.

29. Gomes GK, Franco CM, Nunes PRP, Orsatti FL: **High-frequency resistance training is not more effective than low-frequency resistance training in increasing muscle mass and strength in well-trained men**. *J Strength Cond Res* 2018 http://dx.doi.org/10.1519/JSC.0000000000003145. Epub ahead of print.

30. Gentil P, Fisher J, Steele J *et al.*: **Effects of equal-volume resistance training with different training frequencies in muscle size and strength in trained men**. *PeerJ* 2018, **6**:e5020.

31. Grgic J, Schoenfeld BJ, Skrepnik M *et al.*: **Effects of rest interval duration in resistance training on measures of muscular strength: a systematic review**. *Sports Med* 2018, **48**:137-151.

32. Schoenfeld BJ, Pope ZK, Benik FM *et al.*: **Longer interset rest periods enhance muscle strength and hypertrophy in resistance-trained men**. *J Strength Cond Res* 2016, **30**:1805-1812.

33. Jambassi Filho JC, Gurjao ALD, Ceccato M *et al.*: **Chronic effects of different rest intervals between sets on dynamic and isometric muscle strength and muscle activity in trained older women**. *Am J Phys Med Rehabil* 2017, **96**:627-633.

34. Grgic J, Lazinica B, Garofolini A *et al.*: **The effects of time of day-specific resistance training on adaptations in skeletal muscle hypertrophy and muscle strength: a systematic review and meta-analysis**. *Chronobiol Int* 2019:1-12.

35. Colquhoun RJ, Gai CM, Walters J *et al.*: **Comparison of powerlifting performance in trained men using traditional and flexible daily undulating periodization**. *J Strength Cond Res* 2017, **31**:283-291.

36. Sieljacks P, Degn R, Hollaender K *et al.*: **Non-failure blood flow restricted exercise induces similar muscle adaptations and less discomfort than failure protocols**. *Scand J Med Sci Sports* 2019, **29**:336-347.

37. Yang Y, Bay PB, Wang YR *et al.*: **Effects of consecutive versus non-consecutive days of resistance training on strength, body composition, and red blood cells**. *Front Physiol* 2018, **9**:725.

38. Paoli A, Gentil P, Moro T *et al.*: **Resistance training with single vs. multi-joint exercises at equal total load volume: effects on body composition, cardiorespiratory fitness, and muscle strength**. *Front Physiol* 2017, **8**:1105.

39. Williams TD, Tolusso DV, Fedewa MV, Esco MR: **Comparison of periodized and non-periodized resistance training on maximal strength: a meta-analysis**. *Sports Med* 2017, **47**:2083-2100.

40. Ratamess NA, Alvar BA, Evetoch TK *et al.*: **American college of sports medicine position stand. Progression models in resistance training for healthy adults**. *Med Sci Sports Exerc* 2009, **41**:687-708.

41. Haff GG, Triplett-McBride T: *Essentials of Strength Training and Conditioning*. Champaign, Illinois: Human Kinetics; 2016.

42. Morton RW, Murphy KT, McKellar SR *et al.*: **A systematic review, meta-analysis and meta-regression of the effect of protein supplementation on resistance training-induced gains in muscle mass and strength in healthy adults**. *Br J Sports Med* 2018, **52**:376-384.

43. Roberts MD, Haun CT, Mobley CB *et al.*: **Physiological differences between low versus high skeletal muscle hypertrophic responders to resistance exercise training: current perspectives and future research directions**. *Front Physiol* 2018, **9**:834.

44. Cholewa JM, Rossi FE, MacDonald C *et al.*: **The effects of moderate- versus high-load resistance training on muscle growth, body composition, and performance in collegiate women**. *J Strength Cond Res* 2018, **32**:1511-1524.

45. Schoenfeld BJ, Ogborn D, Krieger JW: **Dose-response relationship between weekly resistance training volume and increases in muscle mass: a systematic review and meta-analysis**. *J Sports Sci* 2017, **35**:1073-1082.

46. Ochi E, Maruo M, Tsuchiya Y *et al.*: **Higher training frequency is important for gaining muscular strength under volume-matched training**. *Front Physiol* 2018, **9**:744.

47. Grgic J, Lazinica B, Mikulic P *et al.*: **The effects of short versus long inter-set rest intervals in resistance training on measures of muscle hypertrophy: a systematic review**. *Eur J Sport Sci* 2017, **17**:983-993.

48. Schoenfeld BJ, Ogborn DI, Vigotsky AD *et al.*: **Hypertrophic effects of concentric vs. eccentric muscle actions: a systematic review and meta-analysis**. *J Strength Cond Res* 2017, **31**:2599-2608.

49. •• Schoenfeld BJ, Vigotsky A, Contreras B *et al.*: **Differential effects of attentional focus strategies during long-term resistance training**. *Eur J Sport Sci* 2018, **18**:705-712.

This study provides an explanation for Counts *et al.* paper, illustrating that increased internal focus (i.e. maximally contracting a muscle group throughout its range of motion) affects RET-induced muscular hypertrophy.

50. Morton RW, McGlory C, Phillips SM: **Nutritional interventions to augment resistance training-induced skeletal muscle hypertrophy**. *Front Physiol* 2015, **6**:245.

51. Hubal MJ, Gordish-Dressman H *et al.*: **Variability in muscle size and strength gain after unilateral resistance training**. *Med Sci Sports Exerc* 2005, **37**.

52. West DW, Burd NA, Churchward-Venne TA *et al.*: **Sex-based comparisons of myofibrillar protein synthesis after resistance exercise in the fed state**. *J Appl Physiol (1985)* 2012, **112**:1805-1813.

53. Merrigan JJ, White JB, Hu YE *et al.*: **Differences in elbow extensor muscle characteristics between resistance-trained men and women**. *Eur J Appl Physiol* 2018, **118**:2359-2366.