What influence does resistance exercise order have on muscular strength gains and muscle hypertrophy? A systematic review and meta-analysis

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REVIEW

What influence does resistance exercise order have on muscular strength gains and muscle hypertrophy? A systematic review and meta-analysis

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Abstract
The objectives of this paper were to: (a) systematically review studies that explored the effects of exercise order (EO) on muscular strength and/or hypertrophy; (b) pool their results using a meta-analysis; and (c) provide recommendations for the prescription of EO in resistance training (RT) programmes. A literature search was performed in four databases. Studies were included if they explored the effects of EO on dynamic muscular strength and/or muscle hypertrophy. The meta-analysis was performed using a random-effects model with Hedges' g effect size (ES). The methodological quality of studies was appraised using the TESTEX checklist. Eleven good-to-excellent methodological quality studies were included in the review. When all strength tests, that is, both in multi-joint (MJ) and single-joint (SJ) exercises were considered, there was no difference between the EOs ($ES = -0.11$; $p = 0.306$). However, there was a difference between the MJ-to-SJ and SJ-to-MJ orders for strength gains in the MJ exercises, favouring starting the exercise session with MJ exercises ($ES = 0.32$; $p = 0.034$), and the strength gains in the SJ exercises, favouring starting the exercise session with SJ exercises ($ES = -0.58$; $p = 0.032$). No significant effect of EO was observed for hypertrophy combining site-specific and indirect measures ($ES = 0.03$; $p = 0.862$). In conclusion, increases in muscular strength are the largest in the exercises performed at the beginning of an exercise session. For muscle hypertrophy, our meta-analysis indicated that both MJ-to-SJ and SJ-to-MJ EOs may produce similar results.

Keywords: *Muscle contraction, strength training, muscle strength, muscle growth, pre-exhaustion*

Highlights

- Results of the present meta-analysis indicate a significant influence of resistance exercise order on gains in muscular strength. In particular, the specificity principle should be considered to optimise strength gains, given that greater improvements in strength are observed in exercises that are performed at the beginning of the resistance training session.
- Similar muscle hypertrophy effects may be achieved regardless of exercise order.

Introduction

Resistance training (RT) is an exercise modality that has been shown to confer positive effects on health-related parameters and well-being, sports performance, and physique aesthetics (Suchomel, Nimphius, & Stone, 2016; Westcott, 2012). When designing RT programmes, several key training variables need to be considered. These variables are related to training intensity (e.g. external load relative to maximum), volume (e.g. the number of sets, repetitions per exercise, and training frequency), level of effort (e.g. sets performed near or to failure) and structure, which refers to exercise order (EO) and selection (Ratamess et al., 2009).

For EO, the current American College of Sports Medicine position stand for resistance exercise prescription recommends performing multi-joint (MJ) exercises that involve larger muscle groups first in the exercise session followed by the performance of

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single-joint (SJ) exercises that involve smaller muscle groups (Ratamess et al., 2009). However, a narrative review on the effects of EO did not necessarily share these recommendations (Simão, de Salles, Figueiredo, Dias, & Willardson, 2012). Specifically, Simão et al. (2012) suggested that EO should be prioritised, whereby muscle groups or specific exercises considered most important to the goals of the trainee are performed at the beginning of the exercise session. These propositions are specific to muscular strength and muscle hypertrophy (Ratamess et al., 2009; Simão et al., 2012).

A limitation of the current guidelines on EO (Ratamess et al., 2009), which have an evidence level category of C, is that they are based only on the results from acute studies. In such studies, the participants perform exercise sessions that only differ in the specific EO. In this regard, the loads to be used on both EO are previously tested in a single order, unlike what occurs in the training sessions in which the loads are adjusted according to the exercise position in the training programme (Carpinelli, 2013; Nunes et al., 2019). Outcomes of these studies commonly include the total number of repetitions and muscle activation with different EOs (Augustsson et al., 2003; Sforzo & Touey, 1996; Spreuwenberg et al., 2006). Therefore, generalising the results from acute studies to hallmark RT adaptations such as muscular strength and hypertrophy must be done with caution (Grgic, Schoenfeld, Skrepnik, Davies, & Mikulic, 2018; Halperin, Vigotsky, Foster, & Pyne, 2018). A higher number of repetitions or an increased acute muscular activation with a given resistance exercise might not necessarily result in greater long-term increases in muscular strength and hypertrophy (Grgic et al., 2018; Halperin et al., 2018; Vigotsky, Halperin, Lehman, Trajano, & Vieira, 2018).

The aforementioned narrative review by Simão et al. (2012) included only three long-term studies, with a total sample size across the studies of 66 participants. Since the publication of this review, multiple long-term studies were subsequently published on the topic of EO. Given the conflicting findings of these studies, the goals of this paper were to: (a) systematically review studies that explored the effects of EO on muscular strength and/or hypertrophy; (b) pool their results using a meta-analysis; and (c) provide recommendations for the prescription of EO in RT based on the meta-analytical findings.

Methods

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (Liberati et al., 2009).

Literature search

The literature search was performed through PubMed/MEDLINE, Scopus, Scielo, and SPORTDiscus databases on 13 February 2020. Searches were carried out using the following search syntax: ("resistance exercise" OR "resistance training" OR "strength training" OR "strength exercise") AND (order) AND (strength OR hypertrophy OR "lean body mass" OR "fat-free mass"). Secondary searches were performed for: (a) screening the reference lists of the included studies; and (b) conducting forward citation tracking of the included studies through Google Scholar. The study selection was carried out independently by two authors (JPN and JG) to minimise potential selection bias.

Inclusion criteria

Studies were included in this review if they met the following inclusion criteria: (1) published in English or Portuguese; (2) the study design was a longitudinal investigation comparing the effects of different intra-session resistance EO on dynamic muscular strength and/or hypertrophy (both site-specific and indirect measures of hypertrophy were considered); (3) the training protocols included at least two RT exercises (i.e. the minimum number of exercises that could be used to explore the effect of EO); and (4) the training intervention lasted a minimum of six weeks. Direct or site-specific measures of hypertrophy were considered to be magnetic resonance imaging, computed tomography, B-mode ultrasound, and muscle biopsy. Indirect measures of hypertrophy were considered to be dual-energy x-ray absorptiometry (DXA), hydrostatic weighing, bioimpedance, air-displacement plethysmography, and skinfolds.

Coding of studies

The following data were extracted from the included studies and tabulated on a predefined Microsoft Excel coding sheet (Microsoft Corporation. Redmond, USA): (1) author(s) name(s), manuscript title and year of publication; (2) descriptive information of the sample including number of participants, sex, age, and training status; (3) characteristics of the RT programme: duration, weekly training frequency, number of sets, intensity (i.e. repetition maximum), EO and exercise selection; (4) methods used for assessment of muscular strength and hypertrophy; (5) mean and standard deviation of pre- and post-training muscular strength and hypertrophy values. When necessary, the corresponding author of the study was contacted by the lead author (JPN) to request the required information. Coding sheets were cross-checked between authors (JPN and JG), while discussion and consensus resolved any discrepancies. To assess potential coder drift, we randomly reselected 30% of the included studies for additional re-coding. The agreement between authors (JPN and JG) was 100%.

Classification of training status and age

Resistance-trained individuals were defined herein as having at least six months of RT experience (Ratamess et al., 2009). For age groups, participants were stratified based on the following classification: (1) 18–39 years was considered as young, (2) 40–60 years as middle-aged, (3) ≥ 60 years as older adults.

Methodological quality

We assessed the methodological quality of the included studies using the "*Tool for the assEsment of Study qualiTy and reporting in EXercise*" (TESTEX) checklist (Smart et al., 2015). The items on this checklist are explained in full detail elsewhere (Smart et al., 2015). The checklist has two sections that refer to study quality (items 1–5) and study reporting (items 6–12). Each item on the TESTEX checklist is answered with "yes" if the criteria are satisfied or with a "no" if the criteria are not satisfied (only the answer "yes" is associated with a point). Items 6 and 8 have three and two questions, respectively. The answer "yes" to each of these sub-questions is also associated with a point. Therefore, the maximum number of possible points on the checklist is 15. Based on the summary scores, we classified studies as "excellent quality" (12–15 points), "good quality" (9–11 points), "fair quality" (6–8 points), or "poor quality" (<6 points). Two authors (JPN and JG) independently performed the quality assessment, and any observed differences were resolved via discussion and agreement.

Statistical analyses

The following meta-analytic comparisons for the effects of EO on strength were explored: (a) the overall increase in strength between the groups using different EO while considering data from both MJ and SJ exercises strength tests; (b) the effects of MJ-to-SJ and SJ-to-MJ EOs on strength gains in MJ exercises and in SJ exercises; and (c) the effects of training specificity on strength when considering all exercises, and on strength gains in machine-based vs. free-weight exercises. For the first two comparisons, a positive effect indicated a benefit for MJ-to-SJ EO. For training specificity, positive effects were considered when the strength gain in the tested exercises favoured the group that trained these exercises earlier in the RT session (MJ exercises for groups that performed MJ-to-SJ EO, and SJ exercises for groups that performed SJ-to-MJ EO; and for the study from Saraiva et al. (2014), upper-body exercises for the upper-body-to-lower-body group, and lower-body exercises for the lower-body-to-upper-body group). For the meta-analyses on muscle hypertrophy, we explored: (a) the effects of EO on site-specific muscle hypertrophy (assessed using B-mode ultrasound); (b) the effects of EO on hypertrophy as assessed using indirect measures (e.g. DXA, bioimpedance, air-displacement plethysmography, and skinfolds); and (c) the effects of EO on hypertrophy when considering both site-specific and indirect measures. In both of the analyses that included indirect measures, we conducted a sensitivity analysis in which we excluded one study that used skinfolds for the hypertrophy assessment. One included study used both direct and indirect methods of hypertrophy assessment (B-mode ultrasound and DXA; Avelar et al., 2019). Therefore, in the analysis in which we combined direct and indirect measures of hypertrophy, we conducted a sensitivity analysis where we examined the pooled results after using data reported for: (a) muscle thickness; and, (b) lean body mass, from the Avelar et al. (2019) study.

In each analysis, the effect size (ES) was calculated as the difference between post-test and pre-test scores, divided by the pooled standard deviation, with Hedges' g adjustment for small sample bias (Borenstein, Hedges, Higgins, & Rothstein, 2009). For studies with multiple outcomes, the mean of the selected outcomes was used (assuming dependence). Heterogeneity was explored using the I^2 statistic, in which values <50% indicate low heterogeneity, 50–75% moderate heterogeneity and >75% high level of heterogeneity. Funnel plot asymmetry could not be explored given that less than 10 studies were included in the analyses. The random-effects model was used in each meta-analysis. Meta-analyses were performed using the "Comprehensive Meta-analysis" software (version 3; BiostatInc. Englewood, USA). Effects were considered significant at $p < 0.05$. Data are reported as Hedges' g ES and 95% confidence interval (CI).

Results

The search process is depicted in Figure 1. A total of 2327 search results were initially screened. After excluding the studies based on title, abstract, or full-text, a total of ten studies (Assumpção, Tibana, Viana, Willardson, & Prestes, 2013; Avelar et al.,

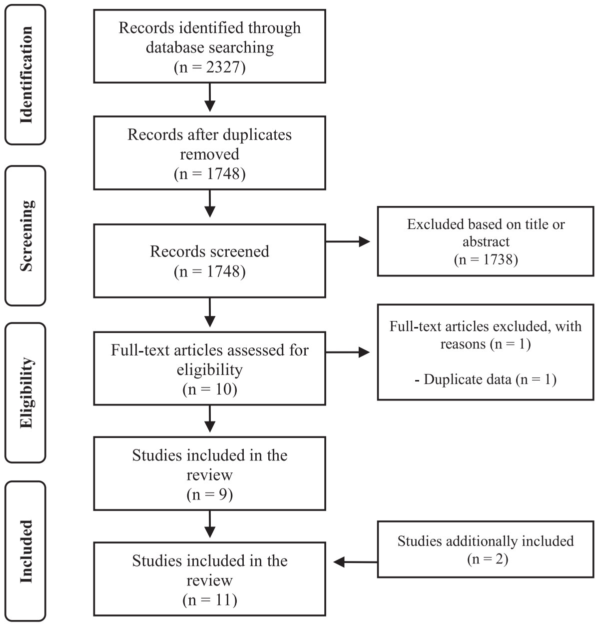

Figure 1. Flow diagram of the search process.

2019; Cardozo et al., 2019; Dias, de Salles, Novaes, Costa, & Simão, 2010; Fisher, Carlson, Steele, & Smith, 2014; Nazari, Azarbayjani, & Azizbeigi, 2016; Saraiva et al., 2014; Simão et al., 2010; Spineti et al., 2010, 2014) were included. However, one study was removed because it included duplicate data (Spineti et al., 2014), and two additional studies were included from the author's library (Pina et al., 2013; Tomeleri et al., 2019). Therefore, the final number of included studies amounted to 11 (Assumpção et al., 2013; Avelar et al., 2019; Cardozo et al., 2019; Dias et al., 2010; Fisher et al., 2014; Nazari et al., 2016; Pina et al., 2013; Saraiva et al., 2014; Simão et al., 2010; Spineti et al., 2010; Tomeleri et al., 2019) (Table I).

Characteristics of the included studies

The average duration of training interventions was 9 weeks (range: 6–12 weeks). A total of 268 subjects participated in the studies (average of 12 participants per group; range: 8–19). Three of the 11 studies employed resistance-trained subjects (Assumpção et al., 2013; Fisher et al., 2014; Pina et al., 2013), and the rest included untrained subjects (Avelar et al., 2019; Cardozo et al., 2019; Dias et al., 2010; Nazari et al., 2016; Saraiva et al., 2014; Simão et al., 2010; Spineti et al., 2010; Tomeleri et al., 2019). The study of Saraiva et al. (2014) was in Judo athletes, who had some experience in RT but not enough to qualify as resistance-trained. Three studies explored the effects of EO in older adults (Cardozo et al., 2019; Pina et al., 2013; Tomeleri et al., 2019), one in middle-aged adults (Fisher et al., 2014), and the rest in young adults (Assumpção et al., 2013; Avelar et al., 2019; Dias et al., 2010; Nazari et al., 2016; Saraiva et al., 2014; Simão et al., 2010; Spineti et al., 2010). Two studies had a sample of female subjects (Nazari et al., 2016; Tomeleri et al., 2019), one study had a mixed-sex sample (Fisher et al., 2014), and the rest of the studies included only male subjects (Assumpção et al., 2013; Avelar et al., 2019; Cardozo et al., 2019; Dias et al., 2010; Pina et al., 2013; Saraiva et al., 2014; Simão et al., 2010; Spineti et al., 2010).

The muscular strength assessment was obtained through 1RM (Avelar et al., 2019; Dias et al., 2010; Fisher et al., 2014; Nazari et al., 2016; Pina et al., 2013; Simão et al., 2010; Spineti et al., 2010; Tomeleri et al., 2019), 10RM tests (Cardozo et al., 2019; Saraiva et al., 2014), or both (Assumpção et al., 2013). Muscle hypertrophy was indirectly assessed by DXA (Avelar et al., 2019; Tomeleri et al., 2019), air displacement plethysmography (2014), bioimpedance (Pina et al., 2013), and skinfolds (Cardozo et al., 2019). The studies that performed direct measurements used B-mode ultrasound (Avelar et al., 2019; Simão et al., 2010; Spineti et al., 2010). As previously noted, Avelar et al. (2019) used both DXA and ultrasound to assess muscle hypertrophy, whereas Simão et al. (2010) used muscle thickness as a measure of the size of the muscles analyzed, and Spineti et al. (2010) estimated muscle volume from an equation that includes muscle thickness and some anthropometric measures.

Quality assessment

Table II presents the results of the quality assessment. The average score on the checklist was 12. Eight studies were rated as being excellent methodological quality (Assumpção et al., 2013; Cardozo et al., 2019; Dias et al., 2010; Nazari et al., 2016; Pina et al., 2013; Simão et al., 2010; Spineti et al., 2010; Tomeleri et al., 2019), and three studies were rated as being of good quality (Avelar et al., 2019; Fisher et al., 2014; Saraiva et al., 2014). None of the included studies was classified as being of fair or poor methodological quality.

Influence of EO on muscular strength

Eight studies (Assumpção et al., 2013; Cardozo et al., 2019; Dias et al., 2010; Nazari et al., 2016; Saraiva et al., 2014; Simão et al., 2010; Spineti et al., 2010; Tomeleri et al., 2019) explored the influence of EO on muscular strength. When comparing MJ-to-SJ vs. SJ-to-MJ orders, the study by Saraiva et al. (2014) was not included because it investigated EOs that

Table I. Characteristics of the included studies on resistance exercise order

Studies	Sample		Duration	RT programme	Exercises and EO according to groups	
	Characteristics	*n*				
Assumpção et al. (2013)	Trained young men	MJ-SJ = 8 SJ-MJ = 8	6 weeks	A-B2x/wk, 3 sets of 8–12RM	MJ-SJ SJ-MJ	BP*, IBP, PD, MTE, TE* – LPD*, CLPD, SR, MBC, BC* MTE, TE*, BP*, IBP, PD – MBC, BC*, LPD*, CLPD, SR
Avelar et al. (2019)	Untrained young men	MJ-SJ = 19 SJ-MJ = 17	6 weeks	3x/wk, 3 sets of 8–12RM	MJ-SJ SJ-MJ	BP, LPD, UR, SP, TE, BC, LP, KE, LC, CR BC, TE, SP, UR, LPD, BP, CR, LC, KE, LP
Cardozo et al. (2019)	Untrained older women	MJ-SJ = 15 SJ-MJ = 15	12 weeks	2x/wk, 3 sets of 8–10RM (circuit training)	MJ-SJ SJ-MJ	LP*, LPD*, KE, PD, CR*, TE* TE*, CR*, PD, KE, LDP*, LP*
Dias et al. (2010)	Untrained young men	MJ-SJ = 16 SJ-MJ = 17	8 weeks	3x/wk, 3 sets of 8–12RM	MJ-SJ SJ-MJ	BP*, LPD*, SP*, TE*, BC* BC*, TE*, SP*, LPD*, BP*
Fisher et al. (2014)	Trained middle-age adults	MJ-SJ = 8 SJ-MJ = 17	12 weeks	2x/wk, 1 set of 8–12RM	MJ-SJ SJ-MJ	BP, LP, LPD, PD, KE, PO, ABD, LU PD, BP, KE, LP, PO, LPD, ABD, LU
Nazari et al. (2016)	Untrained young women	MJ-SJ = 8 SJ-MJ = 8	6 weeks	3x/wk, 4 sets of 3–15RM (linear periodisation)	MJ-SJ SJ-MJ	BP*, LPD*, TE*, BC* BC*, TE*, LPD*, BP*
Pina et al. (2013)	Trained older men	MJ-SJ = 9 SJ-MJ = 9	7 weeks	3x/wk, 2 sets of 10–15RM	MJ-SJ SJ-MJ	BP, LPD, TE, BC, KE, LC, HAB, HAD BC, TE, LPD, BP, HAD, HAB, LC, KE
Saraiva et al. (2014)	Judo male athletes	UB-LB = 13 LB-UB = 13	12 weeks	3x/wk, 3 sets of 10–12RM	UB-LB LB-UB	BP*, LPD*, SP*, BC*, SQ*, LP*, KE*, LC* SQ*, LP*, KE*, LC*, BP*, LPD*, SP*, BC*
Simão et al. (2010)	Untrained young men	MJ-SJ = 9 SJ-MJ = 9	12 weeks	2x/wk, 2–4 sets of 3–15RM (linear periodisation)	MJ-SJ SJ-MJ	BP*, LPD*, TE*, BC* BC*, TE*, LPD*, BP*
Spineti et al. (2010)	Untrained young men	MJ-SJ = 11 SJ-MJ = 10	12 weeks	2x/wk, 2–4 sets of 3–15RM (undulating periodisation)	MJ-SJ SJ-MJ	BP*, LPD*, TE*, BC* BC*, TE*, LPD*, BP*
Tomeleri et al. (2019)	Untrained older women	MJ-SJ = 14 SJ-MJ = 15	12 weeks	3x/wk, 3 sets of 10–15RM	MJ-SJ SJ-MJ	BP*, SR, TE, BC*, LP, KE*, LC, CR BC*, TE, SR, BP*, CR, LC, KE*, LP

Notes: MJ-SJ: group that performed the exercises in a multi- (MJ) to single-joint (SJ) order. SJ-MJ: group that performed the exercises in a single- to multiple-joint order. UB-LB: group that performed the exercises in an upper- (UB) to lower-body (LB) order. LB-UB: group that performed the exercises in an upper- to lower-body order. RM: repetition maximum. ABD: abdominal flexion. BC: biceps curl. MBC: machine biceps curl. BP: bench press. IBP: incline bench press. CR: calf raise. HAB: hip abduction. HAD: hip adduction. KE: knee extension. LC: leg curl. LPD: lat-pulldown. CLPD: close-grip lat-pulldown. LP: leg press. LU: lumbar extension. PD: pecdeck. PO: lat-pullover. SP: shoulder press. SQ: squat. SR: seated row. TE: triceps extension. MTE: machine triceps extension. UR: shoulder upright row. * exercise used for strength testing (if no asterisk is noted in any of the exercises, the study did not assess changes in muscular strength).

started either with lower-body or upper-body exercises. When all performed strength tests (MJ and SJ) were considered, there was no difference between the EOs (g ES = −0.11; 95% CI: −0.32, 0.10; p = 0.306; I^2 = 67.5%). There was a difference between the MJ-to-SJ and SJ-to-MJ orders for strength gains in the MJ exercises, which favoured starting with MJ exercises (g ES = 0.32; 95% CI: 0.02, 0.62; p = 0.034; I^2 = 0%). In the same way, there was a difference between MJ-to-SJ and SJ-to-MJ orders for strength gains in the SJ exercises, which favoured starting with SJ exercises (g ES = −0.58; 95% CI: −1.11, −0.05; p = 0.032; I^2 = 0%). Finally, a significant and positive effect was found supporting the principle of specificity when consider all exercises (g ES = 0.45; 95% CI: 0.09, 0.81; p = 0.014; I^2 = 37.4%; Figure 2A), and when considering only machine-based exercises (g ES = 0.45; 95% CI: 0.09, 0.81; p = 0.015; I^2 =

Table II. Quality assessment using the TESTEX checklist

Study	1	2	3	4	5	6a	6b	6c	7	8a	8b	9	10	11	12	Total score
Assumpção et al. (2013)	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	12
Avelar et al. (2019)	1	1	0	1	1	0	0	0	1	1	1	1	1	1	1	11
Cardozo et al. (2019)	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	12
Dias et al. (2010)	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	12
Fisher et al. (2014)	0	1	0	1	1	0	0	0	1	1	1	1	1	1	1	10
Nazari et al. (2016)	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	12
Pina et al. (2013)	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	12
Saraiva et al. (2014)	0	1	0	1	0	0	0	0	1	1	1	1	1	1	1	9
Simão et al. (2010)	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	12
Spineti et al. (2010)	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	12
Tomeleri et al. (2019)	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	13

1 = criteria met; 0 = criteria not met.

33.6%) or free-weight exercises (*g* ES = 0.50; 95% CI: 0.02, 1.00; $p = 0.018$; $I^2 = 58.1\%$).

Influence of EO on muscle hypertrophy

Seven studies (Avelar et al., 2019; Cardozo et al., 2019; Fisher et al., 2014; Pina et al., 2013; Simão et al., 2010; Spineti et al., 2010; Tomeleri et al., 2019) explored the influence of EO on muscle hypertrophy. No significant effect of EO was observed for muscle growth when analyzed by either site-specific measures (*g* ES = −0.02; 95% CI: −0.45, 0.41; $p = 0.937$; $I^2 = 0\%$) or indirect measures (*g* ES = 0.06; 95% CI: −0.27, 0.39; $p = 0.734$; $I^2 = 0\%$). The combined analysis of both site-specific and indirect measures also indicated no significant difference between EOs on muscle hypertrophy (*g* ES = 0.03; 95% CI: −0.26, 0.31; $p = 0.862$; $I^2 = 0\%$; Figure 2B). The exclusion of one study that used skinfolds for hypertrophy assessment did not impact the results to a meaningful degree when considering the analysis only for indirect measures (*g* ES = 0.07; 95% CI: −0.32, 0.45; $p = 0.727$; $I^2 = 0\%$) or combined site-specific and indirect measures (*g* ES = 0.03; 95% CI: −0.30, 0.35; $p = 0.871$; $I^2 = 0\%$). In the sensitivity analysis where we used either ES data for muscle thickness or lean body mass from the Avelar et al. study, the results remained consistent with the use of average ESs (*g* ES = 0.02; 95% CI: −0.28, 0.32; $p = 0.898$; $I^2 = 0\%$, and *g* ES = 0.04; 95% CI: −0.6, 0.33; $p = 0.810$; $I^2 = 0\%$, respectively).

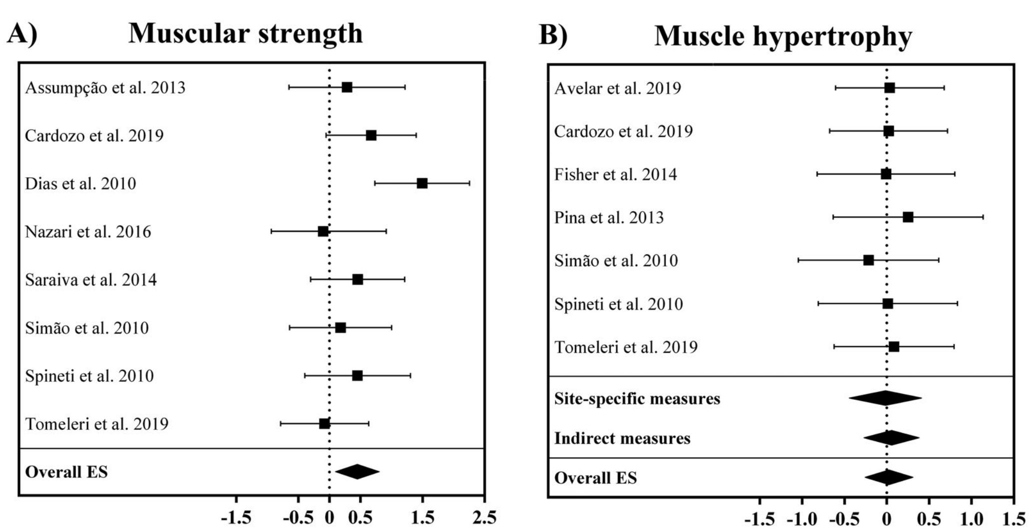

Figure 2. (**Panel A)** Forest plot of studies on changes in muscular strength following resistance training (RT) with different exercise orders (EO), analysing specificity-principle. Positive effects were considered when the strength gain in the tested exercise favoured the group that trained this exercise first in the RT session (multi-joint (MJ) exercises for groups that performed MJ-to-single-joint (SJ) EO, SJ exercises for groups that performed SJ-to-MJ EO; and for the study from Saraiva et al. (2014), upper-body (UB) exercises for the UB-to-lower-body (LB) exercises group and LB exercises for the LB-to-UB group). The data shown are mean ± 95% confidence interval (CI). (**Panel B)** Forest plot of studies comparing muscle hypertrophy following RT performed in SJ-to-MJ EO versus MJ-to-SJ EO. The data shown are mean ± 95% CI. ES = effect size.

Discussion

This is the first systematic review coupled with a meta-analysis to compare the influence of EOs on muscular strength and hypertrophy. Our main finding is that EO influences strength gains as it seems that strength gains are the greatest in the exercises that are performed at the beginning of the exercise session. However, no significant difference between EOs was found for muscle hypertrophy. The included studies were classified as being excellent to good methodological quality, which therefore strengthens confidence in these conclusions.

Regarding muscular strength, our findings confirm previous reports that increases in strength follow the 'Specific Adaptations to Imposed Demands' (SAID) principle (Mattocks et al., 2017; Nunes, Ribeiro, Schoenfeld, & Cyrino, 2018). We observed that EO affected strength gains when considering the effects of MJ-to-SJ and SJ-to-MJ exercise sequences on strength gains in MJ and SJ exercises. In both cases, the increase in strength was greater in the exercises that were performed at the beginning of the exercise session. Placing a given exercise first in an exercise session allows the use of higher external loads in that exercise. The use of higher loads ultimately seems to transfer to greater strength gains in exercises that are performed first. These findings support the previously proposed hypothesis (Simão et al., 2012) that EO should be prioritised based on the desired goal of the individual. The specificity principle for EO may have high practical importance for individuals who aspire to develop maximum strength, especially powerlifters and weightlifters. When the training goal is to optimise strength development in a given exercise, our findings indicate that this exercise should be performed at the beginning of the training session.

The effect of fatigue (local and/or non-local (Halperin, Chapman, & Behm, 2015)) on acute exercise performance is an important factor that also seems to explain the influence of EO on strength gains. Fatigue induced by an exercise performed first in a given sequence tends to negatively affect performance in the ensuing exercises. Local muscular fatigue induced by the first exercise may decrease performance in subsequent exercises that activate the same muscle group (Halperin et al., 2015; Simão et al., 2012). This finding was observed in several acute studies; for example, chest press performance is negatively affected by a prior performance of the triceps pulley exercise, and *vice-versa* (Miranda, Figueiredo, Rodrigues, Paz, & Simão, 2013; Ribeiro et al., 2014; Simão, Farinatti, Polito, Maior, & Fleck, 2005). Non-local muscular fatigue is related to crossover fatigue from one exercised muscle group to another, non-exercised muscle group (e.g. the performance of upper-body exercise is hindered when it is preceded with a lower-body exercise) (Halperin et al., 2015). This may explain the results from Saraiva et al. (2014), in which the group that performed upper-body exercises first in the training sessions gained more strength in upper-body exercises, while the group that performed lower-body exercises first gained more strength in lower-body exercises. These data further highlight the importance of training specificity for strength gains.

An important caveat of the findings presented herein is that all of the included studies explored the effects of EO on RM-strength tests (i.e. tests that are specific to the training programme used). Future investigations should seek to employ strength tests with other 'non-specific' methods (e.g. isokinetic, isometric strength tests) to explore whether EO influences overall muscular strength when assessed using a non-specific strength test (Buckner et al., 2017). If EO does not impact strength gains in other (non-specific) strength tests, this may allow greater flexibility for EO during RT sessions depending on individual goals.

Our findings indicate that similar muscle hypertrophy can be attained regardless of EO. Nonetheless, the relatively low number of studies on the topic highlights a need for future research in this area. Still, several important practical implications can be inferred based on current evidence. It would appear that different EOs (MJ-to-SJ or SJ-to-MJ) induce similar effects on site-specific muscle hypertrophy. However, one important limitation needs to be discussed here. In the studies that used B-mode ultrasound to assess changes in muscle size, the measured sites were not the main targeted muscles in the exercises investigated under different EO. That is, muscle thickness measurements were obtained from muscles that were primary agonists only in SJ exercise, but synergists in MJ exercises. For example, studies that explored the effects of EO on biceps brachii hypertrophy used a biceps curl SJ exercise and the lat-pull down MJ exercise (Avelar et al., 2019; Simão et al., 2010; Spineti et al., 2010). This can be problematic given that the biceps brachii is the agonist in the biceps curl exercise whereas, for the lat-pulldown, biceps brachii acts as a synergist. The results of these three studies (Avelar et al., 2019; Simão et al., 2010; Spineti et al., 2010) may only indicate that the performance of an MJ exercise (in which the measured muscle acts as a synergist) before the SJ exercise (where the muscle is worked as an agonist), does not affect the hypertrophic response. Only Avelar et al. (2019) investigated the effect of exercises performed in a different EO (starting with MJ or SJ exercises) for the same target muscle, in the lower-body. According to the results of this study, which lasted six weeks, EO also appeared to have minimal effects on overall increases in muscle size. In this study, performing the leg press (MJ) or knee extension (SJ) first in the exercise session resulted in similar effects on mid-thigh quadriceps femoris hypertrophy (Avelar et al., 2019).

Similar effects of EO were also observed when considering indirect measures of muscle hypertrophy, as shown in Figure 2B (Avelar et al., 2019; Cardozo et al., 2019; Fisher et al., 2014; Pina et al., 2013; Tomeleri et al., 2019). These indirect methods included DXA (Avelar et al., 2019; Tomeleri et al., 2019), air displacement plethysmography (Fisher et al., 2014), bioimpedance (Pina et al., 2013), and skinfolds (Cardozo et al., 2019). Potential differences between groups might have been diluted because these methods have a limited capability of assessing subtle changes in muscle hypertrophy (Haun et al., 2019), which needs to be mentioned as a potential limitation of the presented findings.

Some authors have suggested that the MJ-to-SJ order may be superior for producing greater overall increases in muscle mass (as compared to SJ-to-MJ order) because it allows accumulation of a greater training volume (i.e. repetitions and/or volume-load) especially in the MJ exercises that activate more muscle groups (Ratamess et al., 2009; Sforzo & Touey, 1996). While this approach may have credence on a general level, a different approach may be warranted when the goal is to focus on hypertrophic development of a specific muscle group (e.g. pectoralis major). In this case, others have speculated that it is better to perform isolated SJ exercises (e.g. pecdeck) prior to the MJ exercises (e.g. chest press) in the exercise session as a means to provide greater stimulation for this specific muscle group (Ribeiro, Nunes, Cunha, Aguiar, & Schoenfeld, 2019). While our results suggest that similar increases in muscle size are achieved regardless of EO, future studies are needed to provide additional insight into these nuanced aspects. Future studies should endeavour to investigate the effect of different EO with exercises for the same target muscles [e.g. pecdeck (SJ) and chest press (MJ), for pectoralis major] using site-specific measurement techniques, and compare the hypertrophic changes of muscles that act as agonists in both MJ and SJ exercise as opposed to just the synergists (Ribeiro et al., 2019; Ribeiro, Schoenfeld, & Nunes, 2017).

It is important to clarify the methodological quality of the included studies, which were classified as being of excellent to good quality. Indeed, most of the key items on the TESTEX checklist (Smart et al., 2015) were satisfied by the majority of the included studies. That said, some limitations warrant mention. Of the 11 included studies, three did not report data on training adherence. Given that differences in training adherence between the groups may have a profound impact on the overall results of a given study, future research should ensure that training adherence is reported for both groups. Additionally, in three studies, it was unclear if the training programmes were supervised. Training supervision has been shown to impact gains in muscular strength, with greater gains observed in supervised vs. unsupervised training programmes (Mazzetti et al., 2000). This information needs to be clearly reported in future studies.

Conclusions

The results of this review indicate that EO influences gains in muscular strength. Increases in strength are greatest in exercises that are performed at the beginning of a training session. Therefore, to optimise strength gain in a given exercise, that exercise should be performed at the beginning of the training session. For muscle hypertrophy, similar results appear to be achieved regardless of EO.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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