Strength and Hypertrophy Adaptations Between Low- vs. High-Load Resistance Training: A Systematic Review and Meta-analysis

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Abstract

Schoenfeld, BJ, Grgic, J, Ogborn, D, and Krieger, JW. Strength and hypertrophy adaptations between low- vs. high-load resistance training: a systematic review and meta-analysis. *J Strength Cond Res* 31(12): 3508–3523, 2017—The purpose of this article was to conduct a systematic review of the current body of literature and a meta-analysis to compare changes in strength and hypertrophy between low- vs. high-load resistance training protocols. Searches of PubMed/MEDLINE, Cochrane Library, and Scopus were conducted for studies that met the following criteria: (a) an experimental trial involving both low-load training [≤60% 1 repetition maximum (1RM)] and high-load training (>60% 1RM); (b) with all sets in the training protocols being performed to momentary muscular failure; (c) at least one method of estimating changes in muscle mass or dynamic, isometric, or isokinetic strength was used; (d) the training protocol lasted for a minimum of 6 weeks; (e) the study involved participants with no known medical conditions or injuries impairing training capacity. A total of 21 studies were ultimately included for analysis. Gains in 1RM strength were significantly greater in favor of high- vs. low-load training, whereas no significant differences were found for isometric strength between conditions. Changes in measures of muscle hypertrophy were similar between conditions. The findings indicate that maximal strength benefits are obtained from the use of heavy loads while muscle hypertrophy can be equally achieved across a spectrum of loading ranges.

Key Words heavy loading, light loading, muscle mass, muscle strength, repetition maximum continuum

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Introduction

Current resistance training (RT) guidelines profess that loads in excess of 70% 1 repetition maximum (RM) are required to maximize adaptations in muscular strength and hypertrophy (2). Similarly, the so-called "RM continuum" purports that gains in muscular strength are optimal with loads of 1–5RM and hypertrophic gains are best achieved with loads of 6–12RM (5). These recommendations are predicated on the belief that heavy loads are necessary to recruit the highest threshold motor units (MUs) responsible for promoting maximal muscular adaptations.

It remains debatable as to whether lighter load training is capable of recruiting the entire MU pool during a given set of repetitions. Prevailing research indicates that muscle fiber recruitment follows the size principle, which dictates that the smallest MUs are recruited first during a given movement with successively larger MUs engaged as force production requirements increase (21). Although this would seem to support the need for heavy loads to maximize muscular adaptations, some researchers have alternatively postulated that training with intensities as low as 30% 1RM will ultimately result in complete MU recruitment provided sets are carried out to momentary muscular failure (8,10).

Surface electromyography (sEMG) studies consistently show lower mean electrical amplitudes when training at low (<50% 1RM) vs. high (>70% 1RM) intensities of load, even when sets are carried out to muscular failure (24,41). Conversely, others have demonstrated comparable peak EMG amplitudes between high- and low-load training, and moderate- and high-load training, and such discrepant findings may result from differing methods of analysis through the time-course of a set to failure (18,40). It should be noted that sEMG amplitude is not only a function of recruitment but also includes factors such as rate coding (firing frequency), synchronization (simultaneous discharge of MUs), propagation velocity (speed at which an action potential travels along the membrane of a muscle fiber), and intracellular

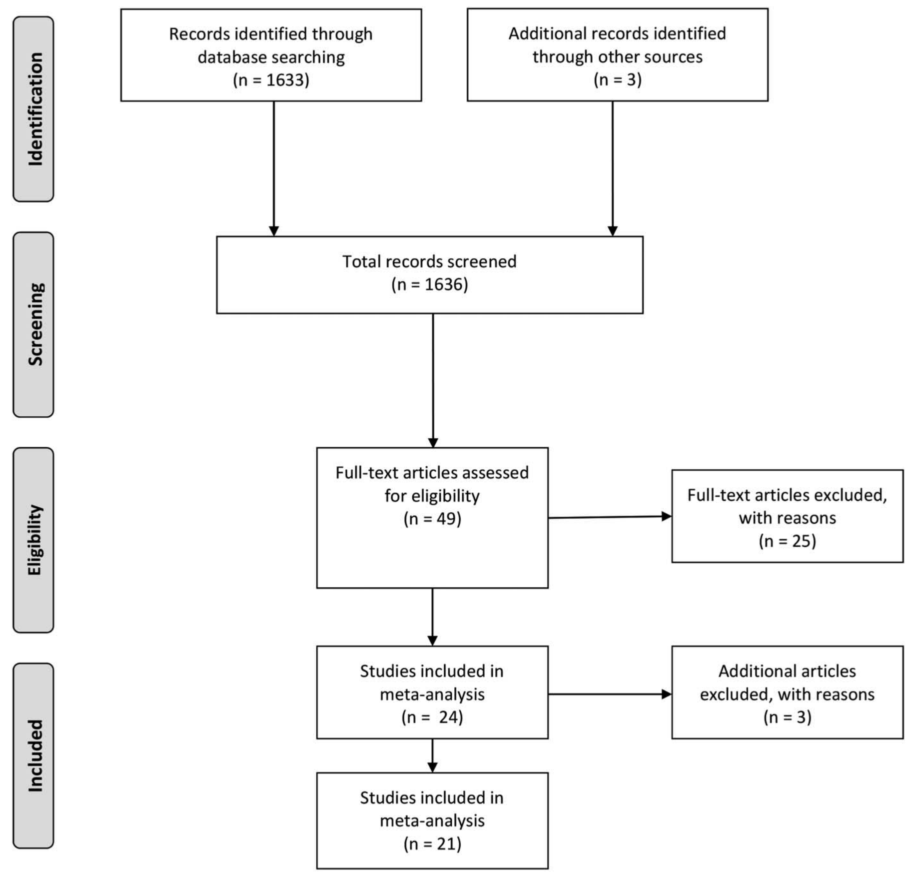

Figure 1. Flow diagram of search process.

action potentials (6,12). These factors, in turn, can be influenced by exercise-induced fatigue, thus potentially confounding the ability to draw inferences as to the effects of loading intensity from EMG findings. Moreover, it has been posited that MUs may momentarily de-recruit and re-recruit (MU "cycling") throughout a light-load set of repetitions to maintain force output (16), thereby altering the magnitude of sEMG amplitude. Importantly, the level of sEMG amplitude does not necessarily correlate with long-term exercise-induced increases in strength and hypertrophy, and thus, conclusions must be tempered in the context of these limitations.

Ultimately, determination of causality on the topic requires longitudinal studies that directly investigate the effects of RT using low vs. high loads. A meta-analysis of such trials by Schoenfeld et al. (43) concluded that both high- and low-load training produced significant increases in both muscle strength and hypertrophy, but noted that statistical probability favored the heavier load conditions for both outcomes. At the time of that search (December 2013), only 9 studies met inclusion criteria, limiting statistical power of the analysis. Subsequently, there have been a number of additional studies published on the topic (4,14,15,32), providing a greater ability to draw practical inferences and carry out subanalysis of potential covariates. Therefore, the purpose of this article was to conduct a systematic review of the current body of literature and a meta-analysis to compare changes in strength and hypertrophy between low- vs. high-load RT protocols.

Methods

Inclusion Criteria

Our analysis was confined to studies published in English-language peer-reviewed journals that met the following criteria: (a) an experimental trial involving both low-load training (≤60% 1RM) and high-load training (>60% 1RM); (b) with all sets in the training protocols being performed to momentary muscular failure; (c) at least one method of estimating changes in muscle mass or dynamic, isometric, or isokinetic strength was used; (d) the training protocol lasted for a minimum of 6 weeks; (e) the study involved participants with no known medical conditions or injuries impairing training capacity. As some studies reported loading as the number

TABLE 1. Overview of studies meeting inclusion criteria.*

Study	Participants' characteristics	Comparison groups [sets × repetition (rest interval duration†)]	Tempo (concentric-isometric-eccentric)	Volume equated?	Duration of intervention; weekly training frequency	Resistance training exercise(s)	Hypertrophy/strength measurement	Findings
Aagaard et al. (1)	Young untrained men (n = 22)	High load: 4 × 8RM Low load: 4 × 16RM‡ Low load: 4 × 24RM Non-exercising control group‡	Not reported	No	12 wks; 3×	Knee extension	Isokinetic knee extension Isokinetic knee flexion	Significant preintervention to postintervention increases in strength only in the high-load group
Anderson et al. (3)	Young untrained men (n = 43)	High load: 3 × 6–8RM Low load: 2 × 30–40RM Low load: 1 × 100–150RM	Not reported	Yes	9 wks; 3×	Bench press	1RM bench press	Significant preintervention to postintervention increases in strength in all groups Significantly greater increases in strength in the high-load vs. low-load groups
Au et al. (4)	Young trained men (n = 46)	High load: 3 × 8–12RM (1 min) Low load: 3 × 20–25RM (1 min) Non-exercising control group‡	Not reported	No	12 wks; 4×	Seated row, bench press, front plank, machine-guided shoulder press, bicep curls, triceps extension, wide grip pull-downs, inclined leg press, cable hamstring curl, machine-guided knee extension	BOD-POD 1RM bench press 1RM leg press	Significant preintervention to postintervention increases in lean body mass, upper- and lower-body strength in both exercising groups, with significant between-group differences only in 1RM bench press strength for high-load vs low-load group

Campos et al. (9)	Young untrained men (n = 32)	High load: 4 × 3–5RM (3 min)	Not reported	Yes	8 wks; 2–3×	Squat, leg press, knee extension	Biopsy	Significant preintervention to postintervention increases in CSA only for the high-load groups
		High load: 3 × 9–11RM (2 min)					1RM squat	Significantly greater increases in muscle strength in the high-load vs. low-load group
		Low load: 2 × 20–28RM (1 min)					1RM leg press	
		Non-exercising control group†					1RM knee extension	
Fink et al. (15)	Young untrained men (n = 21)	High load: 3 × 8–12RM (90 s)	1-0-2 for all groups	No	8 wks; 3×	Unilateral biceps preacher curl	MRI	Significant preintervention to postintervention increases in CSA in all groups, with no significant between-group differences
		Low load: 3 × 30–40RM (90 s)					MVC	Significantly greater increases in muscle strength in the high-load vs. low-load group
		Mixed high- and low-load group: 4 wks of 3 × 8–12RM and 4 wks of 3 × 30–40RM (90 s)‡						
Fink et al. (14)	Young untrained men (n = 20)	High load: 3 × 8RM (3 min)	1-0-2 for both groups	No	8 wks; 3×	Barbell curl, preacher curl, hammer curl, close grip bench press, French press, dumbbell extension	MRI	Significant preintervention to postintervention increases in CSA in both groups, with no significant between-group differences
		Low load: 3 × 20RM (30 s)					MVC	Significantly greater increases in muscle strength in the high-load vs. low-load group
Fisher et al. (17)	Young untrained men (n = 7)	High load: 3 × 80% MVT (2 min) Low load: 3 × 50% MVT (2 min)	2-1-3 for both groups	No	6 wks; 1×	Knee extension	MVT	Significant preintervention to postintervention increases in strength for both groups, with no significant between-group differences

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Hisaeda et al. (22)	Young untrained woman (n = 11)	High load: 8–9 × 5RM ("sufficient") Low load: 5–6 × 15RM (90 s)	Fast as possible	Yes	8 wks; 3×	Knee extension	MRI MVC	Significant preintervention to postintervention increases in CSA and strength for both groups, with no significant between-group differences
Kerr et al. (25)	Untrained middle-aged woman (n = 46)	High load: 3 × 8RM (2–3 min)	Not reported	No	1 year; 3×	Hip extension, hip flexion, hip abduction, hip adduction, leg press, wrist curl, reverse wrist curl, wrist pronation/supination, biceps curl, triceps press-down	1RM hip extension 1RM hip flexion 1RM hip abduction 1RM hip adduction 1RM leg press 1RM wrist curl 1RM reverse wrist curl 1RM wrist pronation/supination 1RM biceps curl 1RM triceps press-down	Significant preintervention to postintervention increases in strength for both groups, with no significant between-group differences
Mitchell et al. (29)	Young untrained men (n = 18)	High load: 3 × 80%RM	Not reported	No	10 wks; 3×	Unilateral knee extension	MRI	Significant preintervention to postintervention increases in CSA for all groups, with no significant between-group differences
		High load: 1 × 80% 1RM‡ Low load: 3 × 30% 1RM					Biopsy 1RM knee extension MVC	Significant preintervention to postintervention increases in strength for all groups, with significantly greater increases in 1RM muscle strength in the high-load vs. low-load group

Morton et al. (32)	Young trained men (n = 49)	High load: 3 × 8–12RM (1 min)	Not reported	No	12 wks; 4×	Seated row, bench press, front plank, machine-guided shoulder press, bicep curls, triceps extension, wide grip pull-downs, inclined leg press, cable hamstring curl, machine-guided knee extension	DEXA	Significant preintervention to postintervention increases in CSA and lean body mass for all groups, with no significant between-group differences
		Low load: 3 × 20–25RM (1 min)					Biopsy 1RM bench press 1RM leg press 1RM shoulder press 1RM knee extension	
Ogasawara et al. (36)	Young untrained men (n = 9)	High load: 3 × 75% 1RM (3 min)	1-0-1 for both groups	No	6 wks; 3×	Bench press	MRI 1RM bench press	Significant preintervention to postintervention increases in CSA for all groups, with no significant between-group differences
		Low load: 4 × 30% 1RM (3 min)					MVC	Significant preintervention to postintervention increases in strength for all groups, with significantly greater increases in strength in the high-load vs. low-load group
Popov et al. (37)	Young untrained men (n = 18)	High load: 3 and 7 × 80% MVC (10 min)	Not reported	No	8 wks; 3×	Leg press	MRI	Significant preintervention to postintervention increases in CSA and strength for all groups, with no significant between-group differences
		Low load: 1 and 4 × 50% MVC (10 min)					MVC	

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Rana et al. (38)	Young untrained females (n = 34)	High load: 3 × 6–10RM High load low velocity: 3 × 6–10RM‡ Low load: 3 × 20–30RM Non-exercising control group‡	1-0-2 for high- and low-load groups	No	6 wks; 2–3×	Leg press, back squat (Smith machine), and knee extension	BOD-POD 1RM squat 1RM leg press 1RM knee extension	Significant preintervention to postintervention increases in lean body mass for all groups, with no significant between-group differences
Schoenfeld et al. (42)	Young trained men (n = 18)	High load: 3 × 8–12RM	1-0-2 for both groups	No	8 wks; 3×	Bench press, barbell military press, wide grip pull-downs, seated cable row, barbell back squat, machine leg press, and machine knee	Ultrasound	Significant preintervention to postintervention increases in muscle thickness in both groups, with no significant between-group differences
		Low load: 3 × 25–35RM				Extension	1RM bench press 1RM squat	Significantly greater increases in 1RM squat strength in the high-load vs. low-load group
Schuenke et al. (44) §	Young untrained females (n = 34)	High load: 3 × 6–10RM High load low velocity: 3 × 6–10RM‡ Low load: 3 × 20–30RM Non-exercising control group‡	1-0-2 for high- and low-load groups	No	6 wks; 2–3×	Leg press, back squat (Smith machine), and knee extension	Skinfolds	No significant preintervention to postintervention differences in lean body mass
Stone and Coulter (45)	Young untrained females (n = 50)	High load: 3 × 6–8RM (2–3 min) Low load: 2 × 15–20RM (2–3 min) Low load: 1 × 30–40RM (2–3 min)	Not reported	Yes	9 wks; 3×	Bench press, triceps push-down, arm curl, lat pull-down, squat	1RM bench press 1RM squat	Significant preintervention to postintervention increases in strength in all groups, with no significant between-group differences

Tanimoto and Ishii (46)	Young untrained men (n = 24)	High load: 3 × 80% 1RM (1 min)	1-1-1 for the high- and low-load groups	No	12 wks; 3×	Knee extension	MRI	Significant preintervention to postintervention increases in CSA and MVC strength only in the high-load group
		Low load low velocity: 3 × 50% 1RM (1 min)‡	3-0-3 for the low-load, low-velocity group				1RM knee extension	Significant preintervention to postintervention increases in 1RM knee extension strength in all groups, with no significant between-group differences
		Low load: 3 × 50% 1RM (1 min)					MVC	
Tanimoto et al. (47)	Young untrained men (n = 36)	High load: 3 × 80% 1RM (1 min)	1-1-1 for the high-load group	No	13 wks; 2×	Chest press, lat pull-down, abdominal bend, and back extension, squat	Ultrasound	Significant preintervention to postintervention increases in muscle thickness, lean body mass, and strength in both groups, with no significant between-group differences
		Low load: 3 × 55–60% 1RM (1 min)	3-0-3 for the low-load group				DEXA	
		Non-exercising control group‡					1RM squat 1RM chest press 1RM lat pull-down 1RM abdominal bend 1RM back extension	
Van Roie et al. (50)	Young untrained men (n = 21) and women (n = 15)	High load: 1 × 10–12RM	1-0-2 for both groups	No	9 wks; 3×	Knee extension	1RM knee extensions	Significant preintervention to postintervention increases in 1RM strength in all groups
		Low load: 1 × 60RM + 10–20RM					MVC	Significantly greater increases in 1RM strength in the high-load vs. low-load groups
		Low load: 1 × 10–12 with 40% 1RM‡					Isokinetic knee extension	Significant preintervention to postintervention increases in MVC only for the high-load group Significant preintervention to postintervention increases in isokinetic strength only for the low-load group

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Van Roie et al. (51)	Untrained older men (n = 26) and women (n = 30)	High load: 2 × 10–15RM (2 min)	2-0-3 for all groups	No	12 wks; 3×	Leg press and knee extension	CT	Significant preintervention to postintervention increases in CSA for all groups, with no significant between-group differences
		Low load: 1 × 80–100RM					1RM knee extension	Significantly greater increases in 1RM strength in the high- and low-load+ vs. low-load group; significant preintervention to postintervention increases in MVC strength for all groups, with no significant between-group differences
		Low load: 1 × 60RM + 10–20RM					1RM leg press MVC Isokinetic knee extension	Significant preintervention to postintervention increases in isokinetic strength only for the high-load group

*RM = repetition maximum; BOD-POD = air displacement plethysmography; CSA = cross-sectional area; MRI = magnetic resonance imaging; MVC = maximal voluntary contraction; MVT = maximal voluntary torque; DEXA = dual-energy x-ray absorptiometry; CT = computed tomography.

†Not all studies reported rest interval duration.

‡The group was not included in the meta-analysis.

§The same data as in the study by Rana et al. (38).

of repetitions, rather than a percentage of 1RM, all repetitions up to 15RM were considered as high load, whereas repetitions >15RM were considered as low load.

Search Strategy

The systematic literature search of English-language journals was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (30). Searches of PubMed/MEDLINE, Cochrane Library, and Scopus were conducted from inception of indexing to March 2017. The following syntax was used to carry out the search: muscle hypertrophy AND muscle strength AND (skeletal muscle OR resistance training OR cross-sectional area OR growth OR training intensity OR training load OR high load OR low load OR muscle fibers OR loading OR muscle thickness OR bodybuilding OR fitness). The reference lists of articles retrieved in the search were subsequently perused for any additional articles that had potential applicability to the topic as outlined by Greenhalgh and Peacock (19). Forward citation tracking of the studies meeting the inclusion criteria was performed in Google Scholar. To reduce the potential for selection bias, each of these studies were independently perused by 2 of the investigators (B.J.S. and J.G.), and a mutual decision was made as to whether they met basic inclusion criteria. Any interreviewer disagreements were settled by consensus or consultation with the third investigator (D.O.).

Of the studies initially reviewed, 49 were determined to be potentially relevant to the topic based on information contained in the abstracts. Full text of these articles were then screened and 24 studies were regarded as suitable for inclusion based on the criteria outlined. Attempts were made to contact the authors of a given study in the case that relevant data were missing. Three studies (27,53,54) had to be omitted from analysis because of lack of adequate data, hence leaving 21 studies for analysis. Figure 1 shows a flow chart of the literature search. Table 1 summarizes the studies included for analysis.

Coding of Studies

Studies were read and individually coded by 2 of the investigators (B.J.S. and J.G.) for the following variables: (a) authors, title, and year of publication; (b) participant information, such as sample size, gender, age, and training status. For age, the following classification was used: participants aged 18–39 years are classified as young adults, participants aged 40–64 years are classified as middle-aged adults, and participants aged 65 years and older are classified as older adults. Training status was categorized as in the study by Schoenfeld et al. (43); (c) description of the training intervention, including duration, the intensity of load, weekly training frequency, RT exercises, and where reported, the tempo, and rest interval length; (d) methods used for the assessment of hypertrophy. Methods of measurement were classified as direct (magnetic resonance imaging, computerized tomography, and ultrasound), indirect (skinfolds, dual-energy x-ray absorptiometry, and air displacement plethysmography) and in vitro (i.e., biopsy); (e) test(s) used for assessing strength outcomes [isokinetic knee extension and/or flexion, maximal voluntary contraction and/or maximal dynamic strength (i.e., 1RM)]; (f) region/muscle of body measured (upper, lower, or both); (g) preintervention and postintervention mean ± *SD* values related to hypertrophy and strength outcomes; (h) reported adverse effects and adherence to the training program. Coding files were cross-checked between the authors, with discussion and agreement required for any observed differences. To prevent the potential for coder drift, we randomly selected 30% of the studies for recoding as outlined by Cooper et al. (11). Per case agreement was determined by dividing the number of variables coded the same by the total number of variables. Acceptance required a mean agreement of 90%.

Methodological Quality

The quality of each study was independently assessed by 2 of the authors (J.G. and B.J.S.), and agreement was mutually determined for any observed discrepancies. Study quality was evaluated by use of the 11-point Physiotherapy Evidence Database (PEDro) scale, which has been shown to be a valid measure of the methodologic quality of randomized trials (13) and displays acceptable interrater reliability (33). Given that the assessors are rarely blinded, and that is impossible to blind the participants and investigators, in supervised exercise interventions, we elected to remove items 5–7 from the scale, which are specific to blinding. With the removal of these items, the maximum result on the modified PEDro 8-point scale was 7 (i.e., the first item is not included in the total score). The qualitative methodology ratings were adjusted similar to that used in previous exercise-related systematic reviews (26) as follows: 6–7 = "excellent"; 5 = "good"; 4 = "moderate"; and, 0–3 = "poor."

Calculation of Effect Size

For each hypertrophy outcome, an effect size (ES) was calculated as the pretest-posttest change, divided by the pooled pretest *SD* (31). A percentage change from pretest to posttest was also calculated. An adjustment for small sample bias was applied to each ES (31). The variance around each ES was calculated using the sample size in each study and mean ES across all studies (7).

Statistical Analyses

A random-effects model was employed using robust variance meta-regression for multilevel data structures, with adjustments for small samples (20,49). Study was used as the clustering variable to account for correlated effects within studies. Observations were weighted by the inverse of the sampling variance. Model parameters were estimated by the method of restricted maximum likelihood (48). Separate meta-regressions were performed on ESs for 1RM, isometric strength, isokinetic strength, body composition, direct assessments of muscle size, and muscle fiber size via biopsy. Load classification (high or low) was included as a moderator

TABLE 2. Impact of training load on strength and hypertrophy.*

Outcome	Load	ES	95% CI	p value for difference	Equivalent percentage gain (%)
1RM	High	1.69 ± 0.23	1.25–2.14	0.003	35.3 ± 4.3
	Low	1.32 ± 0.23	0.87–1.76		28.0 ± 4.8
Isometric strength	High	0.64 ± 0.24	0.06–1.22	0.43	22.6 ± 6.3
	Low	0.55 ± 0.18	0.10–1.00		20.5 ± 5.7
Isokinetic strength	Insufficient studies for analysis				
Lean body mass	Insufficient studies for analysis				
Muscle hypertrophy	High	0.53 ± 0.10	0.30–0.76	0.10	8.3 ± 1.5
	Low	0.42 ± 0.08	0.23–0.60		7.0 ± 1.2

*ES = effect size; CI = confidence interval; RM = repetition maximum.

in all regression models. To assess the practical significance of the outcomes, the equivalent percent change was calculated for each meta-regression outcome. To allow generation of a forest plot, mean differences in ESs were calculated for each study to give a study-level ES, and a meta-regression was performed on those ESs. To explore whether an interaction existed between training load and upper- or lower-body muscle groups, separate regressions were performed on training load and its interaction with body half (upper or lower) if sufficient data were available.

To identify the presence of highly influential studies that might bias the analysis, a sensitivity analysis was carried out for each model by removing one study at a time and then examining the training load predictor. Studies were identified as influential if removal resulted in a change of the predictor going from significant or a trend ($p \leq 0.10$) to nonsignificant ($p > 0.10$), or vice versa, or if removal caused a large change in the magnitude of the coefficient.

All analyses were performed using package metafor in R version 3.3.2 (The R Foundation for Statistical Computing, Vienna, Austria). Effects were considered significant at $p \leq 0.05$, and trends were declared at $0.05 < p \leq 0.10$.

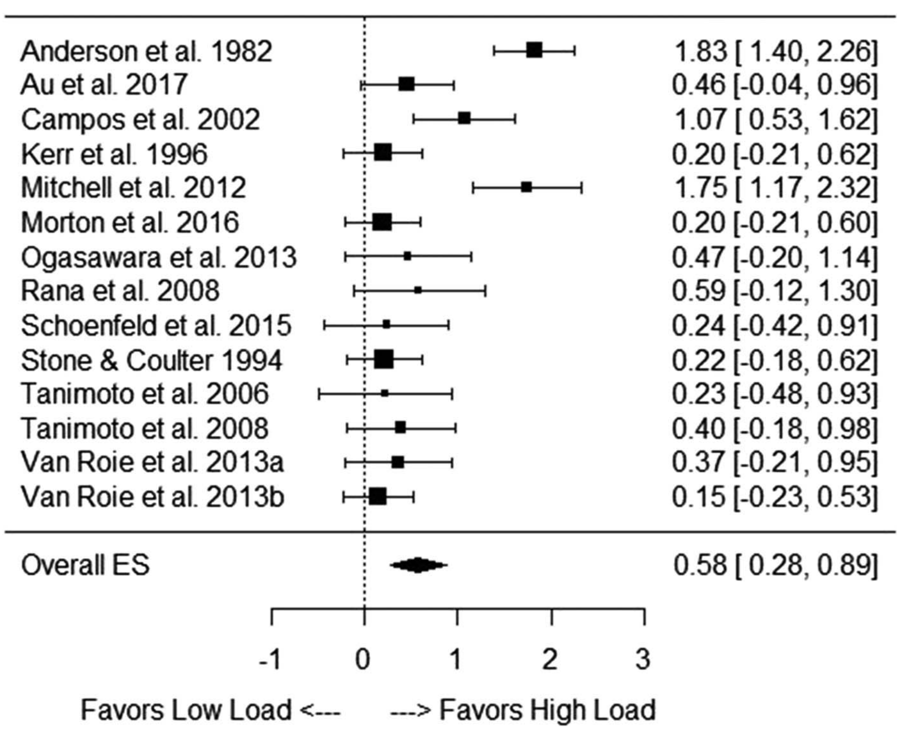

Figure 2. Forest plot of studies comparing changes in 1RM strength in high- vs. low-load training. The data shown are mean ± 95% CI; the size of the plotted squares reflects the statistical weight of each study. CI = confidence interval; ES = effect size; RM = repetition maximum.

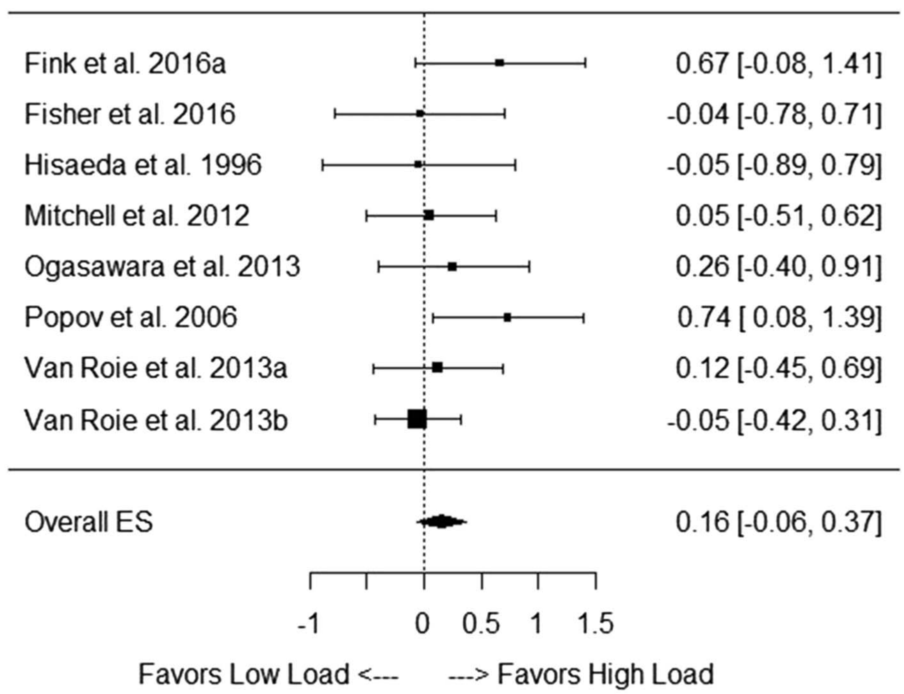

Figure 3. Forest plot of studies comparing changes in isometric strength in high- vs. low-load training. The data shown are mean ± 95% CI; the size of the plotted squares reflects the statistical weight of each study. CI = confidence interval; ES = effect size.

Data are reported as mean ± *SEM* and 95% confidence intervals (CIs).

Results

Results of all outcomes are presented in Table 2. The mean rating of study quality as assessed by the PEDro scale was 5.6, indicating the pool of studies to be of good to excellent quality; no study in the analysis was deemed to be of poor quality.

One Repetition Maximum

The final analysis comprised 84 ESs from 14 studies. The mean ES across all studies was 1.50 ± 0.23 (CI: 1.01–1.99). The mean percent change was 31.6 ± 4.5% (CI: 22.0–41.2). There was a significant difference in mean ES between high and low loads (Δ = −0.37 ± 0.10; CI: −0.59 to −0.16; $p = 0.003$), with high load resulting in a greater mean ES and percentage gain (Table 2). Study level analysis revealed an ES that significantly favored high loads (ES = 0.58 ± 0.16; CI: 0.28–0.89; $p = 0.002$; Figure 2). There was no interaction between training load and the half of the body trained ($p = 0.69$). Sensitivity analyses did not reveal any influential studies.

Isometric Strength

The final analysis comprised 23 ESs from 8 studies. The mean ES across all studies was 0.60 ± 0.19 (CI: 0.15–1.05). The mean percent change was 21.5 ± 5.3% (CI: 8.9–34.2). There was no significant difference in mean ES between high and low loads (Δ = −0.09 ± 0.10; CI: −0.34 to 0.17; $p = 0.43$; Table 2). Study level analysis showed no significant impact of load (ES = 0.16 ± 0.11; CI: −0.10 to 0.41; $p = 0.19$; Figure 3). There was insufficient data to examine the interaction between training load and the half of the body trained. Sensitivity analysis revealed one influential study. Removal of the study by Van Roie et al. (51) changed the magnitude of the nonsignificant difference between high and low loads (Δ = −0.24 ± 0.13; CI: −0.57 to 0.08; $p = 0.11$).

Isokinetic Strength

There were 41 isokinetic strength ESs from 4 studies. There was an insufficient number of studies to model the impact of loading on isokinetic strength.

Lean Body Mass

There were 14 body composition ESs from 5 studies. There was an insufficient number of studies to model the impact of loading on lean mass changes.

Muscle Hypertrophy

The final analysis comprised 41 ESs from 10 studies. The mean ES across all studies was 0.47 ± 0.08 (CI: 0.28–0.65). The mean percent change was 7.6 ± 1.2% (CI: 4.9–10.4). There was a trend toward a difference in mean ES between

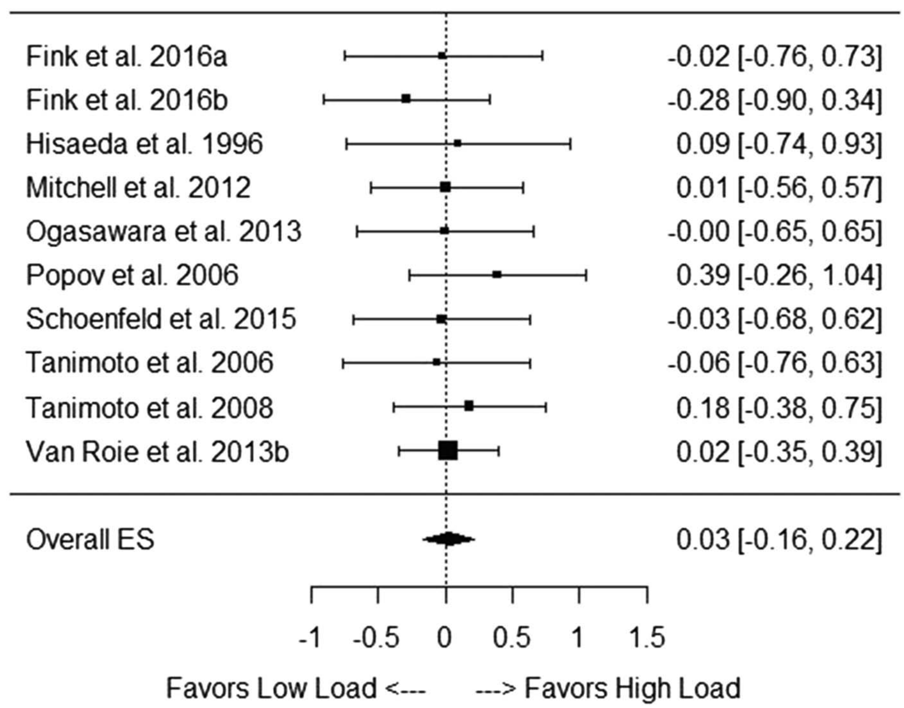

Figure 4. Forest plot of studies comparing changes in muscle hypertrophy in high- vs. low-load training. The data shown are mean ± 95% CI; the size of the plotted squares reflects the statistical weight of each study. CI = confidence interval; ES = effect size.

high and low loads ($\Delta = -0.11 \pm 0.06$; CI = −0.24 to 0.03; $p = 0.10$), with high load being slightly greater than low loads (Table 2). However, study level analysis showed no impact of load (ES = 0.03 ± 0.05; CI: −0.08 to 0.14; $p = 0.56$; Figure 4). There was no interaction between training load and half of the body trained ($p = 0.46$). Sensitivity analyses revealed 5 influential studies (Table 3). Removal of each of the 3 most influential studies (37,47,51) resulted in nonsignificant p-values ($p = 0.22$–0.46) along with decreases in the ES difference between high and low loads ($\Delta = -0.06$ to -0.09).

Table 3. Sensitivity analyses for hypertrophy.*

Study removed	Δ ES between high and low loads	95% CI	p value for difference
None	−0.11 ± 0.06	−0.24 to 0.03	0.10
Fink et al. (15)	−0.13 ± 0.05	−0.25 to 0.00	0.04
Hisaeda et al. (22)	−0.11 ± 0.06	−0.25 to 0.03	0.11
Popov et al. (37)	−0.08 ± 0.06	−0.23 to 0.07	0.26
Tanimoto et al. (47)	−0.06 ± 0.08	−0.25 to 0.12	0.46
an Roie et al. (51)	−0.09 ± 0.07	−0.25 to 0.07	0.22

*ES = effect size; CI = confidence interval.

Muscle Fiber Size

There were 23 muscle fiber size ESs from 4 muscle biopsy studies. There was an insufficient number of studies to model the impact of loading on muscle fiber size.

Discussion

The present meta-analysis encompassed a total of 21 studies –more than double that of the previous meta-analysis on the topic (43). This fairly large body of research provided ample statistical power to draw inferences as to the effects of loading on muscle hypertrophy and isotonic and isometric strength, although data remain insufficient for assessing changes in measures of isokinetic strength, and muscle fiber and lean body mass. The analysis produced several interesting revelations.

The outcomes for strength were somewhat conflicting depending on the modality of testing. Heavy loading showed a clear advantage for gains in 1RM strength, with probability estimates indicating an almost certain likelihood of differences compared with low-load training ($p = 0.003$) (23). The superiority of heavy loading for maximal isotonic strength is consistent with the principle of specificity, which dictates that the more closely a training program replicates the requirements of a given outcome, the greater the transfer of the training to that outcome (5). Considering the essence of 1RM testing is to lift maximal loads, it logically follows that training closer to one's RM would have the greatest transfer to this outcome. Nevertheless, both heavy and light loads showed large effects for 1RM increases (1.69 and 1.32, respectively), translating into mean percentage gains of 35.4 and 28.0%, respectively. Our findings therefore indicate that while heavy loads are required to achieve maximal gains in isotonic strength, lighter loads promote substantial increases in this outcome as well. It should be noted that our findings on the topic are primarily based on untrained subjects as only 3 studies investigated isotonic strength changes between conditions in those with RT experience. A subanalysis of training status showed that the direction of the interaction was even larger in trained subjects, suggesting that heavier loading may become increasingly more important for maximal gains in isotonic strength as one garners training experience. However, the paucity of data on the topic limits the ability to draw definitive conclusions.

With respect to isometric strength, both high and low loads produced similar gains, with minimal differences displayed in mean percentage changes (22.6 vs. 20.5%, respectively). At face value, this implies that when training specificity is offset by testing on a neutral instrument, increases in force production can be equally achieved regardless of loading zone. However, sensitivity analysis showed that removal of the study by Van Roie et al. (51) substantially altered the magnitude of the difference between conditions, with the 95% CI (−0.08 to 0.57) showing an overt advantage to heavier loading. The relatively low number of studies on the topic limited statistical power to draw firm inferences, but examination of the revised CI (−0.57 to 0.08) indicates a likely benefit in favor of heavier loading, albeit of a relatively small magnitude (23).

There was an insufficient number of studies to quantify a magnitude of effect on isokinetic strength in high- vs. load-low training. Of the 3 studies that investigated changes in this outcome measure, Aagaard et al. (1) found that only those training with high loads were able to increase isokinetic strength in a cohort of elite young soccer players. Conversely, Van Roie et al. (51) and Hisaeda et al. (22) reported no significant differences between conditions in untrained community-dwelling elderly adults and young women, respectively. Whether physical activity levels or factors specific to these diverse populations contributed to the discrepancies remains to be determined.

Data from direct measures of muscle size indicate similar hypertrophic changes between high- and low-load conditions. Although differences in mean ES ($p = 0.10$) suggest a likely probability favoring heavier load training (23), study level analysis as illustrated in Figure 4 showed no impact of load ($p = 0.56$) and the mean percentage gains were comparable between high- and low-load conditions (8.3 vs. 7.0%, respectively). Moreover, sensitivity analysis revealed a number of studies unduly influenced results, and the removal of the most influential studies markedly reduced the probability of a difference in mean ES ($p = 0.22$–0.46). The findings therefore indicate that both heavy and light loads can be equally effective in promoting muscle growth provided training is carried out with a high level of effort. Intriguingly, emerging research shows a potential fiber type–specific effect of loading zones, with heavier loads showing greater increases in type II muscle fiber cross-sectional area and lighter loads showing greater increases in type I muscle fiber growth (34,35,52). This implies a potential benefit to training across a spectrum of repetitions when to goal is maximize hypertrophic adaptations. That said, not all studies have found such an effect (32) and further research is therefore needed to draw relevant practical inferences.

Although not all studies reported attendance during the training programs, those that did report a high level of adherence (i.e., >87% of total training sessions). It has been suggested that low-load training might result in greater discomfort compared with high-load training (17). However, the findings would suggest that both the types of training were equally effective regarding adherence to the training protocols. Furthermore, it would seem that training with both high- and low-load might be equally safe, as only 2 of the 21 included studies (25,43) reported mild adverse effects [i.e., minor tendonitis and 2 minor injuries (1 in each group), respectively].

It should be noted that several studies included in the analysis had potential confounding variables that may have impacted results. In the study by Fink et al. (14), interset rest intervals for the low-load condition were 30 seconds, whereas the high-load condition rested 3 minutes. In the study by Popov et al. (37), the low-load group performed repetitions without relaxation, whereas those in the high-load group paused during the isometric portions of the lift. Repetition durations in both studies by Tanimoto et al. (46,47) were different between conditions, with the low-load condition lifting at a tempo of 3s-0s-3s (concentric-isometric-eccentric) vs. a 1s-1s-1s tempo in the high-load condition. The extent and direction to which these factors may have influenced hypertrophic adaptations is not clear.

Practical Applications

The findings of this meta-analysis can provide specific guidance regarding the prescription of training loads to promote increased muscular hypertrophy and strength. With respect to the development of muscular strength, one must consider the needs of the individual first and foremost. For those who participate in strength sports, particularly where maximal loads are required in specific lifts, then training with high loads on the evaluated lifts is advantageous (principle of specificity). Training with low loads to failure requires exercise volume (work) and time in excess of high-load training, suggesting high-load training may be more efficient. Recently, Mattocks et al. (28) demonstrated this principle finding comparable improvements in muscular strength in those who completed only regular 1RM against a higher volume hypertrophy program, albeit in untrained participants.

Given the robust increases from low-load training on measures of isotonic and isometric maximal strength, and the similar changes in muscle hypertrophy when compared with heavy loading, there is significant flexibility in the loading ranges that can be prescribed to promote muscular strength and mass. Emerging evidence indicating fiber type–specific adaptations from training with high vs. low loads suggests a potential benefit to training across a spectrum of loading zones when maximizing muscle hypertrophy is the primary goal. This hypothesis warrants further study.

It should be noted that all included studies in this analysis used momentary muscular failure as the point of set termination. Consequently, application of these findings to RT programming must consider the contribution of concentric failure to the observed findings. Although training to failure may not result in superior adaptations than nonfailure RT despite increased training volume (39), comparable results cannot reasonably be assumed for submaximal, nonfailure training based on the present analysis. This highlights the need for further research on the role of effort, fatigue, and failure in the relationship between training loads and changes in muscular strength and hypertrophy.

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