Canadian Science Publishing | Applied Physiology, Nutrition, and Metal

Muscle hypertrophy and strength gains after resistance training with different volume matched loads: a systematic review and meta-analysis.

Journal:	*Applied Physiology, Nutrition, and Metabolism*
Manuscript ID	apnm-2021-0515.R2
Manuscript Type:	Systematic Review
Date Submitted by the Author:	02-Dec-2021
Complete List of Authors:	Carvalho, Leonardo; Universidade Estadual de Campinas, Junior, Roberto ; UNICAMP Barreira, Júlia; UNICAMP Schoenfeld, Brad; Exercise Science Department, CUNY Lehman College, Bronx, New York, USA, Orazem, John ; Lehman College of CUNY Division of Natural and Social Science Barroso, Renato; Universidade Estadual de Campinas,
Novelty bullets: points that summarize the key findings in the work:	• Muscle hypertrophy is similar irrespective of the magnitude of load, even when volume load is equated between conditions., • Training with higher loads elicits greater gains in 1RM muscle strength when compared to lower loads, even when volume load
Keyword:	strength, training, musculoskeletal, failure, high load, low load
Is the invited manuscript for consideration in a Special Issue? :	Not applicable (regular submission)

TITLE: Muscle hypertrophy and strength gains after resistance training with different volume matched loads: a systematic review and meta-analysis.

Leonardo Carvalho[1]; Roberto Moriggi Junior[1]; Júlia Barreira[1]; Brad J. Schoenfeld[2]; John Orazem[2]; Renato Barroso[1]

[1] Department of Sport Sciences, School of Physical Education, University of Campinas (UNICAMP), Campinas, SP, Brazil.

[2] Department of Health Sciences, CUNY Lehman College, Bronx, NY

Corresponding author:

Renato Barroso, Department of Sport Sciences, School of Physical Education, University of Campinas, e-mail: rbarroso@unicamp.br; https://orcid.org/0000-0001-8112-662

Av. Érico Veríssimo, 701 – Cidade Universitária – Campinas, 13083 – 851. Office: +55 19 3521-6804

Funding details:

This work was supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES under Grant 2018/23-p4748.

ABSTRACT

The purpose of this paper was to conduct a systematic review and meta-analysis of studies that compared muscle hypertrophy and strength gains between resistance training protocols employing very low (VLL<30% of 1RM or >35 RM), low (LL30%-59% of 1RM, or 16–35 RM), moderate (ML60%-79% of 1RM, or 8 -15RM) and high load (HL≥80% of 1RM, or ≤7 RM) with matched volume loads (sets x reps x weight). A pooled analysis of the standardized mean difference for 1RM strength outcomes across the studies showed a benefit favoring HL *vs.* LL and *vs.* ML; and favoring ML *vs.* LL. Results from LL and VLL indicated little difference. A pooled analysis of the standardized mean difference for hypertrophy outcomes across all studies showed no differences between the training loads. Our findings indicate that, when volume load is equated between conditions, the highest loads induce superior dynamic strength gains. Alternatively, hypertrophic adaptations are similar irrespective of the magnitude of load.

NOVELTY BULLETS:

- Training with higher loads elicits greater gains in 1RM muscle strength when compared to lower loads, even when volume load is equated between conditions.
- Muscle hypertrophy is similar irrespective of the magnitude of load, even when volume load is equated between conditions.

Keywords: strength; training; musculoskeletal.

INTRODUCTION

Current resistance training guidelines recommend the use of loads greater than 65% of maximal dynamic strength (1RM) to optimize muscle hypertrophy and strength gains (2009). More recently, these guidelines have been challenged as emerging evidence indicates that resistance training performed across a spectrum of loadings when carried out with a high level of effort may elicit similar changes in muscle size (Schoenfeld et al., 2015, Jenkins et al., 2016). For example, Ogasawara et al. (2013) demonstrated that resistance training to failure either at 75% or at 30% of 1RM elicited similar muscle hypertrophy, but training at 75% of 1RM induced superior strength gains. Subsequently, a systematic review and meta-analysis of the literature on the topic found greater strength gains in favor of high-load training, whereas muscle hypertrophy was similar between conditions (Schoenfeld et al., 2017). Importantly, these findings were specific to training carried out with the number of sets equated between conditions.

Volume load (sets x reps x weight) has been proposed as a potentially important variable when evaluating the effect of the training load on muscle adaptations (Schoenfeld et al., 2014). Simply stated, volume load provides a gauge of the total work performed in a given exercise or session. When the number of sets are equated, training with lower loads produces larger volume loads (Morton et al., 2019). This may have an impact on changes in muscle size (Lasevicius et al., 2018, Mitchell et al., 2012, Ogasawara et al., 2013), as there seems to be a dose-response relationship between volume load and hypertrophy (Grgic et al., 2017).

When different loads are compared but volume load is equalized via the performance of additional sets, some evidence suggests that protocols with heavier loads induce greater gains in muscle size and strength compared to lighter loads. For example, Campos et al. (2002) compared the effects of three resistance training protocols with similar volume loads (i.e., 4 x 3-5RM vs. 3 x 9-11RM vs. 2 x 20-28RM) on muscle hypertrophy of untrained men. After 8 weeks of training, the authors observed that higher loads (i.e., 4 x 3-5RM and 3 x 9-11RM) induced greater increases in muscle fiber cross sectional area (CSA) and strength compared to a lower-load protocol (i.e., 2 x 20-28RM). Lasevicius et al. (Lasevicius et al., 2018) employed a within-subject design in which one leg and one arm trained with a very low load (i.e., 20%RM) and the contralateral limb was randomly assigned to one of the three volume load matched conditions: 40%RM, 60%RM and 80%RM. The highest load condition (i.e., 80%RM) showed greater muscle growth and strength gains after 12 weeks compared to the lowest load condition (i.e., 20%RM). On the other hand, Schoenfeld et al. (2014) reported no differences in muscle size changes when groups trained with 3 sets of 10RM versus 7 sets of 3RM after of 8 weeks of resistance training with volume load equated. However, the authors found a greater increase in muscle strength in the high load group (i.e., 7 x 3RM). Given the discrepancies in findings, the best way to achieve a consensus from the research is to statistically analyze the pooled results from the body of literature on the topic. Therefore, the purpose of this paper was to conduct a systematic review and meta-analysis of studies that compared site-specific muscle hypertrophy and 1RM strength gains between protocols employing different resistance training loads (<60% of 1RM, between 60% and 79% of 1 RM, and >80% of 1 RM). In addition, given the wide range of loads in the lower loads, we performed a subsequent analysis splitting into low and very low loads. In the end, we had the following loading conditions: very low (VLL;<30% of 1RM, or >35 RM), low (LL; between 30% and 59% of 1RM, or 16–35 RM), moderate (ML; between 60% and 79% of 1RM, or 8 -15RM) and high load (HL; ≥80% of 1RM, or ≤7 RM) with matched volume loads (sets x reps x weight).

MATERIAL AND METHODS

Search Strategy

Literature searches were performed on PubMed, Web of Science and Sport Discus EBSCO databases. Searches included studies published until September 2021 using combinations of the following keywords: ("resistance training" OR "resistance exercise" OR "strength exercise" OR "strength training" OR "weight training" OR "weight exercise") AND ("hypertrophy" OR "body composition" OR "muscle size" OR "muscle thickness" OR "cross-sectional area" OR "growth" OR "muscle fiber" OR "muscle mass OR strength OR 1RM") AND ("intensity" OR "load").

Two of the authors (L.C. and R.J.M.) independently analyzed study titles and abstracts. Subsequently, they read the full text of studies deemed potentially eligible for inclusion. A third author (R.B.) resolved any discrepancies between the authors as to eligibility. In addition to articles found in the search, reference lists of articles were reviewed to determine the relevance of any undiscovered studies on the topic.

Inclusion and exclusion criteria: participants, interventions, comparators and outcomes

Studies had to meet the following criteria for inclusion in our review: 1) include healthy human participants, regardless of age and sex; 2) be an experimental trial involving two or more different resistance training loads with volume load matched; 3) employ at least one method of estimating site-specific muscle hypertrophy and/or 1RM testing; 4) have a minimum study duration of 4 weeks; 5) use combined dynamic eccentric and concentric actions in the training protocol. We excluded studies and/or groups that used blood flow restriction training from analysis as this method may promote adaptations via different mechanisms than traditional resistance training. We also excluded studies that employed drop sets or periodized loading schemes, as such strategies may confound the effects of manipulating load. In addition, studies with a randomized-controlled trial was not an inclusion criterion.

Data extraction

Two independent researchers (L.C. and R.J.M.) extracted data from each included study for the following variables: number of participants, age, sex, experimental design, muscle hypertrophy measurement, and muscle strength measurement (i.e., 1RM test). We emailed the corresponding author of studies that did not report mean and standard deviation (SD) values of the dependent variables to request relevant data. Two authors (L.C. and R.J.M.) used the Image J software (ImageJ v. 1.43, National Institute of Health, Bethesda, USA) to obtain mean and standard deviation data from figures when applicable. Table 1 presents the studies included in the analyses.

Study quality assessment

The methodological quality of the studies was evaluated using the PEDro scale, which is composed of 11 items; each item assesses one aspect of the study. A point was awarded for each item where the study met the specified criteria (with the exception of item 1, which is not scored). As per previous work, we removed items 5, 6 and 7 from the scale, given that it is infeasible to blind the subjects and investigators from treatments in supervised resistance training interventions. The highest score on the modified PEDro 8-point scale was 7. The qualitative descriptors for the PEDro scale was classified according to Kümmel et al. (2016): excellent (i.e., 6-7), good (i.e., 5), moderate (i.e., 4) and poor (i.e., 0-3). The evaluation was performed independently by two authors (L.C. and R.J.M.). Previous studies have demonstrated acceptable levels of objectivity using the PEDro scale (Maher et al., 2003). In cases of disagreement, a third author (R.B.) was consulted to reconcile differences. Only studies that presented a score ≥ 4.0 were included for analyses.

Coding of Studies

Studies were read by two researchers independently (L.C. and R.J.M.) and entered into a spreadsheet based on the following variables: descriptive information of the participants by group, including sex, training level (resistance trained individuals were considered as those with more than 6 months of uninterrupted training and untrained individuals were those that had not performed any resistance training for at least 6 months before the start of the study), and age (young [18-39 years], middle-aged [40-64 years] or older [65 or more years]); number of individuals in each group; study duration; training load of each protocol (prescribed by % of the 1RM test or by zones of maximum repetitions); number of sets and weekly frequency; measurement mode of muscle hypertrophy (magnetic resonance imaging [MRI], computed tomography [CT], ultrasound modes B and A, and/or biopsy); body region / muscle measured. We classified loads according to four categories according the following criteria: very low (<30% of 1-RM, or >35 RM), low (between 30% and 59% of 1-RM, or 16–35 RM), moderate (between 60% and 79% of 1-RM, or 8 -15RM), and high (≥80% of 1-RM, or ≤7 RM). We compared only protocols that equated effort level (i.e., muscle to failure or not to failure).

Statistical analysis

For each hypertrophy or strength outcome, the contrast across the different load groups was calculated as the difference in effect sizes (ES), where the ES was determined as the posttest-pretest mean change in each group, divided by the pooled pretest SD, and multiplied by an adjustment for small sample bias (Morris, 2008). ESs were interpreted as: "small" (≤0.20); "moderate" (0.21–0.50); "large" (0.51–0.80); and "very large" (>0.80) (Cohen, 1992). ESs are presented with their respective 95% confidence intervals (95% CI). The variance of the difference in ESs depends on the within-subject posttest-pretest correlation, which was not available from the published data for many of the studies. Among studies for which this correlation could be estimated (back-solving from paired t-test *p*-values or SDs of posttest-pretest change scores, when presented), the median value was 0.73; the value of 0.75 was used to calculate the variance for all studies.

Sensitivity analyses (not presented) were performed using correlations ranging from 0 to 0.85; results were consistent with those using 0.75. When studies report multiple effect sizes, one approach is to use study average effect size, which may result in a loss of information. Therefore, a robust variance meta-analysis model, with adjustments for small samples, was used to account for correlated ESs within studies. This meta-analysis model is specifically designed to deal with dependent effect sizes (e.g., multiple strength tests in a single study) (Hedges et al., 2010, Moeyaert et al., 2017, Tanner-Smith et al., 2016). An overall meta-analysis was conducted, separately for the hypertrophy outcomes and strength outcomes and for each paired comparison. In addition, subgroup analyses were performed to explore the effects of training to failure (yes vs. no), and body region (upper vs. lower), when there was a sufficient number of studies for the analysis. Publication bias was checked by examining funnel plot asymmetry and calculating trim-and-fill estimates. The trim-and-fill estimates (not presented) were similar to the main results. Calculations were performed using the robumeta package within R version 4.0.1. All meta-analyses were performed using the robust variance random effects model. Effects were considered statistically significant at $p < 0.05$.

RESULTS

Included Studies

Figure 1 presents a flowchart of the search carried out according to PRISMA guidelines. Initially, 138,385 articles were identified and after deduplication, 123,358 studies were excluded from the reviewing processes and 14,978 were excluded after title and/or abstract analysis. In total, 49 studies were selected for the full-text reading. Two authors (L.C. and R.J.M.) read these studies completely and, according to our pre-determined inclusion and exclusion criteria, 18 studies ultimately were selected for our review. After reading all articles and reviewing the reference list, 4 additional articles were included for analyses. Two studies presented PEDro score <4 and hence were excluded from analyses. Thus, 20 studies met inclusion for our systematic review and meta-analysis.

INSERT FIGURE 1 NEAR HERE

Participant characteristics

Participants' characteristics are summarized in Table 1. Overall, 480 participants were included in the meta-analysis (Barcelos et al., 2015, Campos et al., 2002, Chestnut and Docherty, 1999, Dons et al., 1979, Holm et al., 2008, Jenkins et al., 2016, Jessee et al., 2018, Lasevicius et al., 2018, Schoenfeld et al., 2014, Taaffe et al., 1996, Kubo et al., 2020, Lasevicius et al., 2019, Vincent et al., 2002, Bemben et al., 2000, Fatouros et al., 2005, Fatouros et al., 2006, Harris et al., 2004, Hortobagyi et al., 2001, Lopes et al., 2017, Pruitt et al., 1995). The number of participants in the studies varied from 10 (Barcelos et al., 2015) to 48 (Fatouros et al., 2006). Fourteen studies exclusively examined males (Campos et al., 2002, Chestnut and Docherty, 1999, Dons et al., 1979, Holm et al., 2008, Jenkins et al., 2016, Lasevicius et al., 2018, Schoenfeld et al., 2014, Barcelos et al., 2015, Kubo et al., 2020, Lasevicius et al., 2019, Fatouros et al., 2005, Fatouros et al., 2006, Hortobagyi et al., 2001, Lopes et al., 2017), three exclusively examined females (Taaffe et al., 1996, Bemben et al., 2000, Pruitt et al., 1995), and three assessed a mixed-sex sample (Jessee et al., 2018, Vincent et al., 2002, Harris et al., 2004). The mean age of study participants ranged from 20 (Kubo et al., 2020) to 72 years (Hortobagyi et al., 2001). The training status of participants ranged from untrained (Barcelos et al., 2015, Campos et al., 2002, Chestnut and Docherty, 1999, Holm et al., 2008, Jenkins et al., 2016, Jessee et al., 2018, Lasevicius et al., 2018, Taaffe et al., 1996, Kubo et al., 2020, Lasevicius et al., 2019, Vincent et al., 2002, Fatouros et al., 2005, Fatouros et al., 2006, Harris et al., 2004, Hortobagyi et al., 2001, Pruitt et al., 1995) to resistance-trained (Schoenfeld et al., 2014, Lopes et al., 2017). One study did not report the training status of participants (Dons et al., 1979).

Intervention characteristics

Resistance training programs for the included studies are summarized in Table 1. According to our inclusion criteria, we only analyzed studies that investigated changes in site-specific muscle hypertrophy and 1RM strength using two or more different magnitudes of load with volume load equated. Most studies compared two loading schemes (Barcelos et al., 2015, Chestnut and Docherty, 1999, Dons et al., 1979, Holm et al., 2008, Jenkins et al., 2016, Jessee et al., 2018, Schoenfeld et al., 2014, Taaffe et al., 1996, Lasevicius et al., 2019, Vincent et al., 2002, Hortobagyi et al., 2001, Lopes et al., 2017, Pruitt et al., 1995). Five investigations compared three loading schemes (Campos et al., 2002, Kubo et al., 2020, Fatouros et al., 2005, Fatouros et al., 2006, Harris et al., 2004) and another compared four loading schemes (Lasevicius et al., 2018). In 10 studies, participants performed the training protocol until failure (Barcelos et al., 2015, Campos et al., 2002, Chestnut and Docherty, 1999, Jenkins et al., 2016, Jessee et al., 2018, Lasevicius et al., 2018, Schoenfeld et al., 2014, Kubo et al., 2020, Harris et al., 2004, Lopes et al., 2017) while in the other nine studies training stopped short of failure (Dons et al., 1979, Holm et al., 2008, Taaffe et al., 1996, Vincent et al., 2002, Fatouros et al., 2005, Fatouros et al., 2006, Hortobagyi et al., 2001, Pruitt et al., 1995, Bemben et al., 2000). One study compared two loads with participants performing the strength protocol until failure and with training stopped short of failure (Lasevicius et al., 2019). The most common load prescription was % of 1RM (Barcelos et al., 2015, Dons et al., 1979, Holm et al., 2008, Jenkins et al., 2016, Jessee et al., 2018, Lasevicius et al., 2018, Taaffe et al., 1996, Lasevicius et al., 2019, Vincent et al., 2002, Bemben et al., 2000, Fatouros et al., 2005, Fatouros et al., 2006, Hortobagyi et al., 2001, Pruitt et al., 1995) and six studies used a repetition maximum zone to prescribe load (Campos et al., 2002, Chestnut and Docherty, 1999, Schoenfeld et al., 2014, Kubo et al., 2020, Harris et al., 2004, Lopes et al., 2017). Intervention duration ranged from 4 (Jenkins et al., 2016) to 52 (Taaffe et al., 1996) weeks, with 8 weeks being the most common.(Barcelos et al., 2015, Campos et al., 2002, Jessee et al., 2018, Schoenfeld et al., 2014, Lasevicius et al., 2019).

Three studies involved resistance training of the upper limbs (Chestnut and Docherty, 1999, Jenkins et al., 2016, Kubo et al., 2020), eight studies involved the lower limbs (Barcelos et al., 2015, Campos et al., 2002, Dons et al., 1979, Holm et al., 2008, Jessee et al., 2018, Taaffe et al., 1996, Lasevicius et al., 2019, Hortobagyi et al., 2001) and nine studies involved both the lower and upper limbs.(Lasevicius et al., 2018, Schoenfeld et al., 2014, Vincent et al., 2002, Bemben et al., 2000, Fatouros et al., 2005, Fatouros et al., 2006, Harris et al., 2004, Lopes et al., 2017, Pruitt et al., 1995) More than half of the studies were carried out three times per week (Chestnut and Docherty, 1999, Dons et al., 1979, Holm et al., 2008, Jenkins et al., 2016, Schoenfeld et al., 2014, Taaffe et al., 1996, Vincent et al., 2002, Bemben et al., 2000, Fatouros et al., 2005, Fatouros et al., 2006, Hortobagyi et al., 2001, Pruitt et al., 1995). Six studies were carried out twice per week (Barcelos et al., 2015, Jessee et al., 2018, Lasevicius et al., 2018, Kubo et al., 2020, Lasevicius et al., 2019, Harris et al., 2004), one study was carried out four times per week (Lopes et al., 2017) and one study carried out training twice per week for the first 4 weeks and three times per week for the last 4 weeks (Campos et al., 2002).

******INSERT TABLE 1 ABOUT HERE******

For muscle strength assessments, 12 studies evaluated muscle strength of the upper limbs (Chestnut and Docherty, 1999, Jenkins et al., 2016, Lasevicius et al., 2018, Schoenfeld et al., 2014, Kubo et al., 2020, Vincent et al., 2002, Bemben et al., 2000, Fatouros et al., 2005, Fatouros et al., 2006, Harris et al., 2004, Lopes et al., 2017, Pruitt et al., 1995) and 17 studies evaluated muscle strength of the lower limbs (Barcelos et al., 2015, Campos et al., 2002, Dons et al., 1979, Holm et al., 2008, Jessee et al., 2018, Lasevicius et al., 2018, Schoenfeld et al., 2014, Taaffe et al., 1996, Lasevicius et al., 2019, Vincent et al., 2002, Hortobagyi et al., 2001, Bemben et al., 2000, Fatouros et al., 2005, Fatouros et al., 2006, Harris et al., 2004, Lopes et al., 2017, Pruitt et al., 1995). The most common exercises that assessed upper limb strength were: elbow flexor exercise (Chestnut and Docherty, 1999, Jenkins et al., 2016, Lasevicius et al., 2018, Bemben et al., 2000, Harris et al., 2004, Pruitt et al., 1995), elbow extensor exercise (Chestnut and Docherty, 1999, Bemben et al., 2000, Harris et al., 2004) and bench press exercise (Schoenfeld et al., 2014, Kubo et al., 2020, Harris et al., 2004, Lopes et al., 2017, Pruitt et al., 1995). The most common exercises that assessed lower limb strength were: knee extensor exercise (Barcelos et al., 2015, Campos et al., 2002, Dons et al., 1979, Holm et al., 2008, Jessee et al., 2018, Taaffe et al., 1996, Jenkins et al., 2016, Lasevicius et al., 2019, Vincent et al., 2002, Fatouros et al., 2005, Harris et al., 2004, Pruitt et al., 1995), leg press exercise (Campos et al., 2002, Lasevicius et al., 2018, Taaffe et al., 1996, Vincent et al., 2002, Bemben et al., 2000, Fatouros et al., 2006, Harris et al., 2004, Pruitt et al., 1995) and squat exercise (Campos et al., 2002, Schoenfeld et al., 2014, Lopes et al., 2017).

For muscle hypertrophy assessments, a majority of studies used ultrasonography (Dons et al., 1979, Jenkins et al., 2016, Jessee et al., 2018, Lasevicius et al., 2018, Schoenfeld et al., 2014, Bemben et al., 2000) and MRI (Barcelos et al., 2015, Chestnut and Docherty, 1999, Holm et al., 2008, Kubo et al., 2020, Lasevicius et al., 2019) while others used biopsy (Campos et al., 2002, Taaffe et al., 1996). Most studies used cross sectional area as a measure of muscle size (Barcelos et al., 2015, Campos et al., 2002, Chestnut and Docherty, 1999, Dons et al., 1979, Holm et al., 2008, Lasevicius et al., 2018, Taaffe et al., 1996, Lasevicius et al., 2019, Bemben et al., 2000), whereas three studies used muscle thickness (Jenkins et al., 2016, Jessee et al., 2018, Schoenfeld et al., 2014) and one study used muscle volume

(Kubo et al., 2020). Six studies assessed muscle hypertrophy of the upper limbs (Chestnut and Docherty, 1999, Jenkins et al., 2016, Lasevicius et al., 2018, Schoenfeld et al., 2014, Kubo et al., 2020, Bemben et al., 2000) and nine studies assessed muscle hypertrophy of the lower limbs (Barcelos et al., 2015, Campos et al., 2002, Dons et al., 1979, Holm et al., 2008, Jessee et al., 2018, Lasevicius et al., 2018, Taaffe et al., 1996, Lasevicius et al., 2019, Bemben et al., 2000). The muscle most commonly evaluated was the *vastus lateralis* (Campos et al., 2002, Jessee et al., 2018, Lasevicius et al., 2018, Taaffe et al., 1996).

Quality assessments

The quality assessment is presented in Table 2. The mean rating of study quality as assessed by the PEDro scale was 6.7, indicating the studies to be of excellent quality; no study in the analysis was classified to be of poor quality.

******INSERT TABLE 2 ABOUT HERE******

Meta-analysis

A pooled analysis of the standardized mean difference for 1RM strength outcomes across the studies showed a benefit favoring HL *vs.* LL (p = 0.006; ES:1.03; 95% CI: 0.37, 1.69; Figure 2) and a benefit favoring HL *vs.* ML (p = 0.012; ES:0.60; 95% CI: 0.17, 1.03; Figure 2). The ML *vs.* LL comparison also showed a benefit for 1RM strength outcomes (p = 0.048; ES: 0.83; 95% CI: 0.01, 1.65) for the higher load. No significant benefit was found for 1RM strength outcomes comparing LL *vs.* VLL (p = 0.079; ES: 0.20; 95% CI: -0.12, 0.52). Sensitivity analysis with outliers omitted did not significantly change findings.

Subanalysis stratifying strength outcomes by body region (upper vs lower) showed little differences between conditions (Table 3). Subanalysis of studies carried to failure *vs.* not to failure showed a significant difference only between HL *vs.* ML (p = 0.049), favoring HL in not to failure condition.

****INSERT FIGURE 2 ABOUT HERE****

A pooled analysis of the standardized mean difference for hypertrophy outcomes across the studies showed no meaningful differences between HL *vs.* LL conditions (p = 0.938; ES: 0.01; 95% CI: -0.30, 0.32; Figure 3), HL *vs.* ML (p = 0.559; ES: 0.04; 95% CI: -

0.12, 0.20), ML *vs.* LL ($p = 0.571$; ES: 0.17; 95% CI: -2.51, 2.84; Figure 3) and LL *vs.* VLL ($p = 0.626$; ES: 0.28; 95% CI: -5.09, 5.65). Sensitivity analysis with outliers omitted did not significantly change findings.

Subanalysis stratifying hypertrophy outcomes by body region (upper *vs.* lower) showed no differences between conditions (Table 3). Subanalysis of studies carried to failure *vs.* not to failure showed a significant difference only between HL *vs.* ML conditions ($p = 0.002$), favoring HL in not to failure condition.

******INSERT FIGURE 3 ABOUT HERE******

******INSERT TABLE 3 ABOUT HERE******

DISCUSSION

The present systematic review and meta-analysis encompassed 20 studies that compared different training loads while matching volume load. The studies were of relatively high quality (PEDro scale = 6.7) and trim and fill analysis did not indicate evidence of significant reporting bias. Results from meta-analysis indicate that when volume load is equated, the highest loads induce superior dynamic strength gains, with the exception of comparisons between low loads and very low loads, which did not show significant differences. Alternatively, no differences were observed between loading conditions for measures of muscle hypertrophy. In addition, subanalysis of studies carried to failure *vs.* not to failure showed a significant difference only between HL *vs.* ML conditions, favoring HL in not to failure condition. We discuss the implications of our findings below.

1RM Strength

The results of our meta-analysis show that when volume load is similar, training with higher loads induces superior increases in 1RM strength compared to using lighter loads. Scrutiny of the forest plot (Figure 1) provides additional support for this conclusion, as 15 of 41 (HL *vs.* LL) and 8 of 22 (HL *vs.* ML) strength measures favored heavier loads training. In contrast, only one strength measure favored the lowest load group (Figure 1A). Hence, the data indicate compelling evidence for the observed effect across the spectrum of loading zones. Moreover, regression analysis showed that results held true irrespective of body region (upper *vs.* lower body). Surprisingly no differences were found for strength gains when VLL and LL were compared. We believe that this finding is a consequence of the low number of studies found (only 2), which limited our statistical power.

Our overall effect size difference for strength gains when comparing HL *vs.* LL was greater than that reported in the meta-analysis by Schoenfeld et al. (2017) (1.03 *vs.* 0.58, respectively), but was similar when comparing HL *vs.* ML (0.60). This difference may be a consequence of the cut-points used to classify loads in the present study, as the HL was composed of studies that contained training protocols with loads above 80% of 1RM, while in the study by Schoenfeld et al. (2017), high loads were considered those >60% of 1RM. The different cut-points used for classification of loads mean that in Schoenfeld et al. (2017) high load condition, studies we classified as ML would be in the same category as those in HL, which differences would have been mitigated, yielding lower ES.

It is noteworthy to mention that the level of effort was not a significant explanatory variable as to changes in strength, with meta regression showing greater strength gains are achieved with the highest loads regardless of whether or not training is carried out to failure.

Our results corroborate findings of the meta-analysis performed by Davies et al. (2016), who reported similar increases in muscle strength between failure and non-failure training. It therefore can be inferred that the magnitude of load is the dominant variable for promoting increases in dynamic strength; training with a very high intensity of effort appears to be of secondary consequence.

Hypertrophy

From a hypertrophy standpoint, a simple pooled meta-analysis showed similar muscle growth irrespective of the magnitude of load when training is carried out under volume-matched conditions. The negligible ES difference (HL *vs.* LL = 0.01 and HL *vs.* ML= 0.04) and narrow corresponding 95% confidence interval (-0.30 to 0.32 and -0.12 to 0.20, respectively) provides strong evidence that loading is not a primary determinant in hypertrophic adaptations. This conclusion is further supported by the forest plots (Figure 2 A and B), which displays a relatively even distribution of point estimates on either side of the line of null effect. It is important to highlight that in the only study that investigated hypertrophy at fiber level there was a difference between HL *vs.* LL. More studies are encouraged to investigate if the specificity of hypertrophy assessment influences the response.

Our findings concur with the meta-analysis of Lopez et al. (2021) and Schoenfeld et al. (2017), and expand on their findings by demonstrating that results hold true when volume is matched for total work. Importantly, however, this inference is specific when comparing moderate (~60% to 80% 1RM) *vs.* lower (≤ 60% 1RM) load training protocols, which was the focus of the previous meta-analysis (Schoenfeld et al., 2017).

A point of interest is whether a minimum loading threshold exists for optimal increases in hypertrophy. In this regard, Lasevicius et al. (2018) reported that increases in muscle CSA are compromised when the magnitude of load is 20% vs 40% 1RM on a work-matched basis. Given previous work showing that the use of 30% 1RM elicits similar hypertrophy compared to higher loading zones (Jenkins et al., 2016, Mitchell et al., 2012, Morton et al., 2016), the findings suggest diminished hypertrophic returns with loads < 30% 1RM. To further investigate this hypothesis, we subanalyzed studies comparing < 30% 1RM (VLL) versus 31% to 59% 1RM (LL) in the low load condition (not displayed); results showed no differences between these conditions (p = 0.626, ES: 0.28, 95% CI: -5.09, 5.65). The lack of significant ES may be a consequence of the low number of studies and consequently a wide 95% CI. However, the scope of research on the topic remains limited and further studies are needed to draw stronger conclusions.

Current theory proposes that the hypertrophic benefits of low-loads are predicated on training to muscular failure. This theory is based on the supposition that a high level of effort is required for maximal recruitment of high-threshold motor units (Morton et al., 2019). Despite having a logical rationale, meta regression showed that intensity of effort did not influence hypertrophic results between loading zones, independently of the comparisons made (LL *vs.* HL; LL *vs.* ML and ML *vs.* HL). The limited direct evidence on the topic seems to support that the need to train closer to failure training becomes increasingly more important when employing low loads (<50% 1RM) (Lasevicius et al., 2019, Nóbrega et al., 2018). However, research on the topic can be considered preliminary and more study is required to draw stronger conclusions.

Study limitations

Our meta-analysis has several limitations that should be taken into consideration when attempting to draw evidence-based conclusions. First, the intervention duration was relatively short in most studies on the topic. The longest study included had a duration of 52 weeks but the others spanned 12 weeks or less; the median of duration was 10 weeks. While this limits extrapolation of findings over longer time periods, it should be noted that research consistently shows such intervention durations are sufficient to observe significant improvements in muscle hypertrophy and strength. Second, the strength results are specific to dynamic 1RM testing that employed exercises similar to that used in the training protocol. Evidence indicates that strength gains are relatively similar between loading zones when testing is carried out under isometric conditions and training volume is set-equated (Schoenfeld et al., 2016). It remains to be determined whether such results would hold true when conditions are work-matched. Third, only one study on the topic included resistance-trained participants (Morton et al., 2019). Given that trained muscle responds differently to mechanical stimuli compared to untrained muscle (Bagley et al., 2020), findings may not necessarily be generalizable to those with resistance training experience. Finally, there is a paucity of data for women and older individuals. Further research in these groups are warranted to gain greater insights into the loading response across populations.

Concluding Remarks

Our findings show that training with higher loads elicits greater gains in 1RM muscle strength when compared to lower loads. Moreover, these results appear to follow a dose-response relationship, with the heaviest of loads providing the greatest strength-related benefit. From a practical standpoint, these results indicate that individuals seeking to optimize dynamic muscular strength should employ the use of heavier loads. That said, evidence shows that strength can be increased even with the use of relatively light loads. Whether these increases are sufficient to optimize athletic performance or activities of daily living would be specific to individual needs and abilities. Moreover, it is not clear how often an individual needs to employ higher loads to achieve maximal strength gains. This topic warrants further study.

Alternatively, those seeking to maximize hypertrophy can choose to train across a wide-spectrum of loading zones. Given that the magnitude of the effect for hypertrophic adaptations is relatively similar to previous meta-analytic data that equated volume by the number of sets (Schoenfeld et al., 2017), matching total work between heavier and lighter load conditions does not yield additional increases in this regard. Individual preference and needs (i.e. musculoskeletal injury, etc.) therefore can guide loading prescription from a hypertrophy standpoint. It should be noted that evidence indicates training with lower loads until to concentric failure induces greater perceived effort, discomfort, discontent, elevated heart rate and blood pressure compared to higher loads (Nóbrega et al., 2018, Ribeiro et al., 2019). These outcomes may influence exercise adherence and thus should be considered in individualized program prescription.

ACKNOWLEDGMENTS

The authors are grateful to CAPES for financial support.

COMPETING INTERESTS

The authors declare that they have no competing interest.

AUTHOR'S CONTRIBUTIONS

LC conceived the idea for the review, performed the searches, data extraction, and methodological quality assessment, as well as drafted the manuscript; RMJ performed the searches, data extraction, and methodological quality assessment, as well drafted the manuscript; JB analyzed the data and critically revised the manuscript content; BJ analyzed the data and drafted the manuscript; JO analyzed the data and critically revised the manuscript content; RB conceived the idea for the review, performed the methodological quality assessment and drafted the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

REFERENCES

2009. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine Science Sports Exercise,* 41**,** 687-708. PMID: 19204579

BAGLEY, J. R., BURGHARDT, K. J., MCMANUS, R., HOWLETT, B., COSTA, P. B., COBURN, J. W., AREVALO, J. A., MALEK, M. H. & GALPIN, A. J. 2020. Epigenetic responses to acute resistance exercise in trained vs. sedentary men. *The Journal of Strength & Conditioning Research,* 34**,** 1574-1580. PMID: 32459413

BARCELOS, L. C., NUNES, P. R. P., DE SOUZA, L. R. M. F., DE OLIVEIRA, A. A., FURLANETTO, R., MAROCOLO, M. & ORSATTI, F. L. 2015. Low-load resistance training promotes muscular adaptation regardless of vascular occlusion, load, or volume. *European journal of applied physiology,* 115**,** 1559-1568. PMID: 25731927.

BEMBEN, D. A., FETTERS, N. L., BEMBEN, M. G., NABAVI, N. & KOH, E. T. 2000. Musculoskeletal responses to high-and low-intensity resistance training in early postmenopausal women. *Medicine Science Sports Exercise,* 32**,** 1949-1957. PMID: 11079527.

CAMPOS, G. E., LUECKE, T. J., WENDELN, H. K., TOMA, K., HAGERMAN, F. C., MURRAY, T. F., RAGG, K. E., RATAMESS, N. A., KRAEMER, W. J. & STARON, R. S. 2002. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. *European journal of applied physiology,* 88**,** 50-60. PMID: 12436270.

CHESTNUT, J. L. & DOCHERTY, D. 1999. The effects of 4 and 10 repetition maximum weight-training protocols on neuromuscular adaptations in untrained men. *The Journal of Strength & Conditioning Research,* 13**,** 353-359. DOI: 10.1519/1533-287(1999)013<0353:TEOARM>2.0.CO;2.

COHEN, J. 1992. A power primer. *Psychological bulletin,* 112**,** 155. PMID: 19565683.

DAVIES, T., ORR, R., HALAKI, M. & HACKETT, D. 2016. Effect of training leading to repetition failure on muscular strength: a systematic review and meta-analysis. *Sports Medicine,* 46**,** 487-502. PMID: 26666744.

DONS, B., BOLLERUP, K., BONDE-PETERSEN, F. & HANCKE, S. 1979. The effect of weight-lifting exercise related to muscle fiber composition and muscle cross-sectional area in humans. *European journal of applied physiology and occupational physiology,* 40, 95-106. PMID: 42837.

FATOUROS, I., TOURNIS, S., LEONTSINI, D., JAMURTAS, A., SXINA, M., THOMAKOS, P., MANOUSAKI, M., DOUROUDOS, I., TAXILDARIS, K. & MITRAKOU, A. 2005. Leptin and adiponectin responses in overweight inactive elderly following resistance training and detraining are intensity related. *The Journal of Clinical Endocrinology & Metabolism,* 90, 5970-5977.

FATOUROS, I. G., KAMBAS, A., KATRABASAS, I., LEONTSINI, D., CHATZINIKOLAOU, A., JAMURTAS, A. Z., DOUROUDOS, I., AGGELOUSIS, N. & TAXILDARIS, K. 2006. Resistance training and detraining effects on flexibility performance in the elderly are intensity-dependent. *The Journal of Strength & Conditioning Research,* 20, 634-642. PMID: 16091494.

GRGIC, J., MIKULIC, P., PODNAR, H. & PEDISIC, Z. 2017. Effects of linear and daily undulating periodized resistance training programs on measures of muscle hypertrophy: a systematic review and meta-analysis. *PeerJ,* 5, e3695. PMID: 28848690.

HARRIS, C., DEBELISO, M. A., SPITZER-GIBSON, T. A. & ADAMS, K. J. 2004. The effect of resistance-training intensity on strength-gain response in the older adult. *The Journal of Strength and Conditioning Research,* 18, 833-838. PMID: 15574091.

HEDGES, L. V., TIPTON, E. & JOHNSON, M. C. 2010. Robust variance estimation in meta-regression with dependent effect size estimates. *Research synthesis methods,* 1, 39-65. PMID: 26056092.

HOLM, L., REITELSEDER, S., PEDERSEN, T. G., DOESSING, S., PETERSEN, S. G., FLYVBJERG, A., ANDERSEN, J. L., AAGAARD, P. & KJAER, M. 2008. Changes in muscle size and MHC composition in response to resistance exercise with heavy and light loading intensity. *Journal of applied physiology,* 105, 1454-1461. PMID: 18787090.

HORTOBAGYI, T., TUNNEL, D., MOODY, J., BEAM, S. & DEVITA, P. 2001. Low-or high-intensity strength training partially restores impaired quadriceps force accuracy and steadiness in aged adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* 56, B38-B47. PMID: 11193224.

JENKINS, N. D., HOUSH, T. J., BUCKNER, S. L., BERGSTROM, H. C., COCHRANE, K. C., HILL, E. C., SMITH, C. M., SCHMIDT, R. J., JOHNSON, G. O. & CRAMER, J. T. 2016. Neuromuscular adaptations after 2 and 4 weeks of 80% versus 30% 1 repetition maximum resistance training to failure. *The Journal of Strength and Conditioning Research,* 30, 2174-2185. PMID: 26848545.

JESSEE, M. B., BUCKNER, S. L., MOUSER, J. G., MATTOCKS, K. T., DANKEL, S. J., ABE, T., BELL, Z. W., BENTLEY, J. P. & LOENNEKE, J. P. 2018. Muscle adaptations to high-load training and very low-load training with and without blood flow restriction. *Frontiers in physiology,* 9, 1448. PMID: 30386254.

KUBO, K., IKEBUKURO, T. & YATA, H. 2020. Effects of 4, 8, and 12 Repetition Maximum Resistance Training Protocols on Muscle Volume and Strength. *The Journal of strength and conditioning research*. PMID: 32304514.

KÜMMEL, J., KRAMER, A., GIBOIN, L.-S. & GRUBER, M. 2016. Specificity of balance training in healthy individuals: a systematic review and meta-analysis. *Sports Medicine,* 46, 1261-1271. PMID: 26993132.

LASEVICIUS, T., SCHOENFELD, B. J., SILVA-BATISTA, C., BARROS, T. D. S., AIHARA, A. Y., BRENDON, H., LONGO, A. R., TRICOLI, V., PERES, B. & TEIXEIRA, E. L. 2019. Muscle Failure Promotes Greater Muscle Hypertrophy in Low-Load but Not in High-Load Resistance Training. *The Journal of strength and conditioning research*. PMID: 31895290.

LASEVICIUS, T., UGRINOWITSCH, C., SCHOENFELD, B. J., ROSCHEL, H., TAVARES, L. D., DE SOUZA, E. O., LAURENTINO, G. & TRICOLI, V. 2018. Effects of different intensities of resistance training with equated volume load on muscle strength and hypertrophy. *European journal of sport science,* 18, 772-780. PMID: 29564973.

LOPES, C. R., AOKI, M. S., CRISP, A. H., DE MATTOS, R. S., LINS, M. A., DA MOTA, G. R., SCHOENFELD, B. J. & MARCHETTI, P. H. 2017. The effect of different resistance training load schemes on strength and body composition in trained men. *Journal of human kinetics,* 58, 177. PMID: 28828088.

LOPEZ, P., RADAELLI, R., TAAFFE, D. R., NEWTON, R. U., GALVÃO, D. A., TRAJANO, G. S., TEODORO, J. L., KRAEMER, W. J., HÄKKINEN, K. & PINTO, R. S. 2021. Resistance training load effects on muscle hypertrophy and strength gain: systematic review and network meta-analysis. *Medicine and science in sports and exercise,* 53, 1206. PMID: 33433148.

MAHER, C. G., SHERRINGTON, C., HERBERT, R. D., MOSELEY, A. M. & ELKINS, M. 2003. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther,* 83, 713-21. PMID: 12882612.

MITCHELL, C. J., CHURCHWARD-VENNE, T. A., WEST, D. W., BURD, N. A., BREEN, L., BAKER, S. K. & PHILLIPS, S. M. 2012. Resistance exercise load does not determine training-mediated hypertrophic gains in young men. *Journal of applied physiology,* 113, 71-77. PMID: 22518835.

MOEYAERT, M., UGILLE, M., NATASHA BERETVAS, S., FERRON, J., BUNUAN, R. & VAN DEN NOORTGATE, W. 2017. Methods for dealing with multiple outcomes in meta-analysis: a comparison between averaging effect sizes, robust variance estimation and multilevel meta-analysis. *International Journal of Social Research Methodology,* 20, 559-572. PMID: 22518835.

MORRIS, S. B. 2008. Estimating effect sizes from pretest-posttest-control group designs. *Organizational research methods,* 11, 364-386.

MORTON, R. W., SONNE, M. W., FARIAS ZUNIGA, A., MOHAMMAD, I. Y., JONES, A., MCGLORY, C., KEIR, P. J., POTVIN, J. R. & PHILLIPS, S. M. 2019. Muscle fibre activation is unaffected by load and repetition duration when resistance exercise is performed to task failure. *The Journal of physiology,* 597**,** 4601-4613. PMID: 31294822.

NÓBREGA, S. R., UGRINOWITSCH, C., PINTANEL, L., BARCELOS, C. & LIBARDI, C. A. 2018. Effect of resistance training to muscle failure vs. volitional interruption at high-and low-intensities on muscle mass and strength. *The Journal of Strength anda Conditioning Research,* 32**,** 162-169. PMID: 29189407.

OGASAWARA, R., LOENNEKE, J. P., THIEBAUD, R. S. & ABE, T. 2013. Low-load bench press training to fatigue results in muscle hypertrophy similar to high-load bench press training. *International Journal of Clinical Medicine,* 4**,** 114. DOI: 10.4236/ijcm.2013.42022 .

PRUITT, L. A., TAAFFE, D. R. & MARCUS, R. 1995. Effects of a one-year high-intensity versus low-intensity resistance training program on bone mineral density in older women. *Journal of Bone and Mineral Research,* 10**,** 1788-1795. PMID: 8592957.

RIBEIRO, A. S., DOS SANTOS, E. D., NUNES, J. P. & SCHOENFELD, B. J. 2019. Acute Effects of Different Training Loads on Affective Responses in Resistance-trained Men. *International journal of sports medicine,* 40**,** 850-855. PMID: 3149956.

SCHOENFELD, B. J., CONTRERAS, B., VIGOTSKY, A. D. & PETERSON, M. 2016. Differential effects of heavy versus moderate loads on measures of strength and hypertrophy in resistance-trained men. *Journal of sports science & medicine,* 15**,** 715. PMID: 27928218.

SCHOENFELD, B. J., GRGIC, J., OGBORN, D. & KRIEGER, J. W. 2017. Strength and hypertrophy adaptations between low-vs. high-load resistance training: a systematic review and meta-analysis. *The Journal of Strength and Conditioning Research,* 31**,** 3508-3523. PMID: 28834797.

SCHOENFELD, B. J., PETERSON, M. D., OGBORN, D., CONTRERAS, B. & SONMEZ, G. T. 2015. Effects of low-vs. high-load resistance training on muscle strength and hypertrophy in well-trained men. *The Journal of Strength and Conditioning Research,* 29**,** 2954-2963. PMID: 25853914.

SCHOENFELD, B. J., RATAMESS, N. A., PETERSON, M. D., CONTRERAS, B., SONMEZ, G. & ALVAR, B. A. 2014. Effects of different volume-equated resistance training loading strategies on muscular adaptations in well-trained men. *The Journal of Strength and Conditioning Research,* 28**,** 2909-2918. PMID: 24714538.

TAAFFE, D., PRUITT, L., PYKA, G., GUIDO, D. & MARCUS, R. 1996. Comparative effects of high-and low-intensity resistance training on thigh muscle strength, fiber area, and tissue composition in elderly women. *Clinical Physiology,* 16**,** 381-392. PMID: 8842574.

TANNER-SMITH, E. E., TIPTON, E. & POLANIN, J. R. 2016. Handling complex meta-analytic data structures using robust variance estimates: A tutorial in R. *Journal of Developmental and Life-Course Criminology,* 2**,** 85-112.

VINCENT, K. R., BRAITH, R. W., FELDMAN, R. A., MAGYARI, P. M., CUTLER, R. B., PERSIN, S. A., LENNON, S. L., MD, A. H. G. & LOWENTHAL, D. T. 2002. Resistance exercise and physical performance in adults aged 60 to 83. *Journal of the American Geriatrics Society,* 50**,** 1100-1107. PMID: 12110072

Study	Subjects	Design	Hypertrophy measurement	Strengh measurement	Findings
Campos et al., 2002	32 untrained young men (5 served as controls)	Random assignment to either 3–5 RM, 9–11 RM or 20–28 RM exercises. Exercise consisted of 2–4 sets of squat, leg press and leg extension, performed 2 d/wk for the first 4 wks and 3 days/wk for the final 4 wks.	Biopsy/CSA	1RM in leg press, squat and leg extension.	Significant increases in CSA for 3–5 RM and 9–11 RM group; no significant increase in CSA for 20–28 RM. Significantly greater increases in strength for 3–5 vs. 9–11 RM and 20–28 RM.
Lasevicius et al., 2018	30 untrained young men	Within-subject design whereby	Ultrasound imaging/CSA	1RM in leg press and	Significant increases in muscle strength and

Table 1: Methodological characteristics and results of all included articles

		one leg and arm were set at 20% 1RM for all participants (G20). The contralateral limb was randomly assigned to one of the three possible conditions: 40% 1RM; 60% 1RM, and 80% 1RM. G20 consisted of 3 sets of elbow flexion and leg press exercise. After G20 training, the number of sets was adjusted for the contralateral limb conditions with volume-matched. Subjects trained 2 d/wk for 12 wks.		elbow flexion.	CSA for all protocols. Significantly greater increases in CSA for 80% of 1RM vs. 20%; Strength increase for elbow flexion significantly greater in 80% 1RM vs 20, 40 and 60% of 1RM. Strength increase for leg press significantly greater in 60 and 80% of 1RM conditions vs 20 and 40% of 1RM.
Schoenfeld et al., 2014	17 resistance-trained men	Random assignment to 3 sets of 10 RM or 7 sets of 3RM. Training consisted of 3 exercises targeting the anterior torso muscles, 3 exercises targeting the posterior torso	Ultrasound imaging/ MT	1RM in bench press and back squat	Significant increases in MT and 1RM occurred from pre- to post testing for both groups. No significant differences noted in MT between groups. Significant strength differences favoring of heavier load condition for the 1RM

		muscles, and 3 exercises targeting the thigh musculature, performed 3 d/wk for 8 wks.			bench press and a trend for greater increases in the 1RM squat.
Jesse et al., 2018	20 untrained men and women	Within-subject, counter-balanced randomization of lower legs to 15% 1RM and 70% 1RM. Protocol consisted of 4 sets of unilateral knee extension performed 2d/wk for 8 wks.	Ultrasound imaging/ MT	1RM in knee extension	Strength increased only 70% 1RM. Significant increases in MT for both groups without significant between-group differences.
Jenkins et al., 2016	15 untrained young men	Random assignment to either 80% 1RM or 30% 1RM. Protocol consisted of 3 sets of forearm flexion performed 3 d/wk for 4 wks.	Ultrasound imaging/ MT	1RM in forearm flexion	Similar increases in MT for 80 vs. 30% 1RM, but only 80% 1RM increased muscle strength.
Holm et al., 2008	11 untrained young men	Within-subject design with random assignment to both 70% 1RM and 15.5% 1RM. Protocol consisted of 10 sets of unilateral knee	MRI/CSA	1RM in knee extension	CSA increased in both protocols, with a greater gain in 70% 1RM. Strength increased in both conditions, with a greater gain in 70% 1RM.

		extensions performed 3 d/wk for 12 wks. The 15.5% 1RM condition performed 36 repetitions per set (one repetition every 5th s for 3 min) and 70% 1RM performed 8 repetitions per set.			
Dons et al., 1979	18 young males (6 served as controls)	Random assignment to either 80% 1RM or 50% 1RM. 50% condition performed 20 repetitions per set of knee extension exercise while 80% group performed 12 repetitions. Training carried out 3 d/wk for 7 wks.	Ultrasound imaging/CSA	1RM knee extension	Strength increased only in 80% 1RM. Significant increases in CSA for 80% 1RM and 50% 1RM, with no significant difference between groups.
Barcelos et al., 2015	28 untrained young men (8 served as controls).	Random assignment to 1 set at 20% 1RM or 3 sets at 50% 1RM. Protocol consisted of unilateral leg extension carried	MRI/CSA	1RM in leg extension	CSA and strength increased in all groups, with no differences between groups.

		out 2 d/wk for 8 wks.			
Chestnut et al., 1999	24 untrained young men (5 served as controls).	Random assignment to 6 sets of 4RM or 3 sets of 10RM. Protocol consisted of triceps bench press, triceps pulley press-down, standing biceps barbell curl, and standing dumbbell curl performed 3 d/wk for 10 wks.	MRI/ CSA	1RM in triceps bench press and biceps curl.	CSA and strength increased in all groups, with no differences noted among groups.
Taaffe et al., 1996	25 untrained old women, 11 - served as control.	Randomly assignment to 3 sets of 14 repetitions at 40% 1RM or 3 sets of 7 rep at 80% 1RM. Protocol consisted of leg press, knee extension and knee flexion, exercise performed 3 d/wk week for 52 wks.	Biopsy/CSA	1RM in leg press, knee extension and knee flexion.	CSA and strength increased in all groups, with no differences noted among groups.
Kubo et al., 2020	42 untrained young men, 10 served as control.	Random assignment to 7 sets of 4RM or 4 sets of 8RM or 3 sets of 12RM. Protocol consisted	MRI/muscle volume	1RM in bench press	Muscle volume increased in all groups, with no differences between groups. Strength increased in all

		of bench press exercise performed 2 d/wk for 10 wks.		groups, with lower increases in the 12RM condition.
Lasevicius et al., 2019	25 untrained young men	Within-subject design whereby each lower limb was allocated to 1 of 4 unilateral knee extension protocols: repetitions to failure with 30% 1RM ; repetitions to failure with 80% 1RM ; repetitions not to failure with 30% 1RM ; and repetitions not to failure with 80% 1RM. All protocols were performed 2 d/wk for 8 wks	1RM/knee extension	Quadriceps CSA increased significantly for high-load to failure and not to failure, and low-load to failure, whereas no significant changes were observed in the low-load not to failure. Strength incre ased in all conditions and cha nges were significantly higher for high-load to failure and not to failure when compared with the low-load to failure and low-load not to failure.
Vincent et al. 2002	46 untrained older men	Random assignment to 1 set of 13 repetitions at 50% 1RM or 1 set of 8 repetitions at 80% 1RM. Protocol consisted of 12 exercises performed 3 d/wk for 24 wks.	1RM/ chest press, leg press, leg curl, biceps curl, seated row, overhead press, triceps dip and leg	Strength increased in all groups, with no differences noted among groups

				extension.	
Lopes et al. 2017	16 resistance trained men	Random assignment to 6 sets of 10RM group or a 3 sets of 20RM group, consisted of 8 exercises performed 4d/wk for 6 wks.		1 RM in Bench Press and Squat	Strength increased in all groups, with no differences between the groups.
Harris et al. 2004	61 untrained older men and women. 14 served as control.	Random assignment to 4 sets of 6RM group, 3 sets of 9RM group or 2 sets of 15RM group, performed 8 resistance exercises 2d/wk for 18-week		sum 1RM biceps curl, triceps extension, lat pull down, shoulder press, and bench press and sum 1RM knee extension, leg press, and leg curl	Strength increased in all groups, with no differences noted among groups.
Bemben et al. 2000.	25 untrained older women. 8 served as control.	Random assignment to 3 sets of 8 rep at 80% 1RM or 3 sets of 16 reps at 40% 1RM. Performed 8 resistance exercises 3d/wk for 24-week	Ultrasound imaging/CSA – rectus femoris and biceps brachii	1 RM in biceps curl, latissimus pull, seated row, shoulder press, triceps, hamstrings, leg press, quadriceps,	CSA increased in all groups, with no differences between groups. There were no significant differences between the groups for the strength. Only the 80% 1RM protocol resulted in significant increases

			hip abduction, hip adduction, hip extension, hip flexion.	in shoulder press, quadriceps, and hip flexion strength. Neither training group exhibited significant improvements in biceps curl, triceps extension, or hip abduction strength.
Fatouros et al. 2005	50 untrained older men. 10 served as control.	Random assignment to 80-85%1RM 8 rep 3 sets: 60-65% 1RM 10 rep 3 sets; 45-50% 1RM 14 reps 3 sets. Performed 8 resistance exercises 3d/wk for 24-week	1RM in lat pull down and leg extension.	Leg strength increased in exercise groups after training, with 80-85%1RM inducing greater gains than the other groups, and 60-65% 1RM being more effective than 45-50% 1RM . Trunk strength increased in all exercise groups, with 80-85%1RM demonstrating greater improvement than the other groups, and 60-65% 1RM being more effective than 45-50% 1RM .
Fatouros et al. 2006	58 untrained older men. 10 served as control.	Random assignment to: 80-85% 1RM 8 rep 3 sets; 60-65% 1RM 10 rep 3 sets; 45-50% 1RM 14 reps 3 sets. Performed 8 resistance	1RM in chest press and leg press.	Leg strength increased in exercise groups after training, with 80-85%1RM inducing greater gains than the other groups, and 60-65%1RM being more effective than 45-

		exercises 3d/wk for 24-week		50%1RM. Trunk strength increased in all exercise groups, with 80-85%1RM demonstrating greater improvement than the other groups, and 60-65%1RM being more effective than 45-50%1RM .
Hortobágyi et al. 2001	27 untrained older men. 9 served as control.	Random assignment to 5 sets of 4-6 rep at 80% 1RM or 5 sets of 8-12 reps at 40% 1RM. Performed 1 resistance exercise 3d/wk for 10-week	1RM in leg press supine position	Strength increased in all groups, with no differences noted among groups.
Pruitt et al. 1995	27 untrained older women. 11 served as control.	Random assignment to 2 sets of 7 rep at 80% 1RM; or 3 sets of 14 reps at 40% 1RM. Performed 10 exercises, 3d/wk for 36-week.	1RM in bench press; military press; biceps curl; lat pull down; back extension; leg abduction plus leg adduction; leg press plus knee extension and flexion	Strength gains for the 80%1RM and 40%1RM groups were statistically similar in 6 of 7 muscle groups. Change in arm muscular strength, however, was significantly greater in the 40%1RM group compared with the 80%1RM group.

CSA = cross sectional area; MT = muscle thickness; MRI = magnetic resonance imaging; 1RM= maximal dynamic strength.

Table 2: The methodological quality assessment by the modified PEDro scale.

Study	2	3	4	8	9	10	11
Campos et al. 2002	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lasevicius et al., 2018	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shoenfeld et al. ,2014	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Jesse et al., 2018	Yes	Yes	No	Yes	Yes	Yes	Yes
Jenkins et al., 2016	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Holm et al., 2008	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dons et al., 1979	Yes	Yes	Yes	No	Yes	No	Yes
Barcelos et al., 2015	Yes	Yes	Yes	No	Yes	Yes	Yes
Chestnut et al.,1999	Yes	Yes	Yes	No	Yes	Yes	Yes
Taafee et al., 1996	Yes	Yes	Yes	No	Yes	Yes	Yes
Kubo et al., 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lasevicius et al., 2019	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Vincent et al., 2002	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lopes et al. 2017	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Harris et al. 2004	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bemben et al. 2000	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fatouros et al. 2005	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fatouros et al. 2006	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hortobágyi et al. 2001	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pruitt et al. 1995	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Outcome	Comparison	Covariate	Estimate (C.I. 95%)	p-value	Difference	p-value
Strength	HL *vs.* LL	Lower limbs	0.98 (0.27, 1.7)	0.014		
		Upper limbs	1.11 (0.05, 2.18)	0.044	0.13 (-0.75, 1.01)	0.747
		Failure	1.11 (0.57, 1.66)	0.008		
		Not failure	1.00 (-0.05, 2.04)	0.059	-0.12 (-1.29, 1.05)	0.809
	HL *vs.* ML	Lower limbs	0.58 (0.05, 1.1)	0.035		
		Upper limbs	0.64 (-0.05, 1.33)	0.061	0.07 (-0.58, 0.71)	0.813
		Failure	0.33 (-0.04, 0.7)	0.071		
		Not failure	1.19 (0.03, 2.35)	0.048	0.86 (0, 1.71)	0.049
	ML *vs.* LL	Lower limbs	0.87 (0, 1.73)	0.049		
		Upper limbs	0.78 (-0.68, 2.24)	0.188	-0.09 (-1.31, 1.14)	0.852
		Failure	0.41 (-0.41, 1.23)	0.166		
		Not failure	1.48 (-2.28, 5.25)	0.125	1.08 (-0.3, 2.46)	0.081
Muscle hypertrophy	HL *vs.* LL	Lower limbs	0.12 (-0.28, 0.53)	0.428		
		Upper limbs	-0.21 (-1.16, 0.74)	0.411	-0.33 (-1.11, 0.44)	0.273
		Failure	0.11 (-0.31, 0.53)	0.458		
		Not failure	-0.15 (-1.06, 0.76)	0.542	-0.26 (-1, 0.48)	0.372
		Fiber	0.51 NC[a]	<0.001		
		Muscle	-0.07 (-0.37, 0.24)	0.556	-0.58 (-0.88, -0.28)	0.007
	HL vs ML	Lower limbs	0.18 (-0.26, 0.61)	0.205		
		Upper limbs	-0.04 (-0.22, 0.14)	0.539	-0.21 (-0.56, 0.13)	0.150
		Failure	0.01 (-0.15, 0.16)	0.930		
		Not failure	0.43 NC[a]		0.42 (0.26, 0.58)	0.002
		Fiber	0.25 (-1.23, 1.73)	0.278		
		Muscle	-0.04 (-0.19, 0.12)	0.493	-0.29 (-0.9, 0.32)	0.166

Table 3: Subgroup analysis for the robust variance meta regression.

[a]The 95% confidence interval could not be calculated because only one study contributed in this subgroup.

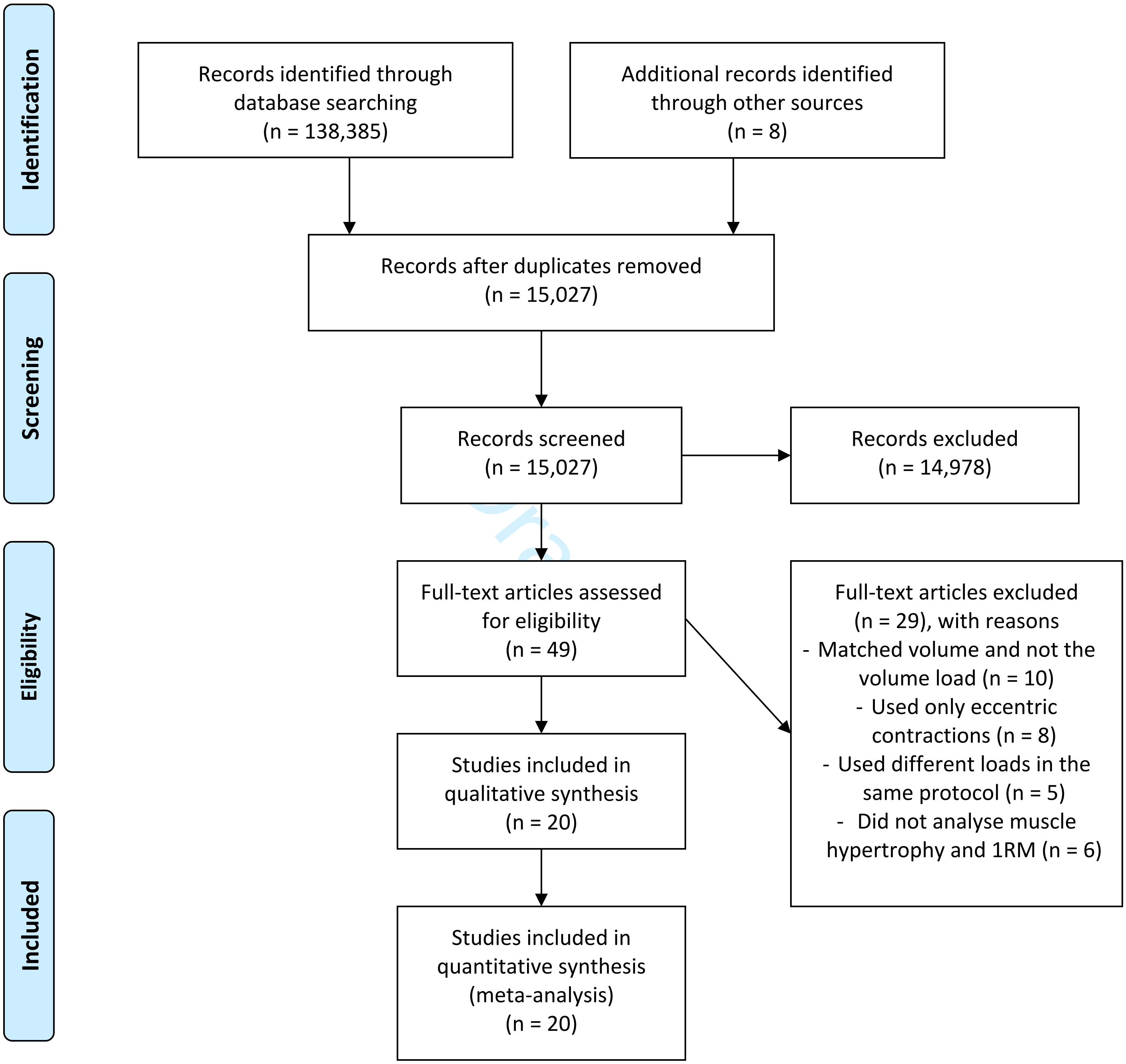
Figure Captions

Figure 1: PRISMA Flow diagram

Figure 2: Forest plots for 1RM strength differences between conditions. (A) HL vs LL; (B) HL vs ML; (C) ML vs LL. Abbreviations: HL = high load; ML = moderate load; LL = light load

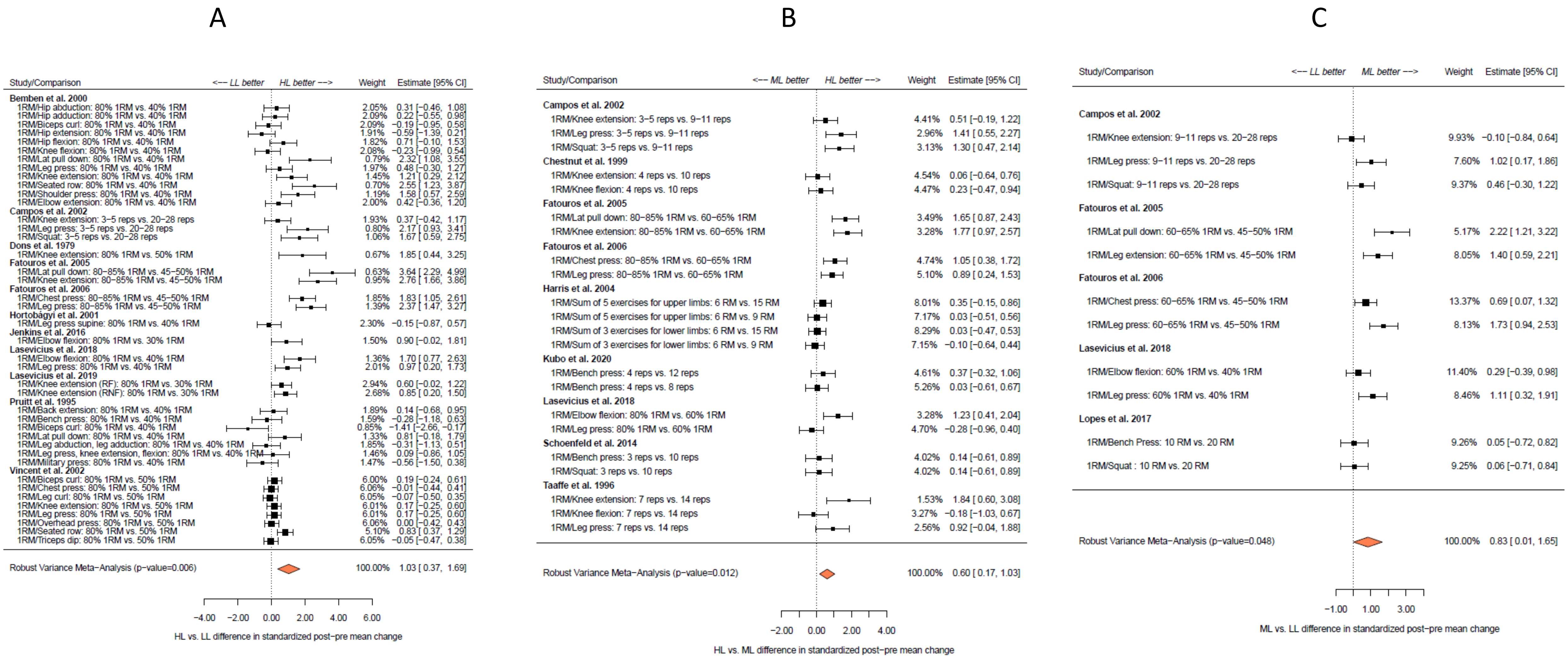
Figure 3: Forest plots for hypertrophy differences between conditions. (A) HL vs LL; (B) HL vs ML; (C) ML vs LL. Abbreviations: HL = high load; ML = moderate load; LL = light load

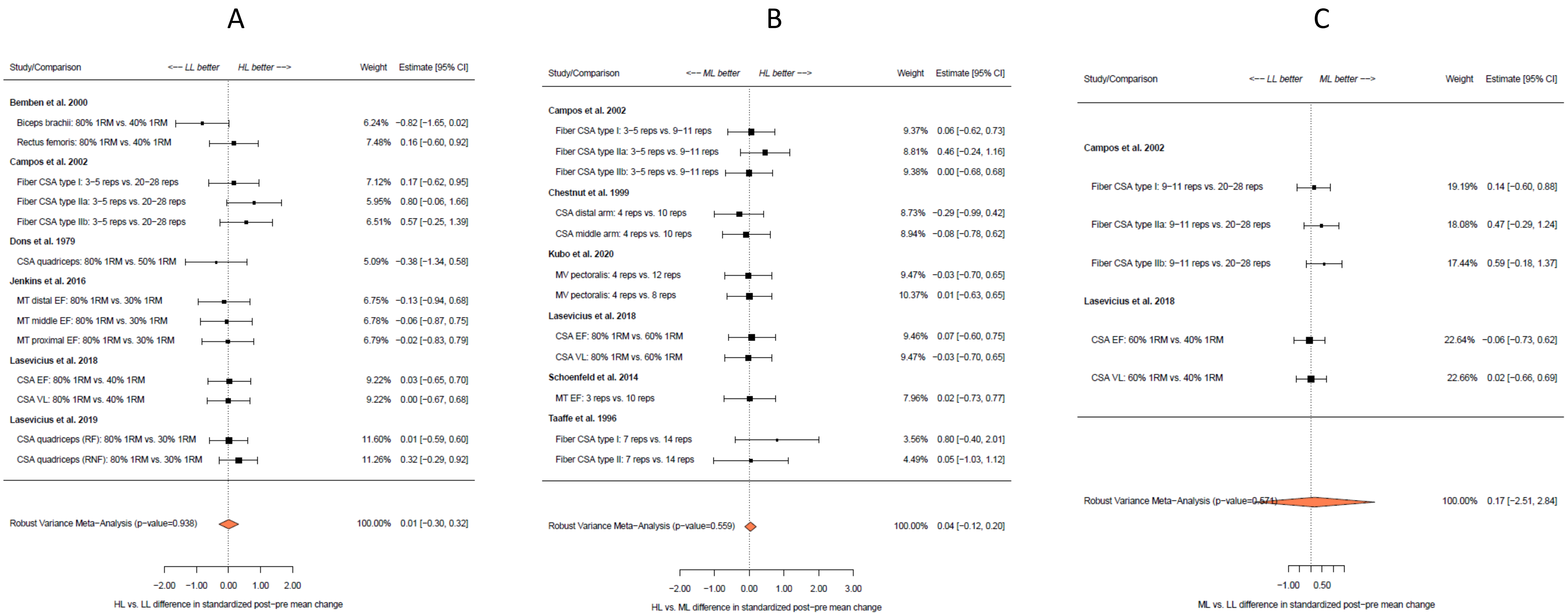
PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.


A
Study/Comparison
<-- LL better
HL better -->
Weight
Estimate [95% CI]
Bemben et al. 2000
1RM/Hip abduction: 80% 1RM vs. 40% 1RM 2.05% 0.31 [−0.46, 1.08]
1RM/Hip adduction: 80% 1RM vs. 40% 1RM 2.09% 0.22 [−0.55, 0.98]
1RM/Biceps curl: 80% 1RM vs. 40% 1RM 2.09% −0.19 [−0.95, 0.58]
1RM/Hip extension: 80% 1RM vs. 40% 1RM 1.91% −0.59 [−1.39, 0.21]
1RM/Hip flexion: 80% 1RM vs. 40% 1RM 1.82% 0.71 [−0.10, 1.53]
1RM/Knee flexion: 80% 1RM vs. 40% 1RM 2.08% −0.23 [−0.99, 0.54]
1RM/Lat pull down: 80% 1RM vs. 40% 1RM 0.79% 2.32 [1.08, 3.55]
1RM/Leg press: 80% 1RM vs. 40% 1RM 1.97% 0.48 [−0.30, 1.27]
1RM/Knee extension: 80% 1RM vs. 40% 1RM 1.45% 1.21 [0.29, 2.12]
1RM/Seated row: 80% 1RM vs. 40% 1RM 0.70% 2.55 [1.23, 3.87]
1RM/Shoulder press: 80% 1RM vs. 40% 1RM 1.19% 1.58 [0.57, 2.59]
1RM/Elbow extension: 80% 1RM vs. 40% 1RM 2.00% 0.42 [−0.36, 1.20]
Campos et al. 2002
1RM/Knee extension: 3−5 reps vs. 20−28 reps 1.93% 0.37 [−0.42, 1.17]
1RM/Leg press: 3−5 reps vs. 20−28 reps 0.80% 2.17 [0.93, 3.41]
1RM/Squat: 3−5 reps vs. 20−28 reps 1.06% 1.67 [0.59, 2.75]
Dons et al. 1979
1RM/Knee extension: 80% 1RM vs. 50% 1RM 0.67% 1.85 [0.44, 3.25]
Fatouros et al. 2005
1RM/Lat pull down: 80−85% 1RM vs. 45−50% 1RM 0.63% 3.64 [2.29, 4.99]
1RM/Knee extension: 80−85% 1RM vs. 45−50% 1RM 0.95% 2.76 [1.66, 3.86]
Fatouros et al. 2006
1RM/Chest press: 80−85% 1RM vs. 45−50% 1RM 1.85% 1.83 [1.05, 2.61]
1RM/Leg press: 80−85% 1RM vs. 45−50% 1RM 1.39% 2.37 [1.47, 3.27]
Hortobágyi et al. 2001
1RM/Leg press supine: 80% 1RM vs. 40% 1RM 2.30% −0.15 [−0.87, 0.57]
Jenkins et al. 2016
1RM/Elbow flexion: 80% 1RM vs. 30% 1RM 1.50% 0.90 [−0.02, 1.81]
Lasevicius et al. 2018
1RM/Elbow flexion: 80% 1RM vs. 40% 1RM 1.36% 1.70 [0.77, 2.63]
1RM/Leg press: 80% 1RM vs. 40% 1RM 2.01% 0.97 [0.20, 1.73]
Lasevicius et al. 2019
1RM/Knee extension (RF): 80% 1RM vs. 30% 1RM 2.94% 0.60 [−0.02, 1.22]
1RM/Knee extension (RNF): 80% 1RM vs. 30% 1RM 2.68% 0.85 [0.20, 1.50]
Pruitt et al. 1995
1RM/Back extension: 80% 1RM vs. 40% 1RM 1.89% 0.14 [−0.68, 0.95]
1RM/Bench press: 80% 1RM vs. 40% 1RM 1.59% −0.28 [−1.18, 0.63]
1RM/Biceps curl: 80% 1RM vs. 40% 1RM 0.85% −1.41 [−2.66, −0.17]
1RM/Lat pull down: 80% 1RM vs. 40% 1RM 1.33% 0.81 [−0.18, 1.79]
1RM/Leg abduction, leg adduction: 80% 1RM vs. 40% 1RM 1.85% −0.31 [−1.13, 0.51]
1RM/Leg press, knee extension, flexion: 80% 1RM vs. 40% 1RM 1.46% 0.09 [−0.86, 1.05]
1RM/Military press: 80% 1RM vs. 40% 1RM 1.47% −0.56 [−1.50, 0.38]
Vincent et al. 2002
1RM/Biceps curl: 80% 1RM vs. 50% 1RM 6.00% 0.19 [−0.24, 0.61]
1RM/Chest press: 80% 1RM vs. 50% 1RM 6.06% −0.01 [−0.44, 0.41]
1RM/Leg curl: 80% 1RM vs. 50% 1RM 6.05% −0.07 [−0.50, 0.35]
1RM/Knee extension: 80% 1RM vs. 50% 1RM 6.01% 0.17 [−0.25, 0.60]
1RM/Leg press: 80% 1RM vs. 50% 1RM 6.01% 0.17 [−0.25, 0.60]
1RM/Overhead press: 80% 1RM vs. 50% 1RM 6.06% 0.00 [−0.42, 0.43]
1RM/Seated row: 80% 1RM vs. 50% 1RM 5.10% 0.83 [0.37, 1.29]
1RM/Triceps dip: 80% 1RM vs. 50% 1RM 6.05% −0.05 [−0.47, 0.38]
Robust Variance Meta−Analysis (p−value=0.006) 100.00% 1.03 [0.37, 1.69]
−4.00 −2.00 0.00 2.00 4.00 6.00
HL vs. LL difference in standardized post−pre mean change
B
Study/Comparison
<-- ML better
HL better -->
Weight
Estimate [95% CI]
Campos et al. 2002
1RM/Knee extension: 3−5 reps vs. 9−11 reps 4.41% 0.51 [−0.19, 1.22]
1RM/Leg press: 3−5 reps vs. 9−11 reps 2.96% 1.41 [0.55, 2.27]
1RM/Squat: 3−5 reps vs. 9−11 reps 3.13% 1.30 [0.47, 2.14]
Chestnut et al. 1999
1RM/Knee extension: 4 reps vs. 10 reps 4.54% 0.06 [−0.64, 0.76]
1RM/Knee flexion: 4 reps vs. 10 reps 4.47% 0.23 [−0.47, 0.94]
Fatouros et al. 2005
1RM/Lat pull down: 80−85% 1RM vs. 60−65% 1RM 3.49% 1.65 [0.87, 2.43]
1RM/Knee extension: 80−85% 1RM vs. 60−65% 1RM 3.28% 1.77 [0.97, 2.57]
Fatouros et al. 2006
1RM/Chest press: 80−85% 1RM vs. 60−65% 1RM 4.74% 1.05 [0.38, 1.72]
1RM/Leg press: 80−85% 1RM vs. 60−65% 1RM 5.10% 0.89 [0.24, 1.53]
Harris et al. 2004
1RM/Sum of 5 exercises for upper limbs: 6 RM vs. 15 RM 8.01% 0.35 [−0.15, 0.86]
1RM/Sum of 5 exercises for upper limbs: 6 RM vs. 9 RM 7.17% 0.03 [−0.51, 0.56]
1RM/Sum of 3 exercises for lower limbs: 6 RM vs. 15 RM 8.29% 0.03 [−0.47, 0.53]
1RM/Sum of 3 exercises for lower limbs: 6 RM vs. 9 RM 7.15% −0.10 [−0.64, 0.44]
Kubo et al. 2020
1RM/Bench press: 4 reps vs. 12 reps 4.61% 0.37 [−0.32, 1.06]
1RM/Bench press: 4 reps vs. 8 reps 5.26% 0.03 [−0.61, 0.67]
Lasevicius et al. 2018
1RM/Elbow flexion: 80% 1RM vs. 60% 1RM 3.28% 1.23 [0.41, 2.04]
1RM/Leg press: 80% 1RM vs. 60% 1RM 4.70% −0.28 [−0.96, 0.40]
Schoenfeld et al. 2014
1RM/Bench press: 3 reps vs. 10 reps 4.02% 0.14 [−0.61, 0.89]
1RM/Squat: 3 reps vs. 10 reps 4.02% 0.14 [−0.61, 0.89]
Taaffe et al. 1996
1RM/Knee extension: 7 reps vs. 14 reps 1.53% 1.84 [0.60, 3.08]
1RM/Knee flexion: 7 reps vs. 14 reps 3.27% −0.18 [−1.03, 0.67]
1RM/Leg press: 7 reps vs. 14 reps 2.56% 0.92 [−0.04, 1.88]
Robust Variance Meta−Analysis (p−value=0.012) 100.00% 0.60 [0.17, 1.03]
−2.00 0.00 2.00 4.00
HL vs. ML difference in standardized post−pre mean change
C
Study/Comparison
<-- LL better
ML better -->
Weight
Estimate [95% CI]
Campos et al. 2002
1RM/Knee extension: 9−11 reps vs. 20−28 reps 9.93% −0.10 [−0.84, 0.64]
1RM/Leg press: 9−11 reps vs. 20−28 reps 7.60% 1.02 [0.17, 1.86]
1RM/Squat: 9−11 reps vs. 20−28 reps 9.37% 0.46 [−0.30, 1.22]
Fatouros et al. 2005
1RM/Lat pull down: 60−65% 1RM vs. 45−50% 1RM 5.17% 2.22 [1.21, 3.22]
1RM/Leg extension: 60−65% 1RM vs. 45−50% 1RM 8.05% 1.40 [0.59, 2.21]
Fatouros et al. 2006
1RM/Chest press: 60−65% 1RM vs. 45−50% 1RM 13.37% 0.69 [0.07, 1.32]
1RM/Leg press: 60−65% 1RM vs. 45−50% 1RM 8.13% 1.73 [0.94, 2.53]
Lasevicius et al. 2018
1RM/Elbow flexion: 60% 1RM vs. 40% 1RM 11.40% 0.29 [−0.39, 0.98]
1RM/Leg press: 60% 1RM vs. 40% 1RM 8.46% 1.11 [0.32, 1.91]
Lopes et al. 2017
1RM/Bench Press: 10 RM vs. 20 RM 9.26% 0.05 [−0.72, 0.82]
1RM/Squat : 10 RM vs. 20 RM 9.25% 0.06 [−0.71, 0.84]
Robust Variance Meta−Analysis (p−value=0.048) 100.00% 0.83 [0.01, 1.65]
−1.00 1.00 3.00
ML vs. LL difference in standardized post−pre mean change


A
Study/Comparison
<-- LL better
HL better -->
Weight
Estimate [95% CI]
Bemben et al. 2000
Biceps brachii: 80% 1RM vs. 40% 1RM 6.24% −0.82 [−1.65, 0.02]
Rectus femoris: 80% 1RM vs. 40% 1RM 7.48% 0.16 [−0.60, 0.92]
Campos et al. 2002
Fiber CSA type I: 3−5 reps vs. 20−28 reps 7.12% 0.17 [−0.62, 0.95]
Fiber CSA type IIa: 3−5 reps vs. 20−28 reps 5.95% 0.80 [−0.06, 1.66]
Fiber CSA type IIb: 3−5 reps vs. 20−28 reps 6.51% 0.57 [−0.25, 1.39]
Dons et al. 1979
CSA quadriceps: 80% 1RM vs. 50% 1RM 5.09% −0.38 [−1.34, 0.58]
Jenkins et al. 2016
MT distal EF: 80% 1RM vs. 30% 1RM 6.75% −0.13 [−0.94, 0.68]
MT middle EF: 80% 1RM vs. 30% 1RM 6.78% −0.06 [−0.87, 0.75]
MT proximal EF: 80% 1RM vs. 30% 1RM 6.79% −0.02 [−0.83, 0.79]
Lasevicius et al. 2018
CSA EF: 80% 1RM vs. 40% 1RM 9.22% 0.03 [−0.65, 0.70]
CSA VL: 80% 1RM vs. 40% 1RM 9.22% 0.00 [−0.67, 0.68]
Lasevicius et al. 2019
CSA quadriceps (RF): 80% 1RM vs. 30% 1RM 11.60% 0.01 [−0.59, 0.60]
CSA quadriceps (RNF): 80% 1RM vs. 30% 1RM 11.26% 0.32 [−0.29, 0.92]
Robust Variance Meta−Analysis (p−value=0.938) 100.00% 0.01 [−0.30, 0.32]
−2.00 −1.00 0.00 1.00 2.00
HL vs. LL difference in standardized post−pre mean change
B
Study/Comparison
<-- ML better
HL better -->
Weight
Estimate [95% CI]
Campos et al. 2002
Fiber CSA type I: 3−5 reps vs. 9−11 reps 9.37% 0.06 [−0.62, 0.73]
Fiber CSA type IIa: 3−5 reps vs. 9−11 reps 8.81% 0.46 [−0.24, 1.16]
Fiber CSA type IIb: 3−5 reps vs. 9−11 reps 9.38% 0.00 [−0.68, 0.68]
Chestnut et al. 1999
CSA distal arm: 4 reps vs. 10 reps 8.73% −0.29 [−0.99, 0.42]
CSA middle arm: 4 reps vs. 10 reps 8.94% −0.08 [−0.78, 0.62]
Kubo et al. 2020
MV pectoralis: 4 reps vs. 12 reps 9.47% −0.03 [−0.70, 0.65]
MV pectoralis: 4 reps vs. 8 reps 10.37% 0.01 [−0.63, 0.65]
Lasevicius et al. 2018
CSA EF: 80% 1RM vs. 60% 1RM 9.46% 0.07 [−0.60, 0.75]
CSA VL: 80% 1RM vs. 60% 1RM 9.47% −0.03 [−0.70, 0.65]
Schoenfeld et al. 2014
MT EF: 3 reps vs. 10 reps 7.96% 0.02 [−0.73, 0.77]
Taaffe et al. 1996
Fiber CSA type I: 7 reps vs. 14 reps 3.56% 0.80 [−0.40, 2.01]
Fiber CSA type II: 7 reps vs. 14 reps 4.49% 0.05 [−1.03, 1.12]
Robust Variance Meta−Analysis (p−value=0.559) 100.00% 0.04 [−0.12, 0.20]
−2.00 −1.00 0.00 1.00 2.00 3.00
HL vs. ML difference in standardized post−pre mean change
C
Study/Comparison
<-- LL better
ML better -->
Weight
Estimate [95% CI]
Campos et al. 2002
Fiber CSA type I: 9−11 reps vs. 20−28 reps 19.19% 0.14 [−0.60, 0.88]
Fiber CSA type IIa: 9−11 reps vs. 20−28 reps 18.08% 0.47 [−0.29, 1.24]
Fiber CSA type IIb: 9−11 reps vs. 20−28 reps 17.44% 0.59 [−0.18, 1.37]
Lasevicius et al. 2018
CSA EF: 60% 1RM vs. 40% 1RM 22.64% −0.06 [−0.73, 0.62]
CSA VL: 60% 1RM vs. 40% 1RM 22.66% 0.02 [−0.66, 0.69]
Robust Variance Meta−Analysis (p−value=0.571) 100.00% 0.17 [−2.51, 2.84]
−1.00 0.50
ML vs. LL difference in standardized post−pre mean change