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The Effects of Low-Load vs. High-Load Resistance Training on Muscle Fiber Hypertrophy: A Meta-Analysis

by
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The aim of this meta-analysis was to explore the effects of low-load vs. high-load resistance training on type I and type II muscle fiber hypertrophy. Searches for studies were performed through ten databases. Studies were included if they: (a) compared the effects of low-load vs. high-load resistance training (performed to momentary muscular failure); and, (b) assessed muscle fiber hypertrophy. A random-effects meta-analysis was performed to analyze the data. Ten study groups were included in the analysis. In the meta-analysis for the effects of low-load vs. high-load resistance training on type I muscle fiber hypertrophy, there was no significant difference between the training conditions (standardized mean difference: 0.28; 95% confidence interval: –0.27, 0.82; p = 0.316; I^2 = 18%; 95% prediction interval: –0.71, 1.28). In the meta-analysis for the effects of low-load vs. high-load resistance training on type II muscle fiber hypertrophy, there was no significant difference between the training conditions (standardized mean difference: 0.30; 95% confidence interval: –0.05, 0.66; p = 0.089; I^2 = 0%; 95% prediction interval: –0.28, 0.88). In this meta-analysis, there were no significant differences between low-load and high-load resistance training on hypertrophy of type I or type II muscle fibers. The 95% confidence and prediction intervals were very wide, suggesting that the true effect in the population and the effect reported in a future study conducted on this topic could be in different directions and anywhere from trivial to very large. Therefore, there is a clear need for future research on this topic.

Key words: *loading zones; intensity, volume, cross-sectional area; CSA.*

Introduction

Skeletal muscle hypertrophy is one of the central adaptations to resistance training (American College of Sports Medicine, 2009). According to Haun et al. (2019), muscle hypertrophy can be assessed at the whole-muscle level (macroscopic methods) or the muscle fiber level (microscopic methods). Some of the methods used to measure muscle size at the whole-muscle level include B-mode ultrasound, computed tomography, and magnetic resonance imaging (Haun et al., 2019). Hypertrophy at the muscle fiber level is evaluated using muscle biopsy samples and commonly analyzed according to type I and type II muscle fibers.

When prescribing resistance exercise, one of the most important variables is the external load. Current resistance training guidelines recommend loads of 70% to 85% of one-repetition maximum (1RM) as ideal for muscle hypertrophy (American College of Sports Medicine, 2009). However, recent research has established that both low-load and high-load resistance training may produce similar muscle hypertrophy at the whole muscle level when the training is performed to momentary muscular failure (Schoenfeld et al., 2017; Schoenfeld et al., 2020). Despite these established effects, there is also a lack of consensus regarding the effects of low vs. high-load resistance training on muscle hypertrophy assessed at the muscle fiber level (Grgic and Schoenfeld, 2018).

As compared to high-load training, some authors have hypothesized that low-load resistance training may produce greater

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hypertrophy of type I muscle fibers (Grgic et al., 2018a; Ogborn and Schoenfeld, 2014). In contrast, high-load training is suggested to predominantly impact type II muscle fiber hypertrophy (Folland and Williams, 2007). Grgic and Schoenfeld (2018) recently performed a narrative review on this topic. They concluded that while there is some evidence that low and high-load training may indeed produce different muscle fiber hypertrophy effects, the findings between studies remain highly inconsistent.

In a narrative review, there is no statistical mechanism for assessing the dispersion in effect size from study to study (Borenstein et al., 2009). A meta-analysis, however, incorporates all of the effect sizes from individual studies in a single statistical model and can isolate and quantify the true dispersion (Borenstein et al., 2009). Therefore, by using a meta-analysis, we might be able to provide greater clarity to this topic. Accordingly, the present paper aimed to perform a meta-analysis on the effects of low-load vs. high-load resistance training on type I and type II muscle fiber hypertrophy.

Methods

Search strategy

The search for the studies was performed through ten databases, including Academic Search Elite, CINAHL, ERIC, PsycINFO, OpenDissertations, Open Access Theses and Dissertations, PubMed/MEDLINE, Scopus, SPORTDiscus, and Web of Science databases. In all of these databases, the following search syntax was used: ("high-load" OR "high load" OR "low load" OR "low-load" OR "high repetition" OR "low repetition" OR "higher-repetition" OR "lower-repetition" OR "exercise load" OR "training load" OR "traditional muscular endurance" OR "traditional muscular strength") AND ("cross-sectional area" OR "CSA" OR "muscle fiber" OR "muscle fibre" OR "type I" OR "type II" OR "type IIa" OR "type IIx" OR "muscle biopsy" OR "muscle biopsies" OR "hypertrophy"). After the initial search, secondary searches were conducted. These searches consisted of: (a) checking the reference list of all studies included in the review; (b) screening the studies that cited the included studies (i.e., forward citation tracking), through Scopus and Google Scholar databases; and (c) examining the reference list of previous related reviews (Schoenfeld et al., 2016; Schoenfeld et al., 2017). The search for studies was conducted on February 1st, 2020.

Inclusion criteria

This review included studies that satisfied the following criteria: (a) published in English; (b) compared the effects of low-load (defined as all loads ≤60% of 1RM) vs. high-load (defined as loads >60% of 1RM) resistance training; (c) the training sets were performed to momentary muscular failure; (d) included humans as study participants; and (e) assessed muscle hypertrophy at the muscle fiber level. All studies that did not satisfy these criteria were excluded from the review. The most common reason for exclusion was the lack of muscle hypertrophy assessment at the muscle fiber level.

Data extraction

From all included studies, the following data were extracted: (a) details of the sample (i.e., sample size, sex, and participants' training status); (b) description of low-load and high-load resistance training programs; (c) site of the muscle biopsy assessment; and (d) pre and post-intervention mean ± standard deviation (SD) of type I and type II muscle fiber cross-sectional area. In one case, relevant data was reported in a figure; for this study (Lim et al., 2019), the data was extracted using the *WebPlotDigitizer* software (2010-2019 Ankit Rohatgi). For studies that reported standard errors, the data were converted to SDs.

Methodological quality

The methodological quality of included studies was assessed using the Downs and Black (2000) checklist. This checklist evaluates several aspects of the study design, with items 1-10, 11-13, 14-26, and 27 referring to reporting, external validity, internal validity, and statistical power, respectively. As performed in other reviews (Davies et al., 2017; Grgic et al., 2018b) that focused on the effects of resistance training on muscular adaptations, two additional items were included on the checklist (item 28 and item 29). Item 28 referred to reporting of training adherence while item 29 was related to the supervision of the exercise programs. The maximum score on the checklist was 29 points. Studies were rated as being of "good quality" (>20 points), "moderate quality" (11-20 points), or "poor quality" (<11 points).

Statistical analysis

Meta-analyses were performed based on standardized mean differences (SMD; Hedge's g). SMDs and 95% confidence intervals (CIs) were calculated using the pre- and post-intervention mean and SD of the muscle fiber cross-sectional data and the number of participants in each group. Two separate analyses were performed: (1) for type I fiber cross-sectional area; and, (2) for type II fiber cross-sectional area. For studies that presented data on different subtypes of type II muscle fibers (i.e., IIa and IIx), SMDs and variances were calculated for each outcome separately and the average values were used for the analysis. The interpretation of SMD was based on the following classification: small (≤0.2); medium (0.2-0.5); large (0.5-0.8); and very large (>0.8). Heterogeneity was explored using the I^2 statistic with values ≤50%, 50-75%, and >75% indicating low, moderate, and high levels of heterogeneity, respectively. Meta-analyses were performed using the random-effects model. The statistical significance threshold was set at $p < 0.05$. 95% prediction intervals were calculated using: (a) the number of included studies; (b) the upper limit of the 95% CI; and (c) the tau-squared values. Prediction intervals denote the range in which the SMD of a future study conducted on the topic will likely be. All analyses were performed using the Comprehensive Meta-analysis software, version 2 (Biostat Inc., Englewood, NJ, USA).

Results

Search results and study characteristics

The primary search resulted in 1849 references. Of this number of search results, a total of 50 full-text papers were read, and five studies (Campos et al., 2002; Lim et al., 2019; Mitchell et al., 2012; Morton et al., 2016; Schuenke et al., 2012), with a total of 10 study groups were included in the review. Secondary search resulted in another 3131 results; however, no additional studies were included. The flow diagram of the search process is presented in Figure 1.

The pooled number of participants in all included studies was 120. Study samples ranged from 14 to 49 participants (median: 17 participants). Four studies included only males as study participants, while one study utilized a sample comprising of females (Table 1). Four studies included untrained participants; only one included resistance-trained individuals. The training program in the included studies lasted from 6 to 12 weeks. In all studies, muscle biopsy samples were taken from the quadriceps muscle. The included studies are summarized in Table 1.

Methodological quality

The number of points scored on the Downs and Black checklist varied from 19 to 25. Four studies were classified as being of good methodological quality, and one study was classified as being of moderate methodological quality (Mitchell et al., 2012).

Meta-analysis results

A total of ten study groups were included in the meta-analysis. In the meta-analysis for the effects of low-load vs. high-load resistance training on type I muscle fiber hypertrophy, there was no significant difference between the training conditions (SMD: 0.28; 95% CI: –0.27, 0.82; p = 0.316; I^2 = 18%; Figure 2). The 95% prediction intervals ranged from –0.71 to 1.28. In the meta-analysis for the effects of low-load vs. high-load resistance training on type II muscle fiber hypertrophy, there was no significant difference between the training conditions (SMD: 0.30; 95% CI: –0.05, 0.66; p = 0.089; I^2 = 0%; Figure 3). The 95% prediction intervals ranged from –0.28 to 0.88.

Discussion

In this meta-analysis, there were no significant differences between low-load and high-load resistance training on hypertrophy of type I or type II muscle fibers. Even though it might be tempting to conclude that these results indicate that muscle fiber hypertrophy is not resistance training load-dependent, non-significant test results are generally not indicative of the absence of a true effect in the population (Lakens, 2017). In both performed analyses, the 95% CIs were wide, suggesting that the true effect in the population could be in different directions and anywhere from *trivial* to *very large*. Additionally, for type I muscle fiber hypertrophy, 95% predication intervals ranged from –0.71 to 1.28, suggesting that the next new observation on this topic will likely fall within this very wide range. Therefore, given the width of the 95% confidence and prediction intervals, there is a clear need for future research on this topic.

Table 1

Summary of the studies included in the review

Study	Participants	Training programs	Resistance exercise(s) used in the training program	Duration of the training; weekly training frequency
Campos et al. (2002)	16 young untrained men	Low-load: 2 sets per exercise performed for 20 to 28 RM High-load: 4 sets per exercise performed for 3 to 5 RM	Leg press, squat, and leg extension	8 weeks; 2-3 times per week
Lim et al. (2019)	14 young untrained men	Low-load: 3 sets per exercise with 30% 1RM High-load: 3 sets per exercise with 80% 1RM	Leg press, leg extension, and leg curl	10 weeks; 3 times per week
Mitchell et al. (2012)	12 young untrained men	Low-load: 3 sets per exercise with 30% 1RM High-load: 3 sets per exercise with 80% 1RM	Leg extension	12 weeks; 3 times per week
Morton et al. (2016)	49 young resistance-trained men	Low-load: 3 sets per exercise with 30% to 50% 1RM High-load: 3 sets per exercise with 75% to 90% 1RM	Seated row, bench and shoulder press, front plank, bicep curls, triceps extension, pull downs, leg press, curl, and extension	12 weeks; 3 times per week
Schuenke et al. (2012)	17 young untrained women	Low-load: 3 sets per exercise performed for 20 to 30 RM High-load: 3 sets per exercise performed for 6 to 10 RM	Leg press, squat, and leg extension	6 weeks; 2-3 times per week

RM: repetition maximum

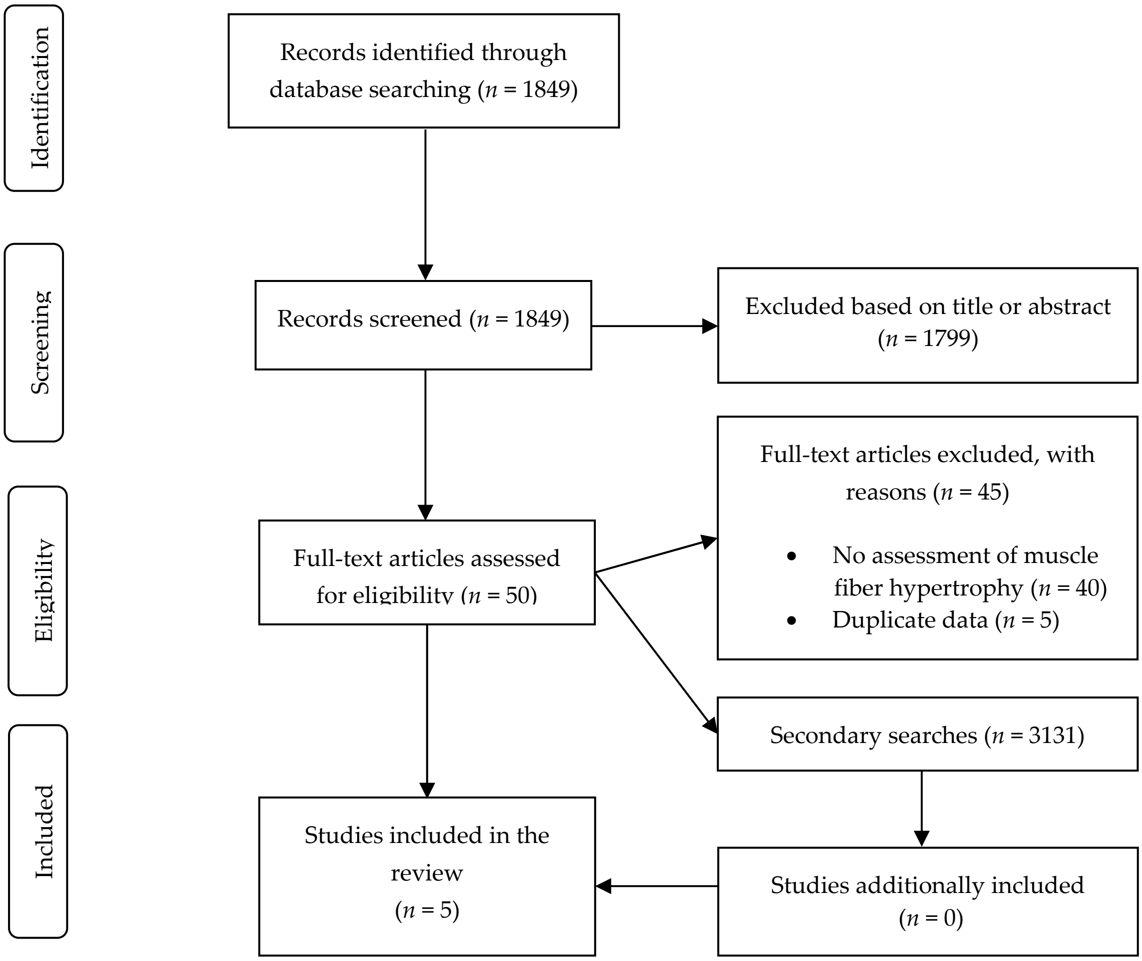

Figure 1

Flow diagram of the search and study selection process

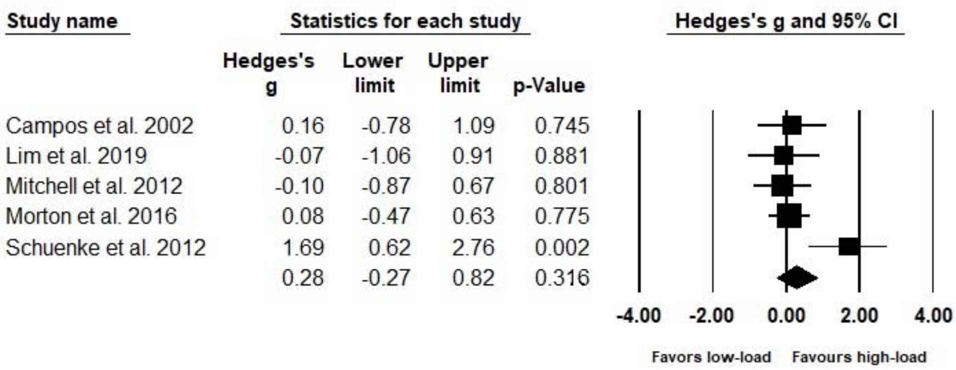

Figure 2

The forest plot is presenting the results of the meta-analysis on the effects of low-load vs. high-load resistance training on type I muscle fiber hypertrophy. The squares denote standardized mean difference (Hedges's g) while the lines denote their respective 95% confidence intervals (CI)

Study name	Hedges's g	Lower limit	Upper limit	p-Value
Campos et al. 2002	0.65	-0.31	1.61	0.185
Lim et al. 2019	0.03	-0.95	1.01	0.952
Mitchell et al. 2012	0.05	-0.73	0.83	0.901
Morton et al. 2016	0.17	-0.38	0.72	0.548
Schuenke et al. 2012	1.01	0.05	1.97	0.039
	0.30	-0.05	0.66	0.089

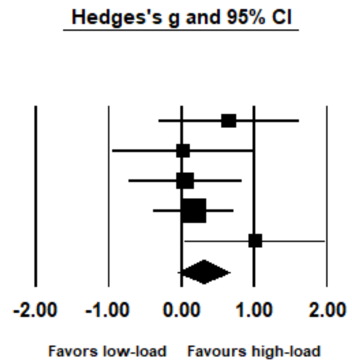

Figure 3
The forest plot is presenting the results of the meta-analysis on the effects of low-load vs. high-load resistance training on type II muscle fiber hypertrophy. The squares denote standardized mean difference (Hedges's g) while the lines denote their respective 95% confidence intervals (CI)

The review's main finding is that when the training is performed to muscular failure, there is not enough available data to conclude that low-load is more effective for muscle fiber hypertrophy than high-load, or *vice-versa*. However, we need to consider some associated physiological responses to resistance training when extrapolating the data to practice. According to Henneman's size principle, motor units are recruited in an orderly fashion (Henneman et al., 1965). At the beginning of a set with low-loads (e.g., 30% 1RM), lower threshold motor units associated with type I muscle fibers are recruited to lift the load (Duchateau et al., 2006). As these motor units fatigue, higher threshold motor units associated with type II muscle fibers will be recruited, ultimately resulting in the recruitment of the entire motor unit pool. When exercising with high-loads (e.g., 80% 1RM), the recruitment of all motor units occurs from the exercise's onset (Duchateau et al., 2006). Therefore, if the training is performed to muscular failure, the recruitment of high and low threshold motor units may be similar regardless of load used in training. Similar recruitment of motor units with low-load and high-load training may, over time, also result in comparable hypertrophy of muscle fibers. Furthermore, recent data reported similar hypertrophy of the soleus (a predominantly slow-twitch muscle) and the gastrocnemius (muscle with a similar composition of slow and fast-twitch fibers) when training with high-loads or low-loads (Schoenfeld et al., 2020). These results may be explained by the data from Morton et al. (2020), where no significant difference in glycogen depletion of type I and type II fibers and phosphorylation of relevant signaling proteins was found between low-load and high-load training. When considering the whole body of literature, it might be that the effects of high-load and low-load training on muscle fiber hypertrophy are similar in terms of their magnitude. Nevertheless, given the already identified limitations of the data (i.e., wide 95% CIs and prediction intervals), this topic needs to be further investigated.

In the analysis for type II muscle fiber hypertrophy, the pooled SMD favored high-loads, even though the effect was not statistically significant (p = 0.089). However, it is also worth noting that the data from Schuenke et al. (2012) impacted the pooled estimate in this analysis. Specifically, the SMD from this study amounted to 1.01, which is substantially higher than the effects observed in other studies. When this study was excluded from the analysis, the pooled estimate was reduced to 0.20 (95% CI: –0.18, 0.57; p = 0.310). This study differed from other research by the inclusion of females as study participants. All other included studies utilized samples comprised exclusively of males. Tentatively, these results may indicate that training with low and high-loads produces different effects on muscle fiber hypertrophy in females, but not in males. Instead of excluding females, future studies may consider including both sexes and plot the results separately to explore whether a sex difference exists to training with varying loads.

It needs to be mentioned that the results presented in this meta-analysis are specific to the lower-body musculature. Specifically, all studies collected muscle biopsy samples from the quadriceps femoris muscle group, which is the most common location because of its mixed fiber type composition, trainability, and accessibility (Staron et al., 2000). Therefore, while indicative, the results presented herein cannot necessarily be generalized to the upper-body musculature. Future research is needed to explore the effects of low-load and high-load resistance training on muscle fiber hypertrophy in the upper-body musculature.

Using the Downs and Black checklist, the included studies were classified as being of moderate or good methodological quality. Therefore, the pooled data presented in this meta-analysis are not confounded by the inclusion of studies that were of poor methodological quality. However, it also needs to be mentioned that adherence to the training programs was reported only in one study (Morton et al., 2016). Adherence to any training program is one of the critical variables that will determine its effectiveness (Gentil and Bottaro, 2013). In this context, one acute study reported that low-load training (20 to 25 RM) produced higher degrees of effort, discomfort, and displeasure, as compared to high-load training (8 to 12 RM) (Ribeiro et al., 2019). These differences in affective responses may impact long-term adherence of participants to the training program; therefore, future studies should ensure that adherence is reported.

Conclusions

This review did not find significant differences between low-load vs. high-load resistance training on hypertrophy of type I or type II muscle fibers. Therefore, the main finding of this review is that when resistance training is performed to muscular failure, there is not enough available data to conclude that high-load or low-load outperforms the other regarding their effects on type I or type II muscle fiber hypertrophy. Given that the 95% confidence and prediction intervals were very wide, there is a clear need for future research on this topic.

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