BRIEF REVIEW

HYPERTROPHIC EFFECTS OF CONCENTRIC VS. ECCENTRIC MUSCLE ACTIONS: A SYSTEMATIC REVIEW AND META-ANALYSIS

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[1]Department of Health Science, Lehman College, Bronx, New York; [2]Total Rehabilitation and Sports Injuries Clinic, Winnipeg, Manitoba, Canada; [3]Department of Biomedical Engineering, Northwestern University, Evanston, Illinois; [4]MRC-ARUK Center of Excellence for Musculoskeletal Ageing Research, School of Medicine, University of Nottingham, Derby, United Kingdom; and [5]Weightology, LLC, Issaquah, Washington

ABSTRACT

Schoenfeld, BJ, Ogborn, DI, Vigotsky, AD, Franchi, MV, and Krieger, JW. Hypertrophic effects of concentric vs. eccentric muscle actions: A systematic review and meta-analysis. *J Strength Cond Res* 31(9): 2599–2608, 2017—Controversy exists as to whether different dynamic muscle actions produce divergent hypertrophic responses. The purpose of this paper was to conduct a systematic review and meta-analysis of randomized controlled trials comparing the hypertrophic effects of concentric vs. eccentric training in healthy adults after regimented resistance training (RT). Studies were deemed eligible for inclusion if they met the following criteria: (a) were an experimental trial published in an English-language refereed journal; (b) directly compared concentric and eccentric actions without the use of external implements (i.e., blood pressure cuffs) and all other RT variables equivalent; (c) measured morphologic changes using biopsy, imaging (magnetic resonance imaging, computerized tomography, or ultrasound), bioelectrical impedance, and/or densitometry; (d) had a minimum duration of 6 weeks; and (e) used human participants without musculoskeletal injury or any health condition that could directly, or through the medications associated with the management of said condition, be expected to impact the hypertrophic response to resistance exercise. A systematic literature search determined that 15 studies met inclusion criteria. Results showed that eccentric muscle actions resulted in a greater effect size (ES) compared with concentric actions, but results did not reach statistical significance (ES difference = 0.25 ± 0.13; 95% confidence interval: −0.03 to 0.52; $p = 0.076$). The mean percent change in muscle growth across studies favored eccentric compared with concentric actions (10.0% vs. 6.8, respectively). The findings indicate the importance of including eccentric and concentric actions in a hypertrophy-oriented RT program, as both have shown to be effective in increasing muscle hypertrophy.

KEY WORDS lengthening actions, shortening actions, muscle cross-sectional area, muscle mass

INTRODUCTION

Dynamic resistance training (RT) involves 2 basic types of muscle actions: concentric and eccentric. Concentric actions involve the dynamic shortening of sarcomeres, whereas eccentric actions involve the active lengthening of sarcomeres (48). Research suggests that the 2 types of actions produce distinct neuromuscular stimuli leading to different postexercise adaptive responses (46). This is consistent with the principle of specificity, which dictates that the body adapts to the specific demands that are placed upon it.

There is ongoing controversy as to whether differences exist in the hypertrophic response to concentric vs. eccentric actions. There is some evidence that eccentrics promote superior increases in muscle mass (15,20,28,44), and one study actually indicated that maximal hypertrophy is not attained without the inclusion of eccentric actions (23). These findings are consistent with acute research showing that eccentric actions promote a more rapid protein synthetic response and greater increases in anabolic signaling and gene expression when compared with other types of muscle actions (12,18,38,51). However, eccentric strength is approximately 20–50% greater than concentric strength (2), and the greater absolute intensities of load often used during eccentric training may be a confounding factor when comparing adaptations associated with the 2 actions.

It has been postulated that eccentric actions may produce greater hypertrophic gains as a result of increased muscle damage (47). Although concentric exercise can cause

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damage in muscle tissue (9,21), the performance of eccentric actions elicits the greatest disruptions to contractile, structural, and supportive elements (13). This phenomenon has been attributed to heightened force demands on fewer active fibers, which are susceptible to tear when resisting dynamic lengthening (48). Researchers speculate that exercise-induced damage to muscle mediates an anabolic response that ultimately strengthens the affected tissue, thereby helping to protect the muscle against future injury (3). Several mechanisms have been hypothesized to be involved in the process, including the release of myokines, satellite cell activation, and cell swelling (47). However, there is a dearth of studies directly investigating the relationship between myodamage and muscular adaptations, and its ultimate role in the growth response remains undetermined.

To the authors' knowledge, only one previous meta-analysis has attempted to investigate the impact of dynamic muscle actions on hypertrophic changes. Roig et al. (46) found that eccentric actions elicited statistically greater increases in muscle girth compared with concentric actions. However, comparing prestudy and poststudy girth measures may mask changes in protein accretion because it does not specifically measure muscle tissue, and therefore the measure is not considered an accurate proxy for assessing exercise-induced hypertrophy (57). Roig et al. (46) also noted that increases in muscle cross-sectional area (CSA) favored eccentric vs. concentric actions as assessed by imaging modalities, although these findings were limited to only 3 studies available at the time and did not exceed the a priori alpha; a number of studies subsequently have been published that shed further insight on the topic. Moreover, the analysis did not assess fiber type specific growth, which may provide unique insight into potential divergent effects between dynamic muscle actions considering that eccentric exercise has been shown to elicit a preferential recruitment of high-threshold motor units (41). Given the gaps in our knowledge base, the purpose of this article was to systematically review the current literature in an effort to elucidate the hypertrophic effects of concentric vs. eccentric actions after consistent, regimented RT. Meta-regression was used to quantify and compare the magnitude of effects between conditions, as well as to determine the potential influence of covariates on findings.

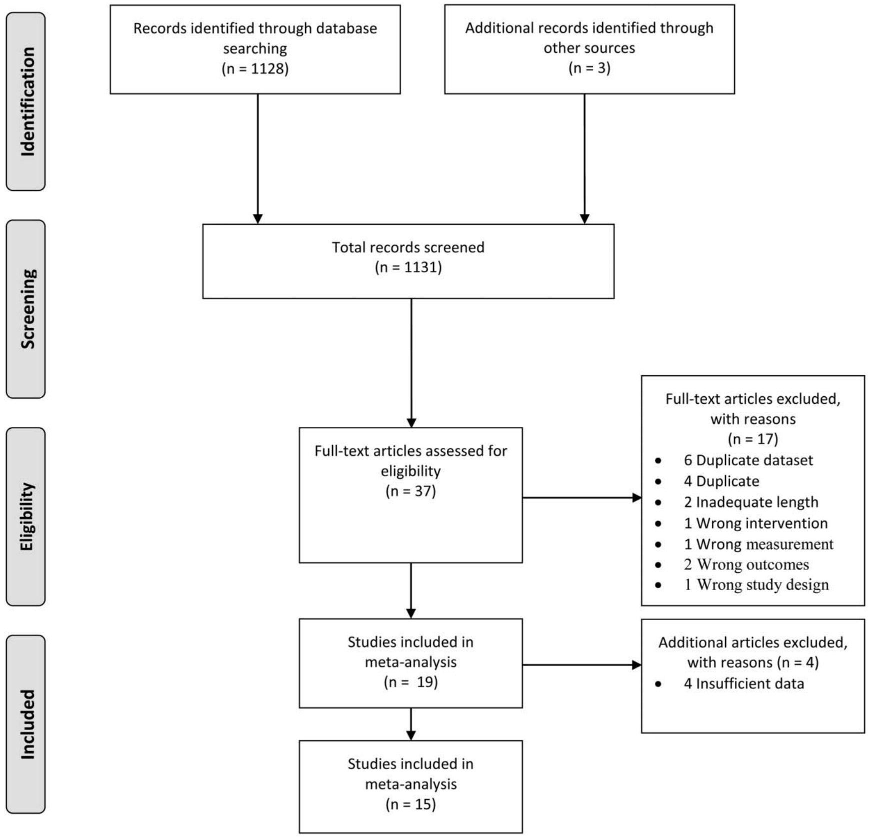

Figure 1. Flow diagram of search process.

Table 1. Summary of hypertrophy training studies investigating type of muscle action.*

Study	Subjects	Design	Study duration	Mode	Hypertrophy measurement	Findings
Cadore et al. (8)	22 recreationally trained young men and women	Random assignment to a resistance training protocol of either eccentric or concentric actions for the knee extensors. All subjects performed 2–5 sets of 8–10 maximal repetitions. Training was performed twice weekly.	6 wk	Isokinetic dynamometer	Ultrasound	No significant differences in muscle thickness between conditions
Farthing and Chilibeck (15)	36 untrained young men and women	Within-subject design in which subjects performed concentric actions of the elbow flexors with one arm and eccentric actions with the other arm. Subjects were randomly assigned to perform the actions at either a fast or slow speed. All subjects performed 2–6 sets of 8 maximal repetitions. Training was performed 3 days per week.	8 wk	Isokinetic dynamometer	Ultrasound	Greater increase in muscle thickness for the eccentric condition
Farup et al. (17)	22 untrained young men	Within-subject design in which subjects performed concentric actions of the knee extensors with one leg and eccentric actions with the other leg. All subjects performed 6–12 sets of 6RM–15RM. Eccentric actions were performed at 120% of concentric 1 repetition maximum. Training was carried out 3 days per week.	12 wk	Knee extension machine	MRI	No significant differences in quadriceps hypertrophy between conditions
Farup et al. (16)	22 untrained young men	Within-subject design in which subjects performed concentric actions of the knee extensors with one leg and eccentric actions with the other leg. All subjects performed 6–12 sets of 6RM–15RM. Eccentric actions were performed at 120% of concentric 1 repetition maximum. Training was performed 3 days per week.	12 wk	Knee extension machine	Muscle biopsy	Significantly greater increases in type II fiber CSA for the concentric condition
Franchi et al. (18)	12 untrained young men	Random assignment to a resistance training protocol of either eccentric or concentric actions of the lower-limb extensors. All subjects performed 4 sets of 8RM–10RM. Eccentric actions were performed at 120% of concentric 1 repetition maximum. Concentric actions were performed for 2 seconds; eccentric actions, for 3 seconds. Training was performed 3 days per week.	10 wk	Leg press machine	MRI	No significant differences in thigh hypertrophy between conditions
Hawkins et al. (25)	8 untrained young women	Within-subject design in which subjects performed concentric actions of the knee extensors with one leg and eccentric actions with the other leg. The concentric condition involved 3 sets of 4 maximal repetitions, whereas the eccentric condition involved 3 sets of 3 maximal repetitions. Training was performed 3 days per week.	18 wk	Isokinetic dynamometer	DXA	Significantly greater increases in mid-thigh lean mass for the eccentric condition

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Higbie et al. (28)	54 untrained young women	Random assignment to a resistance training protocol of either eccentric or concentric actions for the knee extensors. All subjects performed 3 sets of 10 maximal repetitions. Training was performed 3 days per week.	10 wk	Isokinetic dynamometer	MRI	Significantly greater increases in quadriceps muscle hypertrophy for the eccentric condition
Hortobagyi et al. (31)	21 untrained young men	Random assignment to a resistance training protocol of either eccentric or concentric actions for the knee extensors. All subjects performed 4–6 sets of 8–12 maximal repetitions. Training was performed 3 days per week.	12 wk	Isokinetic dynamometer	Biopsy	Significantly greater increase in type II fiber hypertrophy of the quadriceps for the eccentric condition
Jones and Rutherford (32)	12 untrained young men and women	Within-subject design in which subjects performed concentric actions of the knee extensors with one leg and eccentric actions with the other leg. All subjects performed 4 sets of 6 maximal repetitions. Eccentric actions were performed at 145% of concentric 1 repetition maximum. Training was performed 3 days per week.	12 wk	Variable resistance knee extension machine	CT	No significant differences in thigh hypertrophy between conditions
Kim et al. (33)	13 young men and women (training status not disclosed)	Random assignment to a resistance training protocol of either eccentric or concentric actions for the shoulder abductors. All subjects performed 4–6 sets of 6–8 maximal repetitions. Training was performed 3 days per week.	8 wk	Isokinetic dynamometer	Ultrasound	No significant differences in hypertrophy of the supraspinatus between conditions
Moore et al. (39)	9 untrained young men	Within-subject design in which subjects performed concentric actions of the elbow flexors with one arm and eccentric actions with the other arm. All subjects performed 2–6 sets of 10 maximal repetitions. Training was performed twice per week.	9 wk	Isokinetic dynamometer	CT	No significant differences in hypertrophy of the elbow flexors between conditions.
Nickols-Richardson et al. (43)	70 untrained young women	Random assignment to a resistance training protocol of either eccentric or concentric actions for the limbs. All subjects performed 5 sets of 6 maximal repetitions. Training was performed 3 days per week.	5 mo	Isokinetic dynamometer	DXA	No significant differences in fat-free soft tissue mass between conditions
Seger et al. (50)	10 untrained young men	Within-subject design in which subjects performed concentric actions of the knee extensors with one leg and eccentric actions with the other leg. All subjects performed 4 sets of 10 maximal repetitions. Training was performed 3 days per week.	10 wk	Isokinetic dynamometer	MRI	Greater increases in whole quadriceps muscle hypertrophy distally for the eccentric condition
Timmins et al. (54)	28 recreationally trained young men	Random assignment to concentric-only or eccentric-only knee flexor resistance training. Subjects performed 4–6 sets of 6–8 repetitions. Training was performed 2 or 3 days per week.	6 wk	Isokinetic dynamometer	Ultrasound	No significant differences in muscle thickness between conditions

Vikne et al. (56)	17 resistance-trained young men	Random assignment to a resistance training protocol of either eccentric or concentric actions for the elbow flexors. Training was divided between maximum and medium days. Those in the maximum training group performed 3–5 sets of 4RM–8RM; those in the medium training group performed 3 or 4 sets of the same repetition scheme but with lighter loads. Concentric actions were performed explosively, whereas eccentric actions were performed in 3–4 seconds. Training was performed 2 or 3 days per week.	12 wk	Specially designed cable pulley apparatus	CT scan and biopsy	Significantly greater increases in whole muscle CSA of the upper arm for the eccentric condition. Greater increases in type I and type II fiber area for the eccentric condition.

*RM = repetition maximum; MRI = magnetic resonance imaging; CSA = cross-sectional area; DXA = dual energy X-ray absorptiometry; CT = computerized tomography.

METHODS

Inclusion Criteria

Studies were deemed eligible for inclusion if they met the following criteria: (a) were an experimental trial published in an English-language refereed journal; (b) directly compared concentric and eccentric actions without the use of external implements (i.e., pressure cuffs, hypoxic chamber, etc.) and all other RT variables equivalent; (c) measured morphologic changes using biopsy, imaging, bioelectrical impedance, and/or densitometry; (d) had a minimum duration of 6 weeks; and (e) used human participants without musculoskeletal injury or any health condition that could directly, or through the medications associated with the management of said condition, be expected to impact the hypertrophic response to resistance exercise (e.g., coronary artery disease and angiotensin receptor blockers).

Search Strategy

The systematic literature search was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (36) using the online software Covidence (Veritas Health Innovation, Melbourne, Australia). To perform this review, English-language literature searches of the PubMed, Sports Discus, and CINAHL databases were conducted from all time points up until December 2016. Combinations of the following keywords were used as search terms: For training (Resistance training OR resistance exercise OR strength training OR weightlifting OR weight lifting OR weight-lifting); for hypertrophy (Hypertrophy OR CSA OR cross sectional area OR growth OR muscle growth OR lean body mass); for mode (Eccentric OR Concentric OR contraction mode OR shortening OR lengthening).

A total of 1,128 studies were evaluated based on search criteria. To reduce the potential for selection bias, each study was independently reviewed by 3 of the investigators (B.J.S., A.D.V., and D.I.O.), and a mutual decision was made as to whether it met basic inclusion criteria. Any interreviewer disagreements were settled by consensus. The reference lists of articles retrieved were then screened for any additional articles that had relevance to the topic, as described by Greenhalgh and Peacock (22), and 3 additional studies were identified as possibly meeting inclusion criteria. Of the studies initially reviewed, 37 were determined to be potentially relevant to the article based on information contained in the abstracts. Full texts of these articles were then screened, and 19 were deemed suitable for inclusion in accordance with the criteria outlined. Of the studies meeting inclusion criteria, 4 had insufficient data to render an analysis (5,30,35,52), thus leaving a total of 15 studies eligible to be analyzed (Figure 1). Table 1 summarizes the studies analyzed.

Coding of Studies

Studies were read and individually coded by 2 of the investigators (B.J.S. and D.I.O.) for the following variables:

Descriptive information of subjects by group including sex, body mass index, training status (trained subjects were defined as those with at least 1 year regular RT experience), stratified subject age (classified as either young [18–29 years], middle-aged [30–49 years] or elderly [50+ years]); whether the study was a parallel or within-subject design; the number of subjects in each group; duration of the study; weekly training frequency; training mode (isotonic or isokinetic); training intensity as a percentage of 1 repetition maximum; number of sets performed per session; repetition range; whether the study was work matched; whether the study was repetition matched; mode of morphologic measurement (magnetic resonance imaging [MRI], ultrasound, biopsy, dual energy x-ray absorptiometry [DXA], and/or air displacement plethysmography); type of morphological measurement (CSA, volume, and thickness); region/muscle of body measured (upper, lower, or both); and whether hypertrophy measure was direct or indirect. Coding was cross-checked between coders, and any discrepancies were resolved by mutual consensus. To assess potential coder drift, 30% of the studies were randomly selected for recoding as described by Cooper et al. (10). 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 0.90.

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 (1). A percentage change from pretest to posttest was also calculated. A small sample bias adjustment was applied to each ES (40). The variance around each ES was calculated using the sample size in each study and mean ES across all studies (6).

Statistical Analyses

Meta-analyses were performed using robust variance meta-regression for multilevel data structures, with adjustments for small samples (27,55). 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 (REML) (53); an exception was during the model reduction process, in which parameters were estimated by the method of ML, as likelihood ratio tests cannot be used to compare nested models with REML estimates. Meta-regressions on ESs were performed with treatment group (concentric or eccentric) as the moderator variable. For studies with multiple ES outcomes within a treatment group (such as muscle thickness and fiber hypertrophy), an average within-study ES difference between concentric and eccentric groups was calculated to allow for the generation of a forest plot. To assess the practical significance of the outcomes, the equivalent percent change was calculated for each meta-regression outcome. To assess the potential confounding effects of study-level moderators on outcomes, an additional full meta-regression model was created with training mode (isokinetic or isotonic) and body half (upper or lower) as covariates. Other covariates could not be included because of the limited sample size of the data set, and because of some covariates not having factor levels in more than 2 studies. The full model was then reduced by removing predictors one at a time, starting with the most insignificant predictor (7). The final model represented the reduced model with the lowest Bayesian Information Criterion (49), and that was not statistically different ($p > 0.05$) from the full model when compared using a likelihood ratio test. The treatment group (eccentric or concentric) was not removed during the model reduction process. To explore possible interactions between muscle action and other variables, separate regressions were performed on muscle action and its interaction with training duration, training mode, and body half.

To identify the presence of highly influential studies which might bias the analysis, a sensitivity analysis was performed for each model by removing one study at a time, and then examining the muscle action predictor. Studies were identified as influential if removal resulted in a change of p value from $p \leq 0.10$ to $p > 0.10$, or vice versa, or if removal caused a large change in the magnitude of the coefficient.

To assess publication bias, fail-safe N (the number of additional null studies required to reduce the observed ES difference by half) was calculated according to the method described by Orwin (45). Analysis for publication bias was performed using a rank correlation test described by Begg and Mazumdar (4).

All analyses were performed using package metafor in R version 3.3.1 (The R Foundation for Statistical Computing, Vienna, Austria). An a priori alpha for effects was 0.05. Data are reported as $\bar{x}$ ± SEM and 95% confidence intervals (CIs).

RESULTS

The final analysis comprised 30 treatment groups from 15 studies. The mean ES across all studies was 0.89 ± 0.17 (CI_{95}: 0.54–1.25). The mean percent change was 8.4 ± 1.0% (CI_{95}: 6.2–10.5).

Concentric vs. Eccentric Muscle Actions

Eccentric muscle actions resulted in a greater ES compared with concentric actions, but results did not rise to statistical significance (ES difference = 0.25 ± 0.13; CI_{95}: −0.03 to 0.52; $p = 0.076$). The mean ES for concentric actions was 0.77 ± 0.17 (CI_{95}: 0.41–1.13), whereas the mean ES for eccentric actions was 1.02 ± 0.20 (CI_{95}: 0.58–1.45). The mean percent change for concentric actions was 6.8 ± 1.4% (CI_{95}: 3.8–9.7), whereas the mean percent change for eccentric actions was 10.0 ± 1.7% (CI_{95}: 6.3–13.6). Analysis of study-level ESs revealed a similar difference between concentric and eccentric actions (ES difference = 0.27 ± 0.13; CI_{95}: −0.56 to 0.01; $p = 0.057$) (Figure 2). In the final reduced regression model, only body half (upper vs. lower)

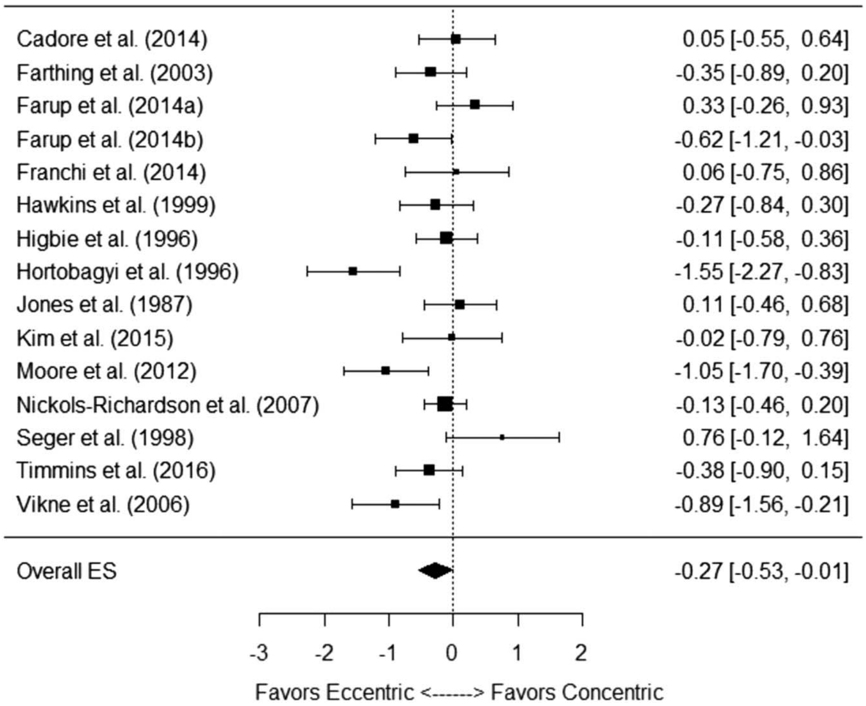

Figure 2. Forest plot of studies comparing changes in muscle hypertrophy in concentric versus eccentric training. The data shown are mean ± 95% CI; the *size of the plotted squares* reflect the statistical weight of each study. ES = effect size.

remained as a statistically predictive covariate ($p = 0.037$). The ES difference between concentric and eccentric actions remained at 0.25 ± 0.13 (CI_{95}: −0.04 to 0.54; $p = 0.089$). There were no statistical interactions between muscle action and training mode (isokinetic vs. isotonic) ($p = 0.85$), body half ($p = 0.28$), or training duration ($p = 0.28$).

Sensitivity Analyses

Because of the limited sample size, sensitivity analyses revealed numerous influential studies (Table 2). Most studies decreased the difference between concentric and eccentric actions on removal (Table 2). Removal of 2 influential studies (16,50) magnified the difference between concentric and eccentric actions so that it exceeded the a priori alpha (Table 2).

Publication Bias

There was no evidence of publication bias according to the rank correlation test ($p = 0.88$). Fail-safe N revealed that 15 null studies would be needed to reduce the observed ES difference in half.

Table 2. Influential studies.

Study removed	New effect size difference (confidence interval)	New p
Farthing et al. (15)	0.22 ± 0.16 (−0.12 to 0.56)	0.19
Farup et al. (17)	0.22 ± 0.13 (−0.07 to 0.51)	0.12
Farup et al. (16)	0.33 ± 0.12 (0.08 to 0.58)	0.015*
Hortobagyi et al. (31)	0.19 ± 0.12 (−0.07 to 0.45)	0.13
Moore et al. (39)	0.22 ± 0.13 (−0.06 to 0.50)	0.11
Nickols-Richardson et al. (43)	0.28 ± 0.16 (−0.07 to 0.62)	0.11
Seger et al. (50)	0.29 ± 0.13 (0.01 to 0.57)	0.04*
Vikne et al. (56)	0.20 ± 0.13 (−0.08 to 0.47)	0.14

*Indicates a statistically significant finding.

DISCUSSION

Our primary analysis found that, on average, eccentric training produced greater increases in hypertrophy compared with concentric training (10.0 vs. 6.8%, respectively). Based on the Hopkins et al. (29) scale, these results were likely/probably not due to chance alone ($p = 0.076$). However, the ES difference (0.25) indicates that the hypertrophic advantage of eccentric training was relatively small. The findings support previous research showing a modest hypertrophic benefit with the use of eccentric actions (46).

Given that maximal strength in eccentric training is approximately 20–50% greater than that of concentric training (2), and considering that the vast majority of studies matched total repetitions as opposed to total work, it can be speculated that the greater amount of work performed during eccentric actions may be responsible for differences in muscle growth. Only 2 included studies matched total work between conditions. Hawkins et al. (25) found only those trained with eccentric actions to have a statistically significant increase in thigh and whole leg lean mass due to training, whereas Moore et al. (37) found a smaller difference in muscle growth favoring eccentrics (6.5 vs. 4.6%) that was not statistically significant. There were not enough studies to perform a subanalysis on this covariate, thereby preventing quantification of data. Consequently, additional research is warranted to determine what, if any, growth-related effects of eccentric exercise are related to loading differences between muscle actions.

A statistically influential effect of body half was found, wherein upper-body training decreased the ES predicted by the models by 0.62 and 0.59 for the full and reduced models, respectively, when contraction mode (concentric or eccentric) and resistance type (isotonic or isokinetic) were held constant. This finding is inconsistent with Abe et al. (1), who found larger mean increases for upper-body muscle growth (12–21%) compared with lower-body muscle growth (7–9%) over a 12-week period of RT, although no statistical difference was found. These inconsistent findings may be at least partially due to different types of measurement being mixed within the same analysis. For example, Nickols-Richardson et al. (43) used DXA to quantify upper-limb and lower-limb lean body mass, which was weighted heavily in the meta-analysis because of its large sample size ($N = 70$), whereas many other studies used imaging and/or biopsy. Moreover, Nickols-Richardson et al. (43) accounts for about 48% of the weight of upper-body ESs included; within the study itself, investigators reported a relative advantage for upper-body training, which further conflicts with the findings of this covariate. Previous work suggests that imaging modalities such as MRI and CT are more sensitive than DXA for measuring subtle changes in CSA and thus more sensitive for detecting effects (11,42). Therefore, observed differences between body halves from varying muscle actions should be taken with circumspection.

Although we investigated whole muscle growth, it is interesting to note that eccentric and concentric actions have been shown to produce regional-specific effects on muscle growth. Franchi et al. (18) found significantly greater hypertrophy in the mid-portion of the vastus lateralis from concentric exercise, whereas eccentric training had a greater effect on distal growth of the muscle. Similar findings have been reported in other research (50). Although the reason for these differences remains to be elucidated, the phenomenon may be due to localized muscle damage along the length of the fiber that brings about nonuniform alterations in muscle activation (26). These findings also demonstrate the need for multiple sampling sites along the length of the measured muscle when comparing eccentric and concentric training, as uniform effects at an individual sampling site may not occur. Regardless of the mechanisms, these data, in combination with research showing diverse intracellular signaling responses between concentric and eccentric training (18), suggest that whole muscle growth is best achieved by performing a combination of the 2 actions.

All 3 muscle biopsy studies included in this review found that eccentric training produces greater type II fiber hypertrophy than concentric training (16,31,56), with only one study suggesting that eccentric training also produces greater type I fiber hypertrophy (56). It can only be speculated as to why this is, but previous work suggests that eccentric loading preferentially recruits higher-threshold motor units (41). If higher-threshold motor units contain more type II muscle fibers, then this may at least partially explain the findings, but at present, it is not clear as to whether or not this is the case (14). Notwithstanding murky neuromuscular physiological mechanisms, selective glycogen depletion of type II fibers has been documented after an 8-week eccentric training program, which suggests that type II fibers are preferentially used (19). Although it would seem logical that differential loads may play a role, preferential type II fiber hypertrophy has also been demonstrated even with lighter loads (50–60% of maximum eccentric force) during combined concentric/eccentric training (23). Moreover, because of lateral force transmission, it is unclear as to whether or not different fibers truly "experience" different loads in vivo (14,24). At present, the interplay between fiber contraction/activation and force transmission is not clear, nor are the mechanisms by which preferential type II hypertrophy occurs with eccentric loading.

It is important to note that results were found to be sensitive to the removal of individual studies. In some cases, removal decreased the magnitude of difference between eccentric and concentric actions (15,17,31,39,43,56), whereas in others, removal strengthened the relationship (16,50). This highlights the need for additional research on the topic to enhance the robustness of findings and provide greater clarity for drawing evidence-based conclusions. Furthermore, it should be noted that our analyses did not take into account measurement error, which would decrease all the ESs; the extent to which this would occur is unclear and could not be calculated because not all the included studies reported reliability measures. Thus, it is imperative that future studies include reliability measures so as to allow both readers and meta-analyses to take measurement error into account when attempting to draw conclusions.

PRACTICAL APPLICATIONS

Given the modest ES difference between exclusively eccentric and concentric training, it seems that eccentric-only training likely provides a small advantage over concentric-only training for promoting a hypertrophic response; notwithstanding, both contraction modes can promote significant muscular hypertrophy. Further research is required to clarify whether the benefit of eccentric training is related to the higher forces produced and ultimately total work completed relative to concentric-only training (39). Practically, the risk/reward ratio of eccentric-only actions must be considered before being used–eccentric actions may elicit a slightly larger hypertrophic response than concentric actions, but at the same time, they also require greater overload and induce greater delayed-onset muscle soreness. Traditionally, RT includes the completion of coupled eccentric and concentric actions, and special equipment or external assistance may be required to complete isolated eccentric actions. Many commercial solutions, such as flywheels, offer eccentric overload relative to the concentric range of motion, which differs from exclusively eccentric or concentric training. Therefore, the results of this study must be considered in this specific context and cannot be used to justify the use of relative eccentric overload when completing coupled eccentric and concentric actions; however, the inclusion of such protocols may be justified according to recent work (34).

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