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SYSTEMATIC REVIEW

Chronic Effects of Altering Resistance Training Set Configurations Using Cluster Sets: A Systematic Review and Meta-Analysis

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Abstract

Background The acute responses to cluster set resistance training (RT) have been demonstrated. However, as compared to traditional sets, the effect of cluster sets on muscular and neuromuscular adaptations remains unclear.

Objective To compare the effects of RT programs implementing cluster and traditional set configurations on muscular and neuromuscular adaptations.

Methods Systematic searches of Embase, Scopus, Medline and SPORTDiscus were conducted. Inclusion criteria were: (1) randomized or non-randomized comparative studies; (2) publication in English; (3) participants of all age groups; (4) participants free of any medical condition or injury; (5) cluster set intervention; (6) comparison intervention utilizing a traditional set configuration; (7) intervention length ≥ three weeks and (8) at least one measure of changes in strength/force/torque, power, velocity, hypertrophy or muscular endurance. Raw data (mean ± SD or range) were extracted from included studies. Hedges' *g* effect sizes (ES) ± standard error of the mean (SEM) and 95% confidence intervals (95% CI) were calculated.

Results Twenty-nine studies were included in the meta-analysis. No differences between cluster and traditional set configurations were found for strength (ES = −0.05 ± 0.10, 95% CI −0.21 to 0.11, $p = 0.56$), power output (ES = 0.02 ± 0.10, 95% CI −0.17 to 0.20, $p = 0.86$), velocity (ES = 0.15 ± 0.13, 95% CI −0.10 to 0.41, $p = 0.24$), hypertrophy (ES = −0.05 ± 0.14, 95% CI −0.32 to 0.23, $p = 0.73$) or endurance (ES = −0.07 ± 0.18, 95% CI −0.43 to 0.29, $p = 0.70$) adaptations. Moreover, no differences were observed when training volume, cluster set model, training status, body parts trained or exercise type were considered.

Conclusion Collectively, both cluster and traditional set configurations demonstrate equal effectiveness to positively induce muscular and neuromuscular adaptation(s). However, cluster set configurations may achieve such adaptations with less fatigue development during RT which may be an important consideration across various exercise settings and stages of periodized RT programs.

1 Introduction

1.1 Background

Structured and ongoing resistance training (RT) is an important component in the development of various physical performance characteristics [1]. In particular, strength [2], power and velocity [3], hypertrophy [4] and endurance [5] are critical components of athletic development, performance and overall health. Traditionally, RT has been prescribed based on set configurations where continuous repetitions are performed followed by inter-set rest periods, ranging from 1 to 5 min in duration [6]. These configurations are referred to in the literature as 'traditional sets' [7] and although they can elicit large amounts of fatigue and metabolite accumulation, they can positively influence muscular strength adaptations [8–10]. However, it is unclear if these set configurations provide an optimal or advantageous stimulus as compared to other techniques. Moreover, in periodized training plans, further consideration must be given to the emphasis of the overall goal(s) of the training phase. For example, when muscular strength and power development are prioritized and fatigue needs to be minimized, traditional

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Key Points

Cluster and traditional set configurations produce similar improvements in muscular strength, power output, movement velocity, muscle hypertrophy and endurance.

The observations remained consistent when outcomes were sub-analyzed for controlling of training volume, cluster set model, training status, body parts trained, and exercise type.

Future research is warranted investigating the chronic effects of altering set configuration in clinical populations in which fatigue and high exertions during resistance training are contraindicated.

set configurations may not be optimal and thus other strategies are required.

Consequently, the implementation of intra-set rest periods, collectively known as 'cluster sets', is suggested to provide a novel RT stimulus that aims to optimize muscular and neuromuscular adaptations [6, 7]. The implementation of cluster sets was first presented in the scientific literature in 1987 by Roll and Omer [11], as part of the spring and summer North American Football program at Tulane University. Anecdotal evidence for the use of cluster sets dates back to the 1950s based upon reports of United States Weightlifting coach, Carl Miller [12]. In particular, the addition of intra-set rest periods has been shown to reduce the magnitude of performance decrement (i.e. fatigue) during sets [13] and thus facilitate greater overload and higher training intensities [6, 7]. There is clear evidence demonstrating the acute benefits of cluster set configurations during RT. Specifically, a recent meta-analysis by Latella et al. [14] indicated that cluster sets are an effective technique for reducing the loss in velocity and power output that are commonly observed during traditional set configurations. Cluster sets may also allow the same number of repetitions to be performed with a lower perceived exertion [15]. Alternatively, the same number of repetitions can be performed with a greater load as compared to traditional set configurations [6, 16]. However, whilst acute responses differ between traditional and cluster sets, the purpose of structured training is to produce adaptations over extended periods of time. Therefore, a greater understanding of the long-term effects of altering set-configuration during training sessions is vital to substantiate their proposed efficacy within training plans.

The current evidence regarding chronic performance adaptations following cluster and traditional sets is somewhat conflicting. For muscular strength and hypertrophy, traditional set configurations have previously been recommended due to the large amount of fatigue that is developed [17], greater time-under-tension [16], metabolite accumulation [18] and greater muscle activation in later phases of the set compared to cluster set configurations [19]. However, while several studies show support for the superiority of traditional compared to cluster set configurations for the development of muscular strength [8, 9, 20–22], others do not [23–25] or show no difference [26–28]. In addition, during specific phases of RT, movement velocity and power output are a primary focus. Greater movement velocity during repetitions and thus, a greater power output, have been demonstrated with cluster sets when fatigue is minimized [13, 16–18, 29]. Greater velocity during training sessions is hypothesized to provide a specific training stimulus for the development of power output and movement velocity and thus, result in positive adaptations in these variables [13, 17, 18]. However, similar to muscular strength and hypertrophy, supporting longitudinal evidence for the development of movement velocity and power output across a training block utilizing cluster sets is, at this stage, unclear [20, 24, 26–28, 30]. Conversely, reducing fatigue during RT may not be conducive to the development of other performance abilities. For example, cluster sets may not be optimal to evoke muscular endurance adaptations [31], but evidence is lacking. Thus, whether cluster or traditional sets promote similar or superior muscular and neuromuscular adaptations is unknown in their current use in applied settings and given apparent differences in the acute response(s) to each.

1.2 Objectives

The aim of this review was to collate evidence from the available literature that directly compared the effects of RT programs implementing cluster and traditional set configurations on human muscular and neuromuscular adaptations. Specifically, systematic and meta-analytic approaches were conducted to determine the chronic effect of each configuration and further influence of controlling for training volume, cluster set model utilized, training status, exercise type and body part(s) trained on subsequent adaptations. We also assessed the quality of available data and identified areas for future research to address. It is intended that the findings of this review will provide comprehensive evidence regarding the effectiveness of altering set configuration on various markers of muscular and neuromuscular performance development. Specifically, this information may assist in training program planning and preparation by strength and conditioning practitioners and exercise professionals.

2 Methods

2.1 Research Question

This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [32]. The primary purpose of this review was to determine the chronic effects of altering set configuration during RT on a variety of neuromuscular and muscular performance parameters. The research question was defined using the participants, interventions, comparisons, outcomes and study design (PICOS) framework;

1. *Participants* Apparently healthy individuals of all training experiences, sexes and ages.
2. *Interventions* RT interventions (≥ 3 weeks) that employed a cluster set protocol or cluster set alternative (e.g., rest–pause method).
3. *Comparator* RT interventions that employ a traditional set configuration.
4. *Outcomes* Neuromuscular and muscular performance parameters including; muscular strength, power, velocity, hypertrophy and muscular endurance.
5. *Study design* Prospective randomized or non-randomized comparative studies.

2.2 Information Sources and Literature Search Strategy

We systematically searched four databases; Embase, Scopus, Medline and SPORTDiscus. TBD and DLT conducted the initial search on the 6th of February, 2020. Searches were limited to English studies in all databases with no date restriction. Searches in Medline and Embase were restricted to human studies only. In addition, forward citation tracking of included articles was conducted to detect studies that were missed in the initial search. The search strategy involved combining the MeSH terms and keywords; 'cluster*' OR 'cluster loading' OR 'cluster-type' OR 'inter-set rest' OR 'rest redistribution' OR 'rest-loading' OR 'rest-pause' OR 'traditional set' OR 'intra set' OR 'inter rep*' OR 'work-to-rest ratio' OR 'repetition mechanics' OR 'set configuration' AND 'weightlifting' OR 'weight lifting' OR 'weight-training' OR 'weight training' OR 'resistance-training' OR 'resistance training' OR 'resistance exercise' OR 'strength-training' OR 'strength training' AND 'power' OR 'power output' OR 'strength' OR 'muscular strength' OR 'neur*' OR 'velocity' OR 'endurance' OR 'performance' OR 'hypertroph*' OR 'force' OR 'musc*'. The search was updated on the 13th of July, 2020.

2.3 Study Selection and Outcomes of Interest

TBD and DLT independently screened titles and abstracts for full-text screening inclusion using Covidence systematic review software (Veritas Health Innovations, Melbourne, Australia) [33]. Duplicates were filtered by Covidence and manually screened in order to ensure all duplicates were identified. TBD and DLT conducted full-text screening for final article inclusion and data extraction. Conflicts at either the title and abstract or full-text screening stages were discussed and resolved by consensus or by a third reviewer (CMH). The primary outcome of interest was muscular strength measured or estimated using the maximal or peak and/or average value from isometric or dynamic testing modalities. Secondary outcomes included measures or estimates of power output (maximal or peak and/or average or in distance travelled for measurements involving projection of objects), velocity (peak and/or average velocity of a movement, barbell or body during motion), skeletal muscle hypertrophy (whole-body muscle mass or muscle-specific thickness/cross-sectional area) and muscular endurance (number of repetitions until task failure or time taken until task failure).

2.4 Inclusion Criteria

The inclusion criteria for this review included: (1) randomized or non-randomized comparative studies; (2) scholarly publication in the English language; (3) participants of all age groups; (4) recruited participants were free of any medical condition or injury; (5) training intervention group that utilized a cluster set configuration (i.e. intra-set rest, inter-repetition rest, rest redistribution and/or rest–pause models) as defined by Tufano et al. [6]; (6) a comparison training intervention group which utilized a traditional set configuration (i.e. continuous repetitions with no intra-set rest strategy); (7) intervention length ≥ three weeks in length (i.e. long-enough to detect changes in muscular strength and hypertrophy) and (8) at least one measure or estimate of changes in strength/force/torque output, power output, muscle hypertrophy, velocity or muscular endurance.

2.5 Data Extraction

Pre- and post-intervention data were extracted as mean ± standard deviation (SD) or as a range where required. Full texts were obtained for studies selected for inclusion in the review. TBD extracted the relevant data of interest including: (1) study information (year of publication, sample size and study author); (2) participant characteristics (age, sex, weight, height and training age/status); (3) RT variables (types of exercise, training frequency, intervention duration, set-configuration, rest periods, tempo, number of repetitions/sets, time of training session, if volume and/or intensity was controlled and relative training volume); (4) reported injuries; (5) muscular performance outcome measures (as defined in the study selection and outcomes of interest section) and (6) methods of outcome assessment. If the data were unclear or not presented in the full text, the corresponding authors were contacted for variables of interest and subsequently included or excluded.

2.6 Study Quality and Reporting Assessment

Quality assessment was conducted by CL and CMH using the 'Tool for the assessment of study quality and reporting in exercise' (TESTEX) [34]. Disagreements were discussed and resolved by consensus or by a third assessor (TBD) for study quality. The TESTEX tool is designed specifically for exercise training interventions and permits a total of 15 points to be awarded (5 for study quality and 10 for reporting). For study quality, a point was given for: (1) eligibility criteria specification; (2) randomization specification; (3) allocation concealment; (4) groups being similar at baseline and (5) blinding of assessor for at least one primary outcome. For study reporting a point was given for: (1) outcome measures assessed in 85% of participants; (2) adverse events were reported; (3) exercise attendance reported; (4) intention-to-treat analysis; between-group statistical comparisons for (5) primary and (6) secondary outcome measure; (7) point estimates provided for all outcomes; (8) activity monitoring in control groups; (9) relative exercise intensity remained constant and (10) if exercise volume and energy expenditure can be calculated. As, to our knowledge, no current method of categorizing study quality based on this scale is currently available, we chose to divide total scores (i.e. out of 15) into quartiles. Based on this approach, we considered a score of < 4 as "poor", 4–7 as "moderate", 8–11 as "good" and > 11 as excellent study quality and reporting.

2.7 Statistical Analysis

For a conservative view on the random error in the data, a random-effects model was implemented for all variables of interest. The data are presented as mean ± SD for descriptive reporting. Hedges' *g* (mean difference divided by pooled weighted standard deviation) effect size (ES) ± standard error of the mean (SEM) and 95% confidence intervals (95% CI) were used to present effects between interventions. ES were interpreted in all analyses as; < 0.2, 0.6, 1.2, 2.0 and > 4.0 for small, moderate, large, very large and extremely large effects, respectively [35], with a positive ES indicating that the effect favored cluster set configurations, while a negative ES favored traditional set configurations. All analyses were conducted using Comprehensive Meta-analysis software version 3 (Biostat, Englewood, NJ, USA). Heterogeneity was assessed by the I^2 and Chi^2 (Q value) statistics. A value of less than 40% was considered as insignificant heterogeneity. For adequate statistical power, a minimum of five studies were included in the pooled random-effects analysis for the main outcomes [36]. Funnel plots of Hedges' *g* and their SEM were used to assess publication bias for all primary analyses [37]. Studies with multiple measures for the outcome of interest or multiple groups were combined into a single ES for analysis to avoid incorrect weighting of studies [38].

Sub-analyses were used to determine the effects of potential primary confounding variables on between-group effects. Specifically, controlling for training volume, cluster set model, training status, body parts trained (i.e. upper and lower body exercises) and exercise type (i.e. isolated and compound exercises) were considered during the sub-analysis for all outcomes where appropriate. For detailed characterization of study interventions or sub-analysis, confounding variables were defined as follows:

1. *Training volume* Volume was considered as "matched" if the absolute training volume (total number of completed repetitions per exercise per session) were equivalent across the intervention. Overall relative training load (volume) was calculated as sets × repetitions × percentage of 1-repetition maximum (1RM) [39]. The total relative training volume was determined as the sum of relative training volume for all sessions.
2. *Cluster set models* We defined cluster set configurations as a rest period implemented between single or groups of repetitions, including undulating and ascending cluster sets [7]. Specifically, cluster set models included; rest redistribution, inter-repetition rest, basic cluster set and the rest–pause method as defined by Tufano et al. [6].
3. *Training status* Similar to the approach by Latella et al. [14], we categorized participants by training status as either untrained ("physically active and/or < 12 months' RT experience"), trained ("> 12 months' RT experience") or athletic ("state-level or above athletes").
4. *Body parts trained* Studies were considered upper body, where the training intervention and outcome measures involved upper body movements. The same logic was applied to lower body exercises. In studies where both upper and lower body outcomes were present, ES were split during the sub-analysis.
5. *Exercise type* Movements were considered "compound" if ≥ two joints were used in the outcome of interest (e.g., bench press). An outcome was considered "isolated" if one distinct joint was used during the movement (e.g., biceps curl).

3 Results

3.1 Study Selection and Participant Characteristics

The screening and study selection process (i.e. PRISMA flow diagram) is shown in Fig. 1. Authors of four studies were contacted to obtain relevant data of interest that were not presented in the published manuscripts [8, 40–42] and two authors responded [40, 42]. A total of 29 studies were included in the meta-analysis, with a total of 803 participants (cluster set: n = 388, traditional set: $n = 415$). The average age ranged from 17 to 63 years, with 14 studies using exclusively males [8, 9, 20, 22, 24, 25, 27, 28, 30, 31, 41, 43–45], four studies using exclusively females [23, 42, 46, 47] and 11 using a mixed-sex sample [21, 26, 40, 48–55]. The majority ($n = 15$) of studies were conducted in untrained participants [8, 21, 23, 25, 27, 31, 40, 41, 43, 47, 49, 50, 52, 54, 55], 13 studies included trained participants [9, 22, 24, 26, 28, 30, 42, 44–46, 48, 51, 53] and only one study included "athletic" participants [20]. Detailed participant and intervention characteristics are shown in Tables 1 and 2.

3.2 Intervention Characteristics

Training frequency ranged from two to four days per week, with two days a week most commonly employed ($n = 19$) [8, 20, 23, 26–28, 30, 31, 40, 41, 44, 45, 47–49, 51, 52, 54, 55]. The median training duration was seven weeks (range: 3 to 12 weeks). Most studies implemented volume ($n = 24$) and/or intensity matched ($n = 25$) protocols. One study had a volume controlled and an uncontrolled traditional group [28]. Of the five studies that had groups where training volumes were not matched, three had higher training volumes in the cluster set configuration group [45, 46, 51]. When intensity was accounted for, 20 studies had an equivalent relative volume load [8, 9, 21, 22, 24, 26, 27, 30, 31, 40, 41, 43, 44, 47–50, 52–54] and five studies had a higher relative volume load in the cluster set configuration [23, 45, 46, 51, 55]. The average total time per exercise per session was higher in the cluster set configuration (14.2 ± 7.3 min/exercise/session) compared to the traditional set configuration protocol (11.2 ± 6.0 min/exercise/session). Although this was not statistically significant, a small effect was observed ($p = 0.09$, ES = 0.49). No adverse events were reported from the included studies; however, only six studies reported such data [23, 26, 30, 46, 48, 50].

3.3 Cluster Set Models

A total of 13 studies (45%) utilized an inter-repetition rest cluster set model [21, 22, 26, 28, 40, 42–44, 47–50, 52], eight studies (28%) used a rest redistribution model [9, 24, 25, 27, 30, 31, 46, 54] and only five studies (17%) used a basic cluster set model [8, 20, 23, 41, 55]. The rest–pause method was less common and employed in a total of three studies (10%) [45, 51, 53].

3.4 Muscular Strength

Out of the 29 included studies, 26 studies (90%) reported our primary outcome measure of muscular strength between cluster and traditional set configurations [8, 9, 20–28, 31, 40–47, 49–51, 53–55]. Overall, cluster set configurations improved muscular strength outcomes by 18.6 ± 13.1% and traditional set configurations resulted in a similar increase of 18.4 ± 16.13%. The pooled analysis showed no difference between cluster and traditional set configurations (ES = – 0.05 ± 0.10, 95% CI – 0.21 to 0.11, $p = 0.56$) and is illustrated in Fig. 2. In studies that assessed muscular strength, the most common cluster set model was the inter-repetition rest model which was implemented in 11 studies (42%) [21, 22, 26, 28, 40, 42–44, 47, 49, 50]. Seven studies (27%) used a rest redistribution model [9, 24, 25, 27, 31, 46, 54], five studies (19%) used a basic cluster set model [8, 9, 20, 23–25, 27, 31, 41, 46, 54, 55] and three studies (12%) used the rest–pause method [45, 51, 53]. Notably, 22 studies (85%) controlled for training volume between cluster and traditional set configurations, and over half (58%) of the studies were conducted in untrained participants.

3.4.1 Method of Assessing Strength, Body Parts Trained and Exercise Type

The most common method of assessing muscular strength was a 1RM test which was conducted in 19 studies (73.1%) [8, 21, 24–28, 31, 40, 43–47, 49–51, 53–55]. Other less commonly employed methods included predicted 1RM (19%) [20, 22, 25, 41, 42], while five studies used maximal voluntary contractions (19.2%) [8, 40, 49, 50, 55], one study used a 6RM test [9] and another used a 10RM test [23]. In the studies that tested strength, 18 studies (69.2%) used an upper body exercise and 18 (69.2%) studies used a lower body exercise. The majority of studies (76.9%) used a compound movement including bench press [9, 23–27, 31, 43, 44, 46, 53, 54], squat [8, 24, 27, 31, 40, 50, 54] and shoulder press [8, 25]. Isolated movements were used in nine studies (34.6%), consisting of leg extension [8, 40, 47, 50], biceps curl [21, 49, 53, 55] and the leg press [23, 53].

3.5 Power Output

Seventeen studies were included in the meta-analysis that measured changes in power output [9, 20, 22, 24, 26–28, 30, 31, 40–42, 46, 47, 52, 54]. The average improvement in measures of power output was similar between the cluster

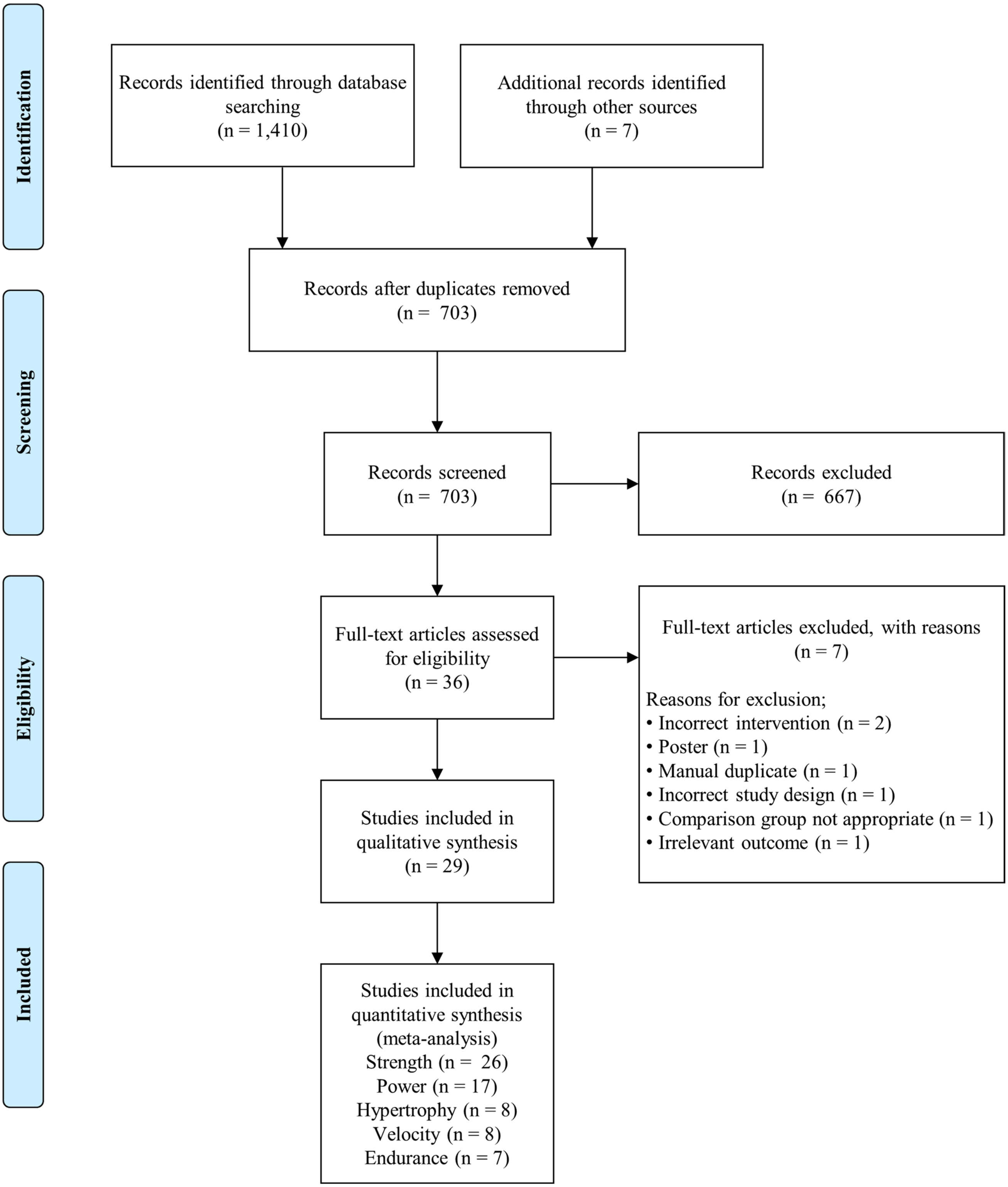


Fig. 1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram of literature search strategy and inclusion

(10.6 ± 11.9%) and traditional set groups (9.1 ± 9.9%). There were no significant differences between groups using cluster or traditional set configurations for changes in power output (ES = 0.02 ± 0.10, 95% CI −0.17 to 0.20, $p = 0.86$) in the pooled analysis (Fig. 3). No individual studies showed statistically significant differences between configurations for

Table 1 Participant characteristics of included studies

Study	Group	Number of participants	Sex distribution	Age [years]^a	Height [cm]^a	Weight [kg]^a	Training status
Arazi et al. [46]	Cluster	10	F	18.2 ± 2.4	161.0 ± 6.0	54.5 ± 6.6	Trained
	Traditional	10	F	18.7 ± 1.5	166.0 ± 5.0	56.5 ± 9.0	
Asadi et al. [30]	Cluster	6	M	20.5 ± 0.6	180.1 ± 4.5	78.4 ± 3.6	Trained
	Traditional	7	M	20.2 ± 0.5	179.6 ± 3.2	79.2 ± 2.8	
Byrd et al. [43]	Cluster (1 s)	10	M	19.4 ± 3.4	176.0 ± 6.0	70.4 ± 7.1	Untrained
	Cluster (2 s)	10	M	21.1 ± 2.3	177.0 ± 4.0	76.8 ± 8.3	
	Traditional	20	M	21.1 ± 3.3	180.0 ± 4.0	72.4 ± 8.8	
Carneiro et al. [47]	Cluster	16	F	63.3 ± 6.7	160.0 ± 1.0	69.9 ± 16.7	Untrained
	Traditional	15	F				
Cuevas-Aburto et al. [44]	Cluster	13	M	20.3 ± 3.1	172.0 ± 5.0	75.0 ± 10.6	Trained
	Traditional	12	M	21.0 ± 2.5	175.0 ± 5.0	73.4 ± 9.2	
Davies et al. [26]	Cluster	11	M/F	26.1 ± 7.1	176.6 ± 8.0	74.2 ± 10.0	Trained
	Traditional	10	M/F	24.6 ± 6.9	174.2 ± 7.6	75.5 ± 9.7	
Davies et al. [48]	Cluster	11	M/F	26.1 ± 7.1	176.6 ± 8.0	74.2 ± 10.0	Trained
	Traditional	10	M/F	24.6 ± 6.9	174.2 ± 7.6	75.6 ± 9.7	
Dias et al. [23]	Cluster	31	F	61.1 ± 4.9	155.7 ± 4.7	64.5 ± 12.8	Untrained
	Traditional	35	F				
Farinas et al. [49]	Cluster	11	M/F	24.0 ± 2.0	175.0 ± 9.0	75.0 ± 11.0	Untrained
	Traditional	12	M/F	24.0 ± 5.0	173.0 ± 8.0	71.1 ± 11.2	
Folland et al. [50]	Cluster	11	M/F	20.0 ± 1.0	176.0 ± 1.0	68.0 ± 7.0	Untrained
	Traditional	12	M/F	22.0 ± 2.0	181.0 ± 0.9	70.0 ± 3.0	
Giessing et al. [51]	Cluster	29	M/F	42.0 ± 7.0	179.1 ± 7.8	76.5 ± 14.7	Trained
	Traditional (G-RM)	21	M/F	42.0 ± 7.0	180.3 ± 10.6	80.6 ± 17.7	
	Traditional (G-MMF)	30	M/F	45.0 ± 8.0	178.4 ± 9.5	77.5 ± 14.2	
Goto et al. [8]	Cluster	9	M	21.9 ± 0.7	170.3 ± 1.7	66.4 ± 2.4	Untrained
	Traditional	9	M	23.1 ± 0.9	171.7 ± 2.3	65.2 ± 3.0	
Hansen et al. [20]	Cluster	9	M	27.8 ± 4.5	185.0 ± 1.0	99.7 ± 10.5	Athletic
	Traditional	9	M	25.7 ± 4.5	193.0 ± 1.0	107.3 ± 6.7	
Iglesias-Soler et al. [40]	Cluster	13	M/F	22.5 ± 2.6	172.8 ± 7.4	66.9 ± 9.1	Untrained
	Traditional	13	M/F				
Iglesias-Soler et al. [52]	Cluster	13	M/F	22.5 ± 2.6	172.8 ± 7.4	66.9 ± 9.1	Untrained
	Traditional	13	M/F				
Izqueirdo et al. [31]	Cluster	15	M	23.9 ± 1.9	181.0 ± 0.1	80.5 ± 7.4	Untrained
	Traditional	14	M	24.8 ± 2.9	180.0 ± 0.1	81.1 ± 4.2	
Karsten et al. [27]	Cluster	9	M	23.0 ± 5.0	176.7 ± 7.0	76.0 ± 13.8	Untrained
	Traditional	9	M	24.0 ± 4.0	174.6 ± 9.6	78.4 ± 24.3	Trained
Korak et al. [45]	Cluster	10	M	23.0 ± 2.0	178.5 ± 5.2	81.5 ± 8.5	
	Traditional	10	M	23.1 ± 2.6	175.4 ± 4.6	77.8 ± 10.4	Trained
Lawton et al. [9]	Cluster	11	M	17.0–20.0	170.0–220.0	65.0–.0	
	Traditional	15	M	17.0–20.0	178.3 ± 6.3	76.6 ± 9.7	Untrained
Morales-Artacho et al. [41]	Cluster	10	M	23.6 ± 5.8			
	Traditional	9	M				
Nicholson et al. [28]	Cluster (CS85)	12	M	21.8 ± 2.6	178.0 ± 6.3	81.1 ± 8.8	Trained
	Cluster (CS90)	11	M				
	Traditional (STR)	11	M				
	Traditional (HYP)	12	M				
Oliver et al. [24]	Cluster	11	M	25.0 ± 4.0	179.7 ± 3.9	82.5 ± 10.0	Trained
	Traditional	11	M	25.0 ± 5.0	179.7 ± 6.2	81.7 ± 11.6	

Table 1 (continued)

Study	Group	Number of participants	Sex distribution	Age [years]^{a}	Height [cm]^{a}	Weight [kg]^{a}	Training status
Prestes et al. [52]	Cluster	9	M/F	30.3 ± 6.5	174.9 ± 8.2	82.2 ± 17.9	Trained
	Traditional	9	M/F	30.1 ± 7.2	167.9 ± 11.5	67.4 ± 13.4	
Rial-Vazquez et al. [53]	Cluster	11	M/F	23.0 ± 4.0	177.0 ± 0.8	72.9 ± 11.0	Untrained
	Traditional	13	M/F				
Rooney et al. [21]	Cluster	14	M/F	18.0–35.0	NR	NR	Untrained
	Traditional	14	M/F				
Samson and Pillai [25]	Cluster	16	M	18.0–26.0	NR	NR	Untrained
	Traditional	16	M				
Stragier et al. [55]	Cluster	16	M/F	24.4 ± 2.2	172.6 ± 9.9	67.5 ± 13.1	Untrained
	Traditional	14	M/F	23.2 ± 2.7	172.2 ± 8.2	68.7 ± 11.7	
Yazdani et al. [42]	Cluster	18	F	18.2 ± 3.0	163.0 ± 0.6	53.3 ± 7.3	Trained
	Traditional		F				
Zarezadeh-Mehrizi et al. [22]	Cluster	11	M	24.7 ± 3.1	176.0 ± 0.4	71.7 ± 6.9	Trained
	Traditional	11	M				

[a] The data are reported as mean ± SD or as a range

cm centimetres, *CS85* Cluster training at 85% 1RM from Nicholson et al. [28], *CS90* cluster-training group at 90% 1RM from Nicholson et al. [28], *F* females, *G-MMF* Momentary muscular failure group from Giessing et al. [51], *G-RM* Repetition maximum group from Giessing et al. [51], *HYP* Hypertrophy-training group from Nicholson et al. [28], *kg* kilograms, *M* males, *NR* not reported, *SD* standard deviation, *STR* Strength-training group from Nicholson et al. [28]

power output outcomes. The most common model of cluster set prescribed in studies that measured power output were the inter-repetition rest ($n=7$, 41%) [22, 26, 28, 40, 42, 47, 52] and rest redistribution ($n=7$, 41%) models [9, 24, 27, 30, 31, 46, 54], while three studies (18%) used a basic cluster set model [20, 23, 41]. Fifteen (88%) studies controlled for training volume between cluster and traditional set configurations, and nine of the 17 (53%) studies were conducted in untrained participants.

3.5.1 Method of Assessing Power, Body Parts Trained and Exercise Type

The majority of studies ($n=15$, 88%) used a lower body exercise to either directly and/or indirectly (e.g. height or distance) assess power output, with a jump variation (i.e. countermovement jump, standing long jump, jump squat) being the most common lower body movement ($n=10$, 67%) [22–24, 27, 28, 30, 31, 41, 42, 46], along with four studies (27%) using a squat [20, 24, 31, 54] and three studies (20%) using a leg extension [40, 47, 52]. Only seven studies (41%) tested power output with an upper body exercise, of which five (86%) used a bench press [24, 26, 27, 31, 54] and two (14%) used a throwing movement [9, 23]. The majority of studies used compound movements to assess power output ($n=14$, 82%) [9, 20, 22–24, 26–28, 30, 31, 41, 42, 46, 54], while only three studies (18%) used an isolated movement [40, 47, 52].

3.6 Velocity

Eight studies were included in the meta-analysis for velocity outcomes [20, 23, 26, 41, 44, 47, 52, 54]. There was an average increase in velocity of 2.5 ± 13.4% in cluster set configurations, while there was an average decrease in velocity of 3.4 ± 8.9% in traditional set configurations. However, the pooled analysis (Fig. 4) showed no statistically significant difference between set configurations (ES = 0.15 ± 0.13, 95% CI − 0.10 to 0.41, $p=0.24$). Half of the studies used an inter-repetition rest cluster set model [26, 44, 47, 52], three studies (37.5%) used a basic cluster model [20, 23, 41] and one study (12.5%) used a rest redistribution model [54]. Almost all studies ($n=7$, 88%) included in the pooled analyses controlled for training volume, and five studies (63%) were in untrained participants.

3.6.1 Method of Assessing Velocity, Body Parts Trained and Exercise Type

A large variation in measurement types was observed for velocity outcomes. Out of the eight studies that reported velocity outcomes, three (37.5%) [26, 47, 54] assessed velocity using a fixed fraction of a 1RM (i.e. the relative load remained the same but the external load varied according to the degree of muscular strength adaptation) [26, 47, 54], while two studies (25%) [20, 44] used a fixed load (i.e. relative load changed but the external load remained the same) [20, 44]. Four studies (50%) used force–velocity profiling to

Table 2 Training characteristics of included studies

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/ week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Arazi et al. [46]	Cluster	Weeks 1–4 (SQ, BP, DL, MP): 3 × 10 clustered after 5 repetitions at 60–80% 1RM (20–30 s), 90–120 s rest between sets, 10 to 30 s rest between clusters Weeks 5–8 (JS, EBP, DL, PC): 3 × 3–15 repetitions (clustered by dividing total repetitions in set by 3) at 30–40% 1RM (UB), 45–55% 1RM (LB), 120–180 rest sec between sets, 10 to 30 s rest between clusters	8	3	14.5	818.0	Ascending load RR	ST: 1RM SQ, BP, DL and MP PT: CMJ (PP)
	Traditional	Weeks 1–4 (SQ, BP, DL, MP): 3 × 10 repetitions at 60–80% 1RM, 120 s of inter-set rest Weeks 5–8 (JS, EBP, DL, PC): 3 × 3–6 repetitions at 30–40% 1RM (UB), 45–55% 1RM (LB), 180 s of inter-set rest			11.4	774.0	Traditional	
Asadi et al. [30]	Cluster	DJ: 5 × 20 repetitions, 90 s of inter-set rest and 30 s of intra-set rest at mid-point of the set	6	2	100.0	910.0	RR	PT: CMJ and SLJ
	Traditional	DJ: 5 × 20 repetitions, 120 s of inter-set rest			100.0	880.0	Traditional (PLYO)	

Table 2 (continued)

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Byrd et al. [43]	Cluster (1 s)	SMP, BC, LP, BP, SU, LC: 3 × 6–10 repetitions, 900 s rest between individual exercises (done as a circuit), 60 s between each exercise in circuit, 1 s of rest per repetition	10	3	18.0	786.0	IRR	ST: 1RM BP and LP
	Cluster (2 s)	SMP, BC, LP, BP, SU, LC: 3 × 6–10 repetitions, 900 s rest between individual exercises (done as a circuit), 60 s between each exercise in circuit, 1 s of rest per repetition			18.0	876.0	IRR	
	Traditional	SMP, BC, LP, BP, SU, LC: 3 × 6–10 repetitions, 900 s rest between individual exercises (done as a circuit). 60 s between each exercise in circuit			18.0	696.0	Traditional	
Carneiro et al. [47]	Cluster	LE: 3 × 4 repetitions at 90% 1RM, 90 s of inter-set rest, 30 s of IRR	8	2	10.8	450.0	IRR	ST: 1RM LE PT: PP at 40, 50 and 60% 1RM HT: estimated thigh CSA VT: $V_{\max}$, velocity at 40%, 50% and 60% 1RM
	Traditional	LE: 3 × 4 repetitions at 90% 1RM, 90 s of inter-set rest			10.8	180.0	Traditional	
Cuevas-Aburto et al. [44]	Cluster	BP: 1 × 30 repetitions at 75% 1RM, 31 s of IRR	6	2	22.5	989.0	IRR	ST: 1RM BP VT: BPT velocity with 30 kg, handball throw velocity
	Traditional	BP: 6 × 5 repetitions at 75% 1RM, 180 s of inter-set rest			22.5	990.0	Traditional	

Table 2 (continued)

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Davies et al. [26]	Cluster	BP: 4×5 repetitions at 85% 1RM, 30 s of IRR and 180 s of inter-set rest	8	2	17.0	1,070.0	IRR	ST: 1RM BP PT: power at 45–95% 1RM VT: velocity at 45–95% 1RM
	Traditional	BP: 4×5 repetitions at 85% 1RM, 300 s of inter-set rest			17.0	950.0	Traditional	
Davies et al. [48]	Cluster	BP: 4×5 repetitions at 85% 1RM, 30 s of IRR and 180 s of inter-set rest	8	2	17.0	1,070.0	IRR	HT: MT of the pectoralis major and triceps brachii ET: repetitions performed at 70% 1RM
	Traditional	BP: 4×5 repetitions at 85% 1RM, 300 s of inter-set rest			17.0	950.0	Traditional	
Dias et al. [23]	Cluster	3×8 repetitions at 75% of 10RM with 120 s of inter-set rest and 30 s of rest every two repetitions (BP, LP, SR, DL), 2×10 repetitions with 3 kg ball, 2×maximum time (PL)	12	2	15.6	606	Basic Cluster	ST: 10RM LP, BP PT: MBT, SLJ, CMJ, SJ ET: Plank hold for time, 2 kg BC to failure VT: gait speed velocity during 6 m walk
	Traditional	3×8 repetitions at 75% of 10RM with 120 s of inter-set rest (BP, LP, SR, DL), 2×10 repetitions with 3 kg ball, 2×maximum time (PL)			13.5	336	Traditional	
Farinas et al. [49]	Cluster	BC: 1×30 repetitions at 10RM (~75% 1RM), 18.5 s of IRR	5	2	22.5	656.5	IRR	ST: 1RM BC, MVC HT: biceps brachii MT ET: work with 10RM load at pre-test
	Traditional	BC: 6×5 repetitions at 10RM (~75% 1RM), 135 s rest of inter-set rest			22.5	660.0	Traditional	

Table 2 (continued)

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Folland et al. [50]	Cluster	LE: 1 × 40 repetitions at 75% 1RM, 30 s of IRR	9	3	30.0	1,330.0	IRR	ST: 1RM LE, LE MVC
	Traditional	LE: 4 × 10 repetitions at 75% 1RM, 30 s of inter-set rest			30.0	250.0	Traditional	
Giessing et al. [51]	Cluster	HE, LE, LC, TF, P-O, LPD, CP, BC: 1 set to self-determined RM, 5–20 s of IRR in the bottom position of each movement at 90% 1RM, ~ 10 s of rest between exercises	10	2	16.2	1,950.0	RP	ST: 1RM LE, LC, TF, CP, BC
	Traditional (G-RM)	HE, LE, LC, TF, P-O, LPD, CP, BC: 1 set to self-determined RM on each exercise at 60% 1RM, ~ 10 s rest between exercises			7.2	190.0	Traditional	
	Traditional (G-MMF)	HE, LE, LC, TF, PO, LPD, CP, BC: 1 set to failure on each exercise at 80% 1RM, ~ 10 s rest between exercises			7.2	160.0	Traditional	
Goto et al. [8]	Cluster	LPD, SP, LE: 3–5 × 10 repetitions at 10RM (~ 75% 1RM), 60 s of inter-set rest and 30 s of rest at repetition 5	12	2	27.5	760.0	Basic Cluster	ST: 1RM SP and LE, LE MVC ET: work at 70% 1RM on the SP and LE
	Traditional	LPD, SP, LE: 3–5 × 10 repetitions at 10RM (~ 75% 1RM), 60 s of inter-set rest			27.5	520.0	Traditional	

Table 2 (continued)

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Hansen et al. [20]	Cluster	FS, CLP, SQ, BS, PC, JS: 3–5 × 3–6 repetitions at 80–95% 1RM clustered at set mid-point, 120–180 s of inter-set rest, 20–30 s rest between cluster	8	2	15.8	604.0	Basic Cluster	ST: predicted 1RM SQ PT: PP at 0, 20, 40 and 60 kg VT: PV at 0, 20, 40 and 60 kg
	Traditional	FS, CLP, SQ, BS, PC, JS: 3–5 × 3–8 repetitions at 80–95% 1RM, 180 s of inter-set rest			19.3	606.0	Traditional	
Iglesias-Soler et al. [40]	Cluster	LE: 1 × 32 repetitions at 10RM (~ 75% 1RM), 17.4 s of IRR	5	2	24.0	667.4	IRR	ST: 1RM LE, LE MVC PT: LE isometric RFD HT: corrected thigh girth ET: LE time to task failure
	Traditional	LE: 4 × 8 repetitions at 10RM (~ 75% 1RM), 180 s of inter-set rest			24.0	668.0	Traditional	
Iglesias-Soler et al. [52]	Cluster	LE: 1 × 32 repetitions at 10RM (~ 75% 1RM), 17.4 s of IRR	5	2	24.0	667.4	IRR	PT: LE isometric RFD VT: slope of F-V, V_{max}
	Traditional	LE: 4 × 8 repetitions at 10RM (~ 75% 1RM), 180 s of inter-set rest			24.0	668.0	Traditional	

Table 2 (continued)

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Izqueirdo et al. [31]	Cluster	SQ, BP: Phase 1: 6×5 repetitions at 10RM (BP), 6×5 repetitions at 80% of 10RM (PS), 120 s of inter-set rest. Phase 2: 6×3 repetitions at 6RM (BP), 6×3 repetitions at 80% of 6RM, 120 s of inter-set rest	11	2	19.4	672.0	RR	ST: 1RM SQ and BP PT: PO at 60% 1RM SQ and BP, CMJ at 0% and 30% of body mass ET: repetitions performed at 75% 1RM on SQ and BP
	Traditional	SQ, BP: "Phase 1: 3×10RM (BP), 3×80% of 10RM (PS), 120 s of inter-set rest. Phase 2: 3×6RM (BP), 3×80% of 6RM, 120 s of inter-set rest			19.4	312.0	Traditional	
Karsten et al. [27]	Cluster	BP, CF, CP, BC, BOR, LR, MP, FR, LPD, RDF, P-O, SC, CGBP, TP, SQ, DL, LC: 8×5 repetitions at ~ 75% 1RM per exercise, 60 s of inter-set rest	6	2	30.0	580.0	RR	ST: 1RM SQ and BP PT: CMJ, power at 50% 1RM on BP HT: VM, biceps and anterior deltoid MT
	Traditional	BP, CF, CP, BC, BOR, LR, MP, FR, LPD, RDF, P-O, SC, CGBP, TP, SQ, DL, LC: 4×10 repetitions at approximately 75% 1RM per exercise, 120 s of inter-set rest			30.0	520.0	Traditional	
Korak et al. [45]	Cluster	BP: 4 sets to failure at 80% 1RM, 4 s of IRR, 120 s of inter-set rest	4	2	55.4	910.2	RP	ST: 1RM BP
	Traditional	BP: 4 sets to failure at 80% 1RM, 120 s of inter-set rest			41.1	565.7	Traditional	

Table 2 (continued)

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Lawton et al. [9]	Cluster	BP: 8 × 3 repetitions at 85–105% of pre-training 6RM, 113 s of inter-set rest	6	3	19.4	863.0	RR	ST: 6RM BP PT: BPT PO at 20, 30 and 40 kg
	Traditional	BP: 4 × 6 at 85–105% of 6RM, 260 s of inter-set rest			19.4	852.0	Traditional	
Morales-Artacho et al. [41]	Cluster	JS: 6 × 6 repetitions at 20% 1RM, 270 s of inter-set rest and 30 s rest every two repetitions	3	2	7.2	1,818.0	Basic Cluster	ST: predicted 1RM SQ PT: $P_{\max}$ VT: $V_{\max}$, slope of F–V
	Traditional	JS: 6 × 6 repetitions at 20% 1RM, 300 s inter-set rest			7.2	1,608.0	Traditional	
Nicholson et al. [28]	Cluster (CS85)	SQ: 4 × 6 repetitions at 85% 1RM, 300 s of inter-set rest and 25 s of IRR	6	2	20.4	1,496.0	IRR	ST: 1RM SQ PT: CMJ PP at 0, 20 and 40 kg
	Cluster (CS90)	SQ: 4 × 6 repetitions at 90% 1RM, 300 s of inter-set rest and 25 s of IRR			20.4	1,496.0	IRR	
	Traditional (STR)	SQ: 4 × 6 repetitions at 85% 1RM, 300 s of inter-set rest			20.4	996.0	Traditional	
	Traditional (HYP)	SQ: 5 × 10 repetitions at 70% 1RM, 90 s of inter-set rest			35.0	560.0	Traditional	

Table 2 (continued)

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Oliver et al. [24]	Cluster	BP, IDBP, SMP, SQ, LP, HP, DBCP, PPress, FS, RDL, STU: 8 × 5 repetitions at 60–75% 1RM, 60 s of inter-set rest	12	4	27.0	540.0	RR	ST: 1RM SQ and BP PT: CMJ, PO at 60% 1RM for SQ and BP HT: LBM
	Traditional	BP, IDBP, SMP, SQ, LP, HP, DBCP, PP, FS, RDL, STU: 4 × 10 repetitions at 60–75% 1RM, 120 s of inter-set rest			27.0	480.0	Traditional	
Prestes et al. [52]	Cluster	BP, LP, BC: Sets to failure at 80% 1RM, 20 s of inter-set rest until 18 repetitions were achieved	6	4	14.4	152.0	RP	ST: 1RM BC, BP and LP HT: arm, chest and thigh MT, LBM ET: repetitions performed at 60% 1RM on BC, BP and LP
	Traditional	BP, LP, BC: 3 × 6 repetitions at 80% 1RM, 120 – 180 s of inter-set rest			14.4	372.0	Traditional	
Rial-Vazquez et al. [53]	Cluster	BP, SQ, LP, LC: 16 × 2 repetitions at 75% 1RM, 60 s of inter-set rest	5	2	24.0	996.0	RR	ST: 1RM SQ and BP PT: P_{max} VT: V_{max}
	Traditional	BP, SQ, LP, LC: 4 × 8 repetitions at 75% 1RM, 300 s of inter-set rest			24.0	996.0	Traditional	
Rooney et al. [21]	Cluster	BC: 1 × 6–10 repetitions at 6RM, 30 s of IRR	6	3	6.8	242.0	IRR	ST: 1RM BC
	Traditional	BC: 1 × 6–10 repetitions at 6RM performed continuously			6.8	32.0	Traditional	

Table 2 (continued)

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Samson and Pillai [25]	Cluster	BP, SP, BOR, SS, SQ, CR: 8 sets of 3 repetitions at 75% 1RM, 15 s of inter-set rest	7	3	18.0	201.0	RR	ST: predicted 1RM BP, SP, BOR, SS, SQ and CR
	Traditional	BP, SP, BOR, SS, SQ, CR: 3×6–10 repetitions at ascending loads (~75 – 85% 1RM), 120 s of inter-set rest			19.2	336.0	Traditional	
Stragier et al. [55]	Cluster	BC: 2×3–7 repetitions per cluster at 70% 1RM, 150 s of inter-set rest, 15 s rest between clusters	12	2	35.0	410.0	Ascending basic cluster	ST: 1RM BC, BC MVC HT: BC MT ET: repetitions to failure at 70% 1RM on BC
	Traditional	BC: 8×6 repetitions at 70% 1RM, 120 s of inter-set rest			33.6	1,242.0	Traditional	

Table 2 (continued)

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Yazdani et al. [42]	Cluster	SQ, LU, LC, FC, BP, JS: Strength phase: 3×5 repetitions at 85% 1RM, 120 s of inter-set rest, 10–30 s of IRR. Power phase: 3×5 repetitions at 80% 1RM (SQ), 20% 1RM (JS) and 45% 1RM (BP), 120 s of inter-set rest, 10–30 s of IRR	7	3	13.9	820.0	IRR	ST: predicted 1RM SQ PT: JS PO at 20% 1RM
	Traditional	SQ, LU, LC, FC, BP, JS, BJ, DeJ, PU: Strength phase: 5×5 repetitions at 85% 1RM, 120 s inter-set rest. Power phase: 3×12 repetitions at 30 cm (BJ), 50 cm (DeJ), unloaded (PU), 20% 1RM (JS) and 45% 1RM (BP), 180 s of inter-set rest			13.2	760.0	Traditional	

Table 2 (continued)

Study	Group	Exercise prescription	Duration [weeks]	Frequency [days/week]	Relative Volume (sets × repetitions × relative load per exercise)	Total session time per exercise [s]	Set-structure manipulation	Outcome measures
Zarezadeh-Mehrizi et al. [22]	Cluster	SQ, LU, LC, FC, BP, JS, BPT: Strength phase: 3×5 repetitions at 85% 1RM, 120 s of inter-set rest, 10–30 s of IRR. Power phase: 5×5 repetitions at 80% 1RM (SQ), 30% 1RM (JS) and 70% 1RM (BPT), 120 s of inter-set rest, 10–30 s of IRR	6	3	9.3	1,520.0	IRR	ST: predicted 1RM SQ PT: JS mean PO at 30% 1RM
	Traditional	SQ, LU, LC, FC, BP, JS, BPT: Strength phase: 3×5 repetitions at 85% 1RM, 180 s inter-set rest. Power phase: 5×5 repetitions at 80% 1RM (SQ), 30% 1RM (JS) and 70% 1RM (BPT), 180 s of inter-set rest			9.3	1,240.0	Traditional	

BC Biceps curl, *BJ* Box jump, *BOR* Bentover row, *BP* Bench press, *BPT* Bench press throw, *BS* Box squat, *CF* Chest fly, *CGBP* Close-grip bench press, *CLP* Clean pull, *cm* centimetre *CMJ* Countermovement jump, *CP* Chest press, *CR* Calf raise, *CSA* Cross-sectional area, *CS85* Cluster-training group at 85% 1RM from Nicholson et al. [28], *CS90* Cluster-training group at 90% 1RM from Nicholson et al. [28], *DBCP* Dumbbell chest press, *DeJ* Deep jump, *DL* Deadlift, *DJ* Depth jump, *EBP* Explosive bench press, *ET* Endurance test, *FC* French curl, *FR* Front raise, *FS* Front squat, *F–V* Force–velocity profile, *G-MMF* Momentary muscular failure group from Giessing et al. [51], *G-RM* Repetition maximum group from Giessing et al. [51], *HE* Hip extension, *HP* Hang pull, *HT* Hypertrophy test, *HYP* Hypertrophy-training group from Nicholson et al. [28], *IBP* Incline bench press, *IDBP* Incline dumbbell press, *IRR* Inter-repetition rest, *JS* Jump squat, *LB* Lower body, *LBM* Lean body mass, *LC* Leg curl, *LE* Leg extension, *LP* Leg press, *LPD* Lat pulldown, *LR* Lateral raise, *LU* Lunge, *MBT* Medicine ball throw, *MP* Military Press, *MT* Muscle thickness, *MVC* Maximum voluntary contraction, *PC* Power clean, *PLYO* Plyometric training, P_{max} Theoretical maximum power output from force–velocity profiling, *PO* Power output, *P–O* pullover, *PP* Peak power, *PPress* Push press, *PT* Power test, *PU* Push-up, *RDF* Rear-delt fly, *RDL* Romanian deadlift, *RFD* Rate of force development, *RM* Repetition maximum, *RP* Rest–pause model, *RR* Rest redistribution model, *SC* Skullcrusher, *sec* seconds, *SJ* Squat jump, *SLJ* Standing long jump, *SMP* Seated military press, *SP* Shoulder press, *SQ* Squat, *SS* Sumo squat, *ST* Strength test, *STR* Strength-training group from Nicholson et al. [28], *STU* Step-up, *SU* Sit-up, *TF* Trunk flexion, *TP* Triceps pushdown, *UB* Upper body, V_{max} Velocity at zero force derived from force–velocity profiling, *VM* Vastus medialis, *VT* Velocity test

Study name	**Statistics for each study**			**Relative Weight (%)**
	Hedges' g ± SEM	**95% CI**	***p***	
Arazi et al. [46]	0.05 ± 0.43	-0.79 to 0.89	0.90	3.21
Byrd et al. [43]	-0.00 ± 0.39	-0.78 to 0.77	0.99	3.57
Carneiro et al. [46]	0.09 ± 0.35	-0.60 to 0.77	0.81	4.60
Cuevas-Aburto et al. [47]	0.06 ± 0.39	-0.70 to 0.82	0.88	3.86
Davies et al. [26]	-0.01 ± 0.42	-0.83 to 0.82	0.99	3.34
Dias et al. [23]	0.18 ± 0.24	-0.30 to 0.66	0.47	8.31
Farianas et al. [49]	0.01 ± 0.40	-0.78 to 0.80	0.97	3.59
Folland et al. [50]	-0.42 ± 0.41	-1.22 to 0.38	0.30	3.52
Giessing et al. [51]	0.03 ± 0.27	-0.50 to 0.56	0.91	7.09
Goto et al. [8]	-1.96 ± 0.57	-3.07 to -0.84	0.00	1.90
Hansen et al. [20]	-0.44 ± 0.45	-1.33 to 0.45	0.33	2.88
Iglesias-Soler et al. [40]	0.12 ± 0.38	-0.63 to 0.86	0.76	3.98
Izquierdo et al. [31]	-0.08 ± 0.36	-0.79 to 0.63	0.82	4.35
Karsten et al. [27]	-0.01 ± 0.45	-0.89 to 0.87	0.98	2.95
Korak et al. [45]	0.01 ± 0.43	-0.83 to 0.85	0.99	3.22
Lawton et al. [9]	-0.38 ± 0.39	-1.15 to 0.38	0.32	3.84
Morales-Artacho et al. [41]	-0.16 ± 0.44	-1.02 to 0.70	0.72	3.07
Nicholson et al. [28]	0.15 ± 0.40	-0.64 to 0.94	0.72	3.59
Oliver et al. [24]	0.36 ± 0.41	-0.45 to 1.17	0.38	3.42
Prestes et al. [52]	0.13 ± 0.45	-0.75 to 1.01	0.77	2.94
Rial-Vazquez et al. [53]	0.08 ± 0.38	-0.68 to 0.83	0.84	3.71
Rooney et al. [21]	-0.13 ± 0.37	-0.85 to 0.59	0.72	4.23
Samson and Pillai [25]	0.68 ± 0.36	-0.01 to 1.38	0.05	4.47
Stragier et al. [55]	0.27 ± 0.36	-0.43 to 0.97	0.45	4.43
Yazdani et al. [42]	-0.69 ± 0.46	-1.60 to -0.22	0.14	2.78
Zarezadeh-Mehrizi et al. [22]	-0.97 ± 0.44	-1.83 to -0.12	0.03	3.12
Mean Effect	**-0.05 ± 0.08**	**-0.21 to 0.11**	**0.56**	
Heterogeneity	**I^2 = 11.03%** **Chi^2 (Q) = 28.10 *p* = 0.30** ***df* = 25**			

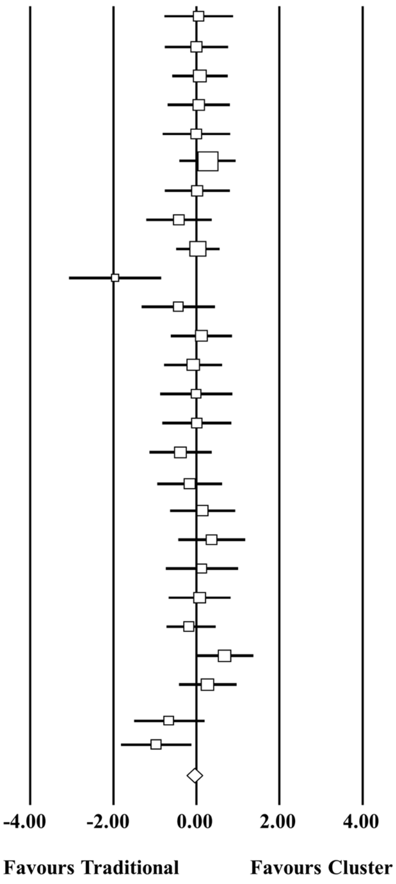


Fig. 2 Hedges' *g*, SEM, 95% confidence intervals and *p* values of individual and mean effects presented as a forest plot for muscular strength. *SEM* standard error of the mean.

estimate the maximum theoretical velocity (i.e. $V_{\max}$) [41, 47, 52, 54] and three studies (37.5%) reported the slope of the force–velocity curve [41, 52, 54]. One study (12.5%) used a functional measure of velocity (i.e. 6-m walking time) [23]. Five studies (62.5%) used a lower body exercise [20, 23, 41, 47, 52] and five studies (62.5%) used a compound exercise [20, 23, 26, 44, 54]. Only two studies used an isolated movement, both using the leg extension [47, 52]. All studies that tested velocity in an upper body movement used either the bench press [26, 54], bench press throw [44] or a handball throw [44]. One study used a countermovement jump [41]. No subgroup analyses regarding movement type were performed due to the limited number of studies that assessed velocity.

3.7 Muscle Hypertrophy

Eight studies reported measures of muscle hypertrophy in the meta-analysis [24, 27, 40, 47–49, 53, 55]. Although there were no significant differences between configurations (ES = – 0.05 ± 0.14, 95% CI – 0.32 to 0.23, $p = 0.73$) in the pooled analysis (Fig. 4), the average increase in measures of muscle hypertrophy was modestly lower in the cluster set configuration (2.7 ± 4.3%) compared to the traditional set configuration (4.8 ± 3.5%). Of the eight studies included in the muscle hypertrophy meta-analysis, four studies (50%) used the inter-repetition rest model [40, 47–49], two studies (25%) used a rest redistribution model [24, 27], one (12.5%) used a basic cluster set model [55] and one (12.5%) used the rest–pause method [53]. Importantly, all studies included in the hypertrophy analysis controlled for training volume and most studies (63%) were in untrained participants.

3.7.1 Method of Assessing Muscle Hypertrophy, Body Parts Trained and Exercise Type

Out of the eight studies that assessed muscle hypertrophy, the most common method was measuring muscle thickness

Study name	Statistics for each study			Relative Weight (%)
	Hedges' g ± SEM	95% CI	*p*	
Arazi et al. [46]	0.08 ± 0.43	-0.76 to 0.92	0.86	4.89
Asadi et al. [30]	0.00 ± 0.52	-1.01 to 1.01	1.00	3.35
Carneiro et al. [47]	0.10 ± 0.35	-0.58 to 0.79	0.77	7.32
Davies et al. [26]	-0.05 ± 0.42	-0.87 to 0.78	0.91	5.09
Dias et al. [23]	0.04 ± 0.25	-0.44 to 0.52	0.86	14.98
Hansen et al. [20]	0.19 ± 0.45	-0.70 to 1.08	0.67	4.37
Iglesias-Soler et al. [40]	-0.19 ± 0.38	-0.94 to 0.56	0.62	6.16
Iglesias-Soler et al. [52]	0.03 ± 0.38	-0.72 to 0.77	0.94	6.22
Izquierdo et al. [31]	0.07 ± 0.36	-0.64 to 0.78	0.84	6.87
Karsten et al. [27]	0.07 ± 0.45	-0.82 to 0.95	0.89	4.45
Lawton et al. [9]	-0.29 ± 0.39	-1.04 to 0.47	0.46	6.01
Morales-Artacho et al. [41]	-0.36 ± 0.44	-1.23 to 0.50	0.41	4.58
Nicholson et al. [28]	0.00 ± 0.40	-0.79 to 0.79	1.00	5.54
Oliver et al. [24]	0.34 ± 0.41	-0.47 to 1.15	0.41	5.26
Rial-Vazquez et al. [53]	0.19 ± 0.39	-0.57 to 0.94	0.63	5.71
Yazdani et al. [42]	-0.78 ± 0.47	-1.69 to 0.14	0.10	4.11
Zarezadeh-Mehrizi et al. [22]	0.63 ± 0.42	-0.20 to 1.45	0.14	5.07
Mean Effect	**0.02 ± 0.10**	**-0.17 to 0.20**	**0.86**	

Heterogeneity **I^2 = 0.00%**
Chi^2 (Q) = 7.75 p = 0.96
df = 16

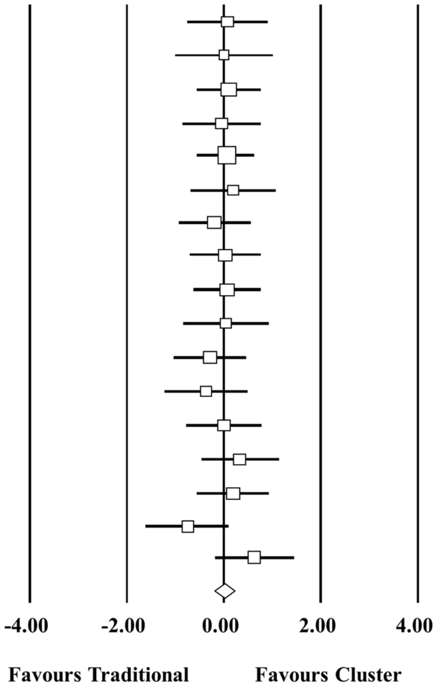


Fig. 3 Hedges' *g*, SEM, 95% confidence intervals and *p* values of individual and mean effects presented as a forest plot for power output. *SEM* standard error of the mean.

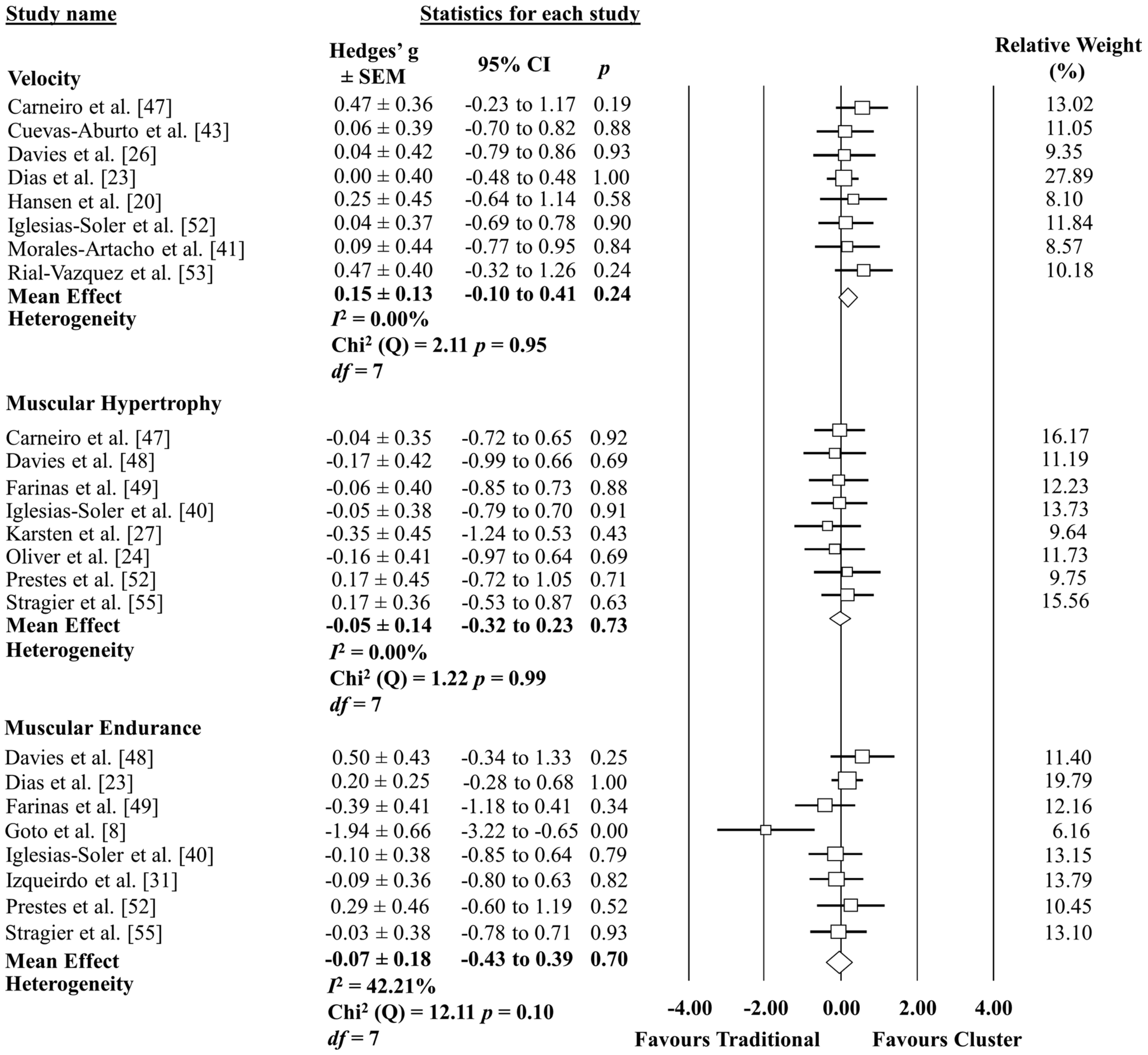
in the upper body ($n = 5$, 62.5%) [27, 48, 49, 53, 55] (i.e. pectoralis major, biceps brachii, anterior deltoid and chest). Two studies (25%) also assessed muscle thickness in the lower body, with one (12.5%) using the thigh [53] and one using the vastus medialis (12.5%) [27]. Other less common methods of assessing hypertrophy included two studies (25%) that measured lean body mass [24, 53], one study (12.5%) that measured corrected thigh girth [40] and one (12.5%) that measured estimated thigh cross-sectional area [47]. No subgroup analyses were performed for hypertrophy due to the limited available studies.

3.8 Muscular Endurance

Measures of muscular endurance were reported in eight studies [8, 23, 31, 40, 48, 49, 53, 55]. The average improvement in muscular endurance was similar, i.e. 25.7 ± 28.4% and 25.4 ± 26.6% in the cluster and traditional set configurations, respectively. There were no significant differences between configurations in the pooled analysis (ES = − 0.07 ± 0.18, 95% CI − 0.43 to 0.29, $p = 0.70$) as shown in Fig. 4. Three studies used a basic cluster set model [8, 23, 55], three studies used an inter-repetition rest model [40, 48, 49], one study used a rest redistribution model [31] and one used the rest–pause method [53]. All studies included controlled for training volume and 71% of studies were in untrained participants.

3.8.1 Method of Assessing Muscular Endurance, Body Parts Trained and Exercise Type

Out of the eight studies that assessed muscular endurance, six studies (75%) performed an absolute muscular endurance test (i.e. maintained a fixed loading during post testing) [23, 31, 40, 49, 53, 55], while three performed a relative muscular endurance test (i.e. maintained a fixed relative load during post testing) [8, 48, 55]. Four studies (50%) quantified muscular endurance by the number of repetitions performed to exhaustion in a single set [23, 31, 48, 53], while four (50%) reported endurance in terms of the work or volume accrued [8, 40, 48, 49]. Two studies (25%) used an isometric task until failure and reported time the contraction was maintained was held [23, 40]. The majority of studies used an upper body exercise ($n = 7$, 87.5%) including the bench press [31, 48, 53], biceps curl [23, 49, 53, 55] or shoulder press [8]. Half of the studies (50%) assessed muscular endurance with a lower body exercise; two studies used leg extension [8, 40], one study used the squat [31] and one study used the leg press [53]. A compound movement was used by five studies (62.5%) [8, 23, 31, 48, 53], while six (75%) used



Study name	Hedges' g ± SEM	95% CI	*p*	Relative Weight (%)
Velocity				
Carneiro et al. [47]	0.47 ± 0.36	-0.23 to 1.17	0.19	13.02
Cuevas-Aburto et al. [43]	0.06 ± 0.39	-0.70 to 0.82	0.88	11.05
Davies et al. [26]	0.04 ± 0.42	-0.79 to 0.86	0.93	9.35
Dias et al. [23]	0.00 ± 0.40	-0.48 to 0.48	1.00	27.89
Hansen et al. [20]	0.25 ± 0.45	-0.64 to 1.14	0.58	8.10
Iglesias-Soler et al. [52]	0.04 ± 0.37	-0.69 to 0.78	0.90	11.84
Morales-Artacho et al. [41]	0.09 ± 0.44	-0.77 to 0.95	0.84	8.57
Rial-Vazquez et al. [53]	0.47 ± 0.40	-0.32 to 1.26	0.24	10.18
Mean Effect	**0.15 ± 0.13**	**-0.10 to 0.41**	**0.24**	
Heterogeneity	**I^2 = 0.00%** **Chi² (Q) = 2.11 *p* = 0.95** ***df* = 7**			
Muscular Hypertrophy				
Carneiro et al. [47]	-0.04 ± 0.35	-0.72 to 0.65	0.92	16.17
Davies et al. [48]	-0.17 ± 0.42	-0.99 to 0.66	0.69	11.19
Farinas et al. [49]	-0.06 ± 0.40	-0.85 to 0.73	0.88	12.23
Iglesias-Soler et al. [40]	-0.05 ± 0.38	-0.79 to 0.70	0.91	13.73
Karsten et al. [27]	-0.35 ± 0.45	-1.24 to 0.53	0.43	9.64
Oliver et al. [24]	-0.16 ± 0.41	-0.97 to 0.64	0.69	11.73
Prestes et al. [52]	0.17 ± 0.45	-0.72 to 1.05	0.71	9.75
Stragier et al. [55]	0.17 ± 0.36	-0.53 to 0.87	0.63	15.56
Mean Effect	**-0.05 ± 0.14**	**-0.32 to 0.23**	**0.73**	
Heterogeneity	**I^2 = 0.00%** **Chi² (Q) = 1.22 *p* = 0.99** ***df* = 7**			
Muscular Endurance				
Davies et al. [48]	0.50 ± 0.43	-0.34 to 1.33	0.25	11.40
Dias et al. [23]	0.20 ± 0.25	-0.28 to 0.68	1.00	19.79
Farinas et al. [49]	-0.39 ± 0.41	-1.18 to 0.41	0.34	12.16
Goto et al. [8]	-1.94 ± 0.66	-3.22 to -0.65	0.00	6.16
Iglesias-Soler et al. [40]	-0.10 ± 0.38	-0.85 to 0.64	0.79	13.15
Izquierdo et al. [31]	-0.09 ± 0.36	-0.80 to 0.63	0.82	13.79
Prestes et al. [52]	0.29 ± 0.46	-0.60 to 1.19	0.52	10.45
Stragier et al. [55]	-0.03 ± 0.38	-0.78 to 0.71	0.93	13.10
Mean Effect	**-0.07 ± 0.18**	**-0.43 to 0.39**	**0.70**	
Heterogeneity	**I^2 = 42.21%** **Chi² (Q) = 12.11 *p* = 0.10** ***df* = 7**			

Fig. 4 Hedges' *g*, SEM, 95% confidence intervals and *p* values of individual and mean effects presented as a forest plot for muscular hypertrophy, velocity and endurance. *SEM* standard error of the mean.

an isolated movement [8, 23, 40, 49, 53, 55]. No subgroup analyses were conducted on movement type for muscular endurance due to the limited amount of studies.

3.9 Sub-Analysis

Detailed sub-analysis results are shown in Electronic Supplementary Material [ESM] Table S1 and Table S2. No subgroup analyses were performed for velocity, muscular endurance or hypertrophy due to limited available studies. There were no differences between cluster and traditional set configurations for muscular strength when volume was controlled (ES = − 0.06 ± 0.09, 95% CI − 0.24 to 0.13, *p* = 0.54) or uncontrolled (ES = 0.00 ± 0.17, 95% CI − 0.33 to 0.33, *p* = 0.99). Likewise, there were no significant differences for muscular strength in trained/athletic (ES = − 0.07, 95% CI − 0.30 to 0.16, *p* = 0.55) or untrained participants (ES = − 0.05 ± 0.12, 95% CI − 0.28 to 0.19, *p* = 0.69). There were also no statistically significant differences when sub-analyses were performed for upper (ES = 0.03 ± 0.09, 95% CI − 0.14 to 0.20, *p* = 0.75) or lower body exercises (ES = − 0.07 ± 0.11, 95% CI − 0.30 to 0.15, *p* = 0.51), nor when compound movements (ES = − 0.04 ± 0.09, 95% CI − 0.23 to 0.14, *p* = 0.64) or isolated movements were assessed (ES = − 0.14 ± 0.18, 95% CI − 0.49 to 0.22, $p = 0.44$).

Similarly, there were no statistically significant differences in power outcomes when sub-analyses were performed for interventions in which volume was controlled (ES = 0.01 ± 0.10, 95% CI − 0.19 to 0.20, $p = 0.95$) or uncontrolled (ES = 0.07 ± 0.25, 95% CI − 0.41 to 0.56, $p = 0.76$), trained/ athletic (ES = 0.11 ± 0.15, 95% CI − 0.19 to 0.40, $p = 0.48$) or untrained sub-groups (ES = − 0.04 ± 0.12, 95% CI − 0.28 to 0.20, $p = 0.72$). However, only three studies were available for the volume uncontrolled sub-analysis which may not be adequately powered. There were also no statistically significant differences when sub-analyses were performed for upper (ES = 0.14 ± 0.14, 95% CI − 0.12 to 0.41, $p = 0.29$) and lower body (ES = 0.02 ± 0.10, 95% CI − 0.18 to 0.22, $p = 0.84$) movements. Moreover, no statistically significant differences were observed when sub-analyses were performed for compound (ES = 0.02 ± 0.11, 95% CI − 0.18 to 0.23, $p = 0.83$) and isolated (ES = − 0.01 ± 0.21, 95% CI − 0.43 to 0.41, $p = 0.96$) movements.

3.10 Study Quality and Reporting

Using the TESTEX scale, the mean total score for study quality and reporting was 2.9 ± 0.8 (median = 3) and 6.2 ± 1.7 (median = 6), respectively (ESM Table S3). Overall, studies scored a total of 9.1 ± 2.1 (median = 9) out of a possible 15 points. The lowest scoring study received a five [43], with the highest scoring study receiving a 14 [48]. Overall, study quality and reporting were classified as "good", with 21 out of 29 studies achieving this threshold. Common study quality and reporting limitations included: activity monitoring in control groups (2/29 studies), blinding of assessors for at least one primary outcome measure (3/29 studies) and randomization specification (4/29 studies). In contrast, nearly all studies reported point measures and measures of variability (28/29 studies), between-group statistical comparisons for the primary outcome (28/29 studies) and all studies scored a point for allocation concealment. Only two studies had an overall score of 'excellent' (≥ 11) [26, 48].

4 Discussion

To the authors' knowledge, this is the first meta-analytical investigation to directly compare the chronic adaptations that result from the use of cluster and traditional set RT interventions. Collectively, the results demonstrate similar adaptations in muscular strength, power, velocity, hypertrophy and endurance with both configurations. In addition, there were no differences observed between cluster and traditional sets when subgroup analyses (muscular strength and power output only) were conducted to examine the impact of volume, cluster set model, body part and exercise selection. These findings further challenge the need for repetition maximum training and the notion that training to failure is necessary to induce hypertrophic or performance-based improvements. Based on the overall evidence, both cluster and traditional set configurations are plausible RT strategies. However, cluster set configurations may achieve similar muscular and neuromuscular adaptation(s) with less fatigue development which may be an important consideration across various applications and stages of periodized training programs.

4.1 Muscular Strength

There were no overall differences in the magnitude of strength gain following RT interventions using cluster or traditional set configurations (ES = − 0.05, 95% CI − 0.22 to 0.11). Similarly, no differences were observed when volume, cluster set model, body part and exercise selection were considered (range of ES: − 0.65 to 0.20). However, heterogeneity was noted between studies that did not control for volume, those that used lower body exercises and isolated movements (see ESM Table S1). The similar strength gain between cluster and traditional set programs is an important and novel finding given that cluster set configurations have commonly been discussed and implemented as a means of emphasizing movement quality and minimizing fatigue [6, 7], rather than primarily focusing on force production and/or strength development. Overall, strength was assessed in 26 of the included studies and of these, only two reported significantly favorable strength gains with the use of a traditional set program [8, 22]. Specifically, as volume was controlled between conditions, Zarezadeh-Mehrizi et al. [22] suggest that this may have occurred due to greater fatigue-related effects when performing the exercise. Similar mechanisms have also been postulated by Goto et al. [8] as lactate, growth hormone and (nor)epinephrine responses were greater with traditional set training and similar responses have been noted in other acute studies [56]. Although greater fatigue, metabolic stress and endocrine responses may occur with traditional set configurations, the necessity of these for strength adaptations has been the subject of ongoing debate [21], with mounting evidence suggesting they are neither essential, nor required [10, 50, 57]. Moreover, less fatigue may also optimize movement quality [29] and therefore, be beneficial for highly skilled complex multijoint movements. In addition, cluster set configurations may also produce more favorable perceptual responses such as reduced feeling of perceived effort or exertion [44, 58, 59], although the evidence appears mixed [60, 61]. However, the minimization of fatigue and perceived effort may be advantageous during certain stages of periodized programs requiring frequent training and/or competition. Moreover, this may also be advantageous in settings where exercise capacity is compromised, or adherence is poor due to subjective factors. Such examples may include clinical exercise programs where the negative effects of illness or disease are limiting factors on physical exertion and further specific studies are recommended.

Furthermore, when averaged across all studies and outcome measures, the amount of strength gained was ~ 18% for both cluster and traditional set configurations. This demonstrates that the programs employed by the studies in this review were sufficient (e.g., nature of program and duration) to induce substantial strength adaptations over the intervention period. However, it should be noted that 12 out of the 26 studies that assessed muscular strength were in untrained participants. Thus, although it is difficult to make specific and direct comparisons of the baseline strength of participants in individual studies due to heterogeneity of participant characteristics (e.g. age and training experience) and assessed exercises, it can be assumed that strength gains over an intervention period would be lower in stronger, well-trained individuals. Despite this, strength adaptation occurred regardless of set configuration, providing further evidence that strength improvement occurs independently of fatigue accrual during RT. Despite this, it is important to consider that muscular strength gains were assessed after interventions ranging between 3 and 12 weeks in duration. It can be hypothesized that these durations were too short to detect potentially small differences or a tendency toward long-term divergent responses between the programs, especially when two active RT groups that, for the most part, only differed in set-configuration were employed. Moreover, it appears that no included study allowed for an adequate taper period towards the end of or following the intervention, which may have improved maximal strength performance during post-testing. That being said, two studies did show greater strength adaptation with traditional set configurations, with Goto et al. [8] using a 12-week intervention and Zarezadeh-Mehrizi et al. [22] using a 6-week intervention. Conversely, the opposite effect was observed by Samson and Pillai [25], with greater strength adaptations observed after 7 weeks using a cluster set configuration. However, as no other individual study differences were found between cluster and traditional set configurations, it is difficult to determine if longer interventions would have shown disparity in muscular strength adaptations.

4.2 Velocity and Power

The importance of movement velocity and muscle power output is well recognized across a number of human performance and health-related settings [62, 63]. Further, it has long been postulated that neuromuscular adaptations occur in specific response to training stimuli. In particular, the modulation of mechanical stimuli is thought to be pivotal in this process [64–66]. At least hypothetically, cluster set configurations seem conducive to elicit positive effects on movement velocity, which can directly impact power. In support, several acute studies report that both of these variables are greater (e.g., loss minimized across sets and repetitions) when cluster sets are employed during a training session [14]. Thus, a focus on movement velocity and power output has been a mainstay in cluster set research and programs (for examples see Tufano et al. [17]; Haff et al. [13]; Hardee et al. [67]). However, despite acute evidence and general hypotheses, the results of this meta-analysis showed no significant difference in the development of movement velocity (+ 2.5% and − 3.4%, ES = 0.15, 95% CI − 0.10 to 0.40, $p = 0.24$) or power output (+ 10.6% and + 9.1%, ES = 0.02, 95% CI − 0.17 to 0.20, $p = 0.86$) between cluster and traditional set interventions, respectively. The reasons for these observations are not entirely clear but could be, at least in part, due to several proposed factors. Firstly, changes in strength were similar between cluster and traditional set programs which is an important factor in the ability to express power [2, 68], especially in individuals where strength levels are suboptimal [62]. Specifically, seven of the 15 included studies in this review that assessed power were conducted in untrained individuals [27, 31, 40, 41, 47, 52, 54]. Thus strength, which improved similarly with both cluster and traditional set programs, likely played a major underpinning role in the improvement in power output observed, especially for untrained individuals. However, in studies employing trained or athletic individuals, similar non-significant effects were also observed (range of ES: − 0.29 to 0.63) between cluster and traditional set configurations. Upon further inspection of the data analyzed, it appears that the strength levels of untrained and trained individuals were quite similar and this may help to explain this result. In particular, two studies showed moderate effects for strength development favoring the traditional set configuration (ES = − 0.69 and − 0.97) [22, 42]. However, non-significant moderate effects were observed for power development with one study favoring cluster set configurations (ES = 0.63, 95% CI − 0.20 to 1.45, $p = 0.14$) [22] and the other favoring traditional set configurations (ES = − 0.78, 95% CI − 1.69 to 0.14, $p = 0.10$). Therefore, drawing any further conclusion based on strength and power outcomes from these studies alone would be speculative at best. Another consideration is that the same authors [41] also included jump squats in the training program with the same task also being used for the pre- and post-assessment of power. This contrasts with several other studies, where power was assessed via a task (e.g., countermovement jump) that was not performed during the training intervention [30, 46]. This potentially highlights a need for task specificity in order to detect training-related changes that may not otherwise be apparent. Despite this thought, the studies that used a task that was performed during the training period also showed no difference in power [9, 20, 22, 24, 26, 27, 31, 41, 47, 52, 54] or velocity [20, 26, 47, 52, 54] development between cluster and traditional set configurations. Many of these were assessed using 'traditional' exercises such as the leg extension [40, 47], bench press or back squat [26, 27, 31, 54, 56] which may not be as conducive to maximal power expression as high-velocity explosive actions.

In addition, power development can be underpinned by faster movement velocities in conjunction with, or in the absence of, strength improvement. However, considering the similar strength and power adaptations observed in this meta-analysis, it is perhaps not surprising that velocity outcomes also showed no difference between cluster and traditional set configurations. This finding may, at least in part, be due to the limited number of included studies ($n=7$) that assessed velocity. Thus, we suggest that future studies with methodological consideration for the most appropriate and sensitive measurement of power and velocity in relation to the training program are required. Future studies should also carefully consider the interpretation of potential power adaptations based on the task employed and data obtained (e.g. jump height versus calculated power output) as such proxies should be met with caution [69, 70]. These considerations may help to reach a more definitive consensus on specific adaptations following cluster and traditional set interventions.

4.3 Endurance and Hypertrophy

A number of included studies also investigated muscular endurance ($n=8$) and hypertrophic ($n=8$) adaptations. Traditionally, improvements in muscle hypertrophy and/or endurance have been associated with high repetition/volume RT performed to, or close to, momentary muscle failure causing high metabolic disturbance [71–73]. However, the comparison of cluster and traditional set configurations in this meta-analysis showed no difference in hypertrophic (ES = − 0.05, 95% CI − 0.32 to 0.23) or muscular endurance (ES = − 0.28, 95% CI − 0.74 to 0.17) adaptations (see Fig. 4). Upon closer inspection, only one study [8] reported a larger improvement in muscle endurance (ES = − 1.94, 95% CI − 3.22 to − 0.65, $p<0.001$) with the use of traditional (3–5 sets of 10RM) compared to cluster sets (3–5 sets of 2 clusters of 5 repetitions). In the same study, strength also improved to a greater degree for traditional (38%) compared to cluster set (21%) training. Both of these factors are in agreement with the previous research suggesting muscular strength is an important factor in endurance performance [74]. In the other studies that assessed endurance outcomes [26, 31, 49, 53, 55], low-volume traditional set RT programs were used (i.e. typically 5–6 repetitions for the majority of the study). In these studies, the average improvement in endurance performance reported, regardless of set configuration, was substantial i.e. ~ 26% This finding corroborates reports by Assuncao et al. [75], showing that low-volume RT is just as effective as higher volume RT to improve muscular endurance. Furthermore, this can occur when fatigue is minimized during training, but strength is increased over time. Although the underpinning mechanisms for the current observations are unclear, it should be noted that four of the six studies that assessed endurance performance used untrained participants [8, 31, 49, 55]. Therefore, it is possible that different effects may be observed when muscular endurance is investigated in highly trained individuals. Specifically, it can be theorized that when initial strength is greater, further improvements are smaller and thus, may have less influence on endurance adaptations. However, due to the low number of studies, further sub-analyses were not conducted in this meta-analysis. The collective findings of this review provide support that both cluster and traditional set RT interventions can improve muscular endurance to a similar degree. Further studies are required to improve statistical power and substantiate these findings.

The magnitude of hypertrophic adaptations averaged ~ 2.7 and ~ 4.8% across studies for cluster and traditional set configurations, respectively. The length of the interventions that assessed hypertrophic adaptations ranged from 6 to 12 weeks and traditional set programs utilized repetitions ranging from 4 to 10 repetitions per set across all studies. Although lower volume RT performed to failure has been shown to cause a similar hypertrophic response to higher volumes [76], training to failure is intentionally avoided in the majority of cluster set models, bar the rest–pause method [6]. Thus, the reasons for the similar hypertrophic adaptations observed in this analysis are also not entirely clear. One possibility is the role of mechanical stimuli which is thought to be important for cell signaling and muscle growth to occur [77]. This possibility is further supported by the fact that all but one study (see Stragier et al. [55]) controlled for training volume. Therefore, it is likely that a 'similar' mechanical loading was induced for cluster and traditional set interventions despite known differences in metabolic stress and repetition kinematics (i.e. power and velocity) during each session [14]. In support, Tufano et al. [16] suggests that cluster sets result in greater mechanical stress without decreasing movement velocity. Thus, the current results dispute the notion that high amounts of fatigue and metabolic stress are required to trigger muscle growth and this notion has recently been questioned [10]. Nonetheless, the hypertrophic adaptations observed following cluster and traditional set RT interventions follow a similar trend to other reported outcome measures (i.e. strength, power, velocity and endurance) and provide further support for the efficacy cluster set configurations as a suitable alternative RT method. Moving forward, we suggest that further research should also seek to establish the effects of cluster sets to improve muscle mass across other domains such as chronic disease and ageing [78, 79] where muscle mass plays an important role in health, function and prognosis.

Consideration of the techniques used to assess hypertrophic and endurance adaptations within the studies included in this review is also warranted. For example, only two studies assessed hypertrophic effects via changes in lean body mass [24, 53]. Of these, Oliver et al. [24] used dual X-ray absorptiometry, while Prestes et al. [53] used a three-site skinfold test to estimate changes in body composition. Alternatively, five studies [27, 48, 49, 53, 55] assessed changes in muscle thickness, one study used estimated thigh cross-sectional area [47] and one study used corrected thigh girth [40]. The accuracy and sensitivity of estimated cross-sectional area and girth measurements in comparison to more advanced techniques should be met with some caution. That being said, we acknowledge that the required equipment and need for trained personnel to conduct such measures is not always viable for all researchers. Regarding muscular endurance, it should be noted that three studies assessed the number of repetitions performed at a submaximal load which accounted for the strength increase after the training period (i.e. relative muscular endurance) [8, 48, 55], while it was not controlled (i.e. absolute muscular endurance) in six studies [23, 31, 40, 49, 53, 55]. Therefore, we suggest that future studies seek to employ consistent and sensitive techniques to assess muscular hypertrophy and endurance. Consequently, this may enable a more definitive consensus to be reached regarding the similarities or differences of each RT method on these outcomes.

4.4 Methodological Quality

Collectively, the body of evidence arises from studies with ‘good’ methodological quality, with only three studies considered to have ‘excellent’ study quality [23, 26, 48] (refer to ESM Table S3). However, several further methodological considerations regarding the included studies warrant discussion. For example, 15 of the included studies did not re-test performance capacity during the intervention [8, 9, 20, 22, 23, 25, 30, 40, 43, 44, 46, 49, 53–55] and therefore, the maintenance of relative exercise intensity cannot be assured. Moreover, five studies were not well matched between interventions at baseline [20, 25, 30, 43, 53] and one study did not perform between-group statistical comparisons [51]. Although publication bias was also detected with the inclusion of all studies (see ESM Figure S1), when these studies were excluded from the analysis, the results did not differ. Therefore, we suggest that future RT intervention studies should rigorously consider and implement recommendations to improve methodological quality and the overall quality of evidence presented [34].

4.5 Limitations and Future Directions

Although the overall results of this review demonstrate no difference between cluster and traditional set configurations on the development of muscular strength, power output, velocity, hypertrophy and endurance, several limitations warrant consideration. In practice, strength and conditioning coaches can utilize cluster set configurations to increase training volume and/or intensity [7]. The additional rest provided attenuates fatigue which theoretically can then allow for greater intensity and volume to be achieved [7, 14]. Of course, this often comes at the expense of longer session durations as demonstrated in this review; cluster: 14.2 ± 7.3 min/exercise/session, traditional: 11.2 ± 6.0 min/exercise/session, especially when using basic cluster sets. The intraset rest duration implemented in the basic cluster set configurations also differed between the studies included in this review (range 60–270 s). This is an important consideration when aiming to compare between studies as fatigue attenuation and neuromuscular performance/recovery etiology between clusters and sets likely differ based on intraset rest duration. Moreover, future studies should also consider the length of the intraset rest period in relation to the intended training phase and the intent to develop certain neuromuscular or performance characteristics such as strength–endurance, strength–power, maximal strength or power, as discussed elsewhere [6, 7, 80] However, as time is often limited in practical settings, the rest redistribution model of cluster set prescription may be useful in reducing intra-session fatigue as compared to traditional set RT without the added burden of increased training time. For strength and conditioning professionals, the rest redistribution model may offer a practical approach to implementing cluster set configurations within training sessions. However, the utilization of rest redistribution models may not allow adequate recovery of adenosine triphosphate (ATP) and phosphocreatine (PCr) due to the abbreviated rest periods as compared to other cluster set models, such as a basic cluster. This incomplete recovery could theoretically result in different metabolic responses and long-term training adaptations between various cluster set configurations. Further research comparing the long-term training responses to cluster sets that employ rest redistribution with more traditional cluster set configurations is warranted.

Furthermore, only one study included an ‘athletic’ cohort; most studies were performed with untrained and recreationally trained participants. It is not unexpected that in untrained participants, improvements in muscular and neuromuscular parameters may be similar regardless of the set configuration utilized, especially in studies of short duration.

In contrast, within elite athlete populations, a plateau in performance parameters is likely and methods to increase training intensity and volumes via cluster sets may be particularly beneficial. To improve the translation of research to practice, it is recommended that future studies are directed towards cluster set models that have higher volume or intensity compared to traditional set configurations which may improve the ecological validity of such training programs. Moreover, study designs that are of longer duration and conducted in highly trained or 'athletic' participants can provide valuable insight into the potential benefits of cluster set configurations in sporting practice. We also suggest that future studies should seek to investigate efficacy of cluster set RT in demographics where exercise capacity is limited or perceptual and muscular fatigue is an ongoing and underlying issue.

In addition, it can be speculated that cluster sets may also offer benefit in other health-related settings (i.e. clinical) where muscular strength, power and mass are of importance but exercise capacity and tolerance are compromised (for examples see Gong et al. 2018 [81]; Jones et al. [82]). As a further example of potential application, the acute hemodynamic response appears to be lower in cluster compared to traditional set configurations [83, 84]. This makes utilizing cluster set configurations appealing in patients with compromised cardiovascular function (i.e. cardiovascular disease and chronic heart failure) where adverse changes in blood pressure and cardiac load are of concern during resistance exercise. However, further research is required to determine the safety and efficacy of cluster set configurations before they are implemented in clinical exercise settings and long-term rehabilitation programs.

4.6 Practical Applications and Recommendations

From a translational perspective, the management of fatigue during exercise training is an important consideration across various settings. In athletes, adequate training stimuli that does not result in copious amounts of fatigue is often required [85], especially during periods of regular competition, or taper periods, and/or when concurrent training is required to enable proficiency in other performance domains (i.e. aerobic capacity, skill acquisition and execution) [86, 87]. In fact, several of the included studies (e.g. see Arazi et al. [46], Hansen et al. [20], Izquierdo et al. [31], Lawton et al. [9], Zarezadeh-Mehrizi et al. [22]), implemented cluster set configurations with competitive athletes demonstrating initial thought towards application in this setting. Furthermore, careful consideration should be given to the overall goal and phase of the training program. For example, the use of cluster sets with longer inter-repetition (e.g. > 10 s) or intraset (e.g. 30–45 s) rest that adhere to a predetermined number of repetitions may have the most benefit during strength and/or power phases of training programs. Conversely, using shorter intraset rest (e.g. 15 s) with higher repetitions or scope to perform additional repetitions (i.e. rest pause technique), may be more applicable during strength–endurance phases as they enable greater training volumes to be performed in an attempt to build athlete work capacity. Overall, both cluster and traditional set configurations demonstrate similar effectiveness to improve muscular strength, despite fatigue and potentially perceptual responses differing between configurations. Moreover, less fatigue development may enable better movement quality which may be of particular importance in skilled movements (e.g. weightlifting movements) [29]. However, coaches should also consider the nature of the movement being performed and the practicality/feasibility of additional rest where loads need to be racked and un-racked as considerable effort is often required by the individual to get into the proper starting position before performing the movement (e.g. barbell squat or bench press). Thus, we suggest that cluster sets may have less practical feasibility in exercises where racking and un-racking of the load is required and intended set repetitions are low (e.g. 1–6). In such tasks, metabolic fatigue is likely minimal and the extra effort required to set and reset for each repetition may counteract the intended benefit of the cluster set itself. Therefore, the application of cluster and traditional set configurations in relation to the timing and specific requirements of the training program should be carefully considered by exercise professionals during the program planning stage.

5 Conclusion

Collectively, the results of this meta-analytical investigation provide novel evidence regarding chronic adaptations to RT interventions that differ in set configuration. In particular, both set configurations demonstrate similar muscular and neuromuscular adaptations between cluster and traditional set RT programs. These outcomes were also similar when volume, cluster set model, exercise selection and body part trained were considered. Although not directly measured, the findings refute the notion that high amounts of fatigue are an important stimulus to induce RT adaptations. Moreover, these results suggest that the same adaptive responses can be achieved whilst fatigue is minimized, making cluster set configurations potentially a less physiologically stressful/taxing technique to evoke such adaptations. Therefore, cluster set configurations may be an efficacious RT approach that can be considered for use in various settings and stages of periodized programs. In particular, the evidence presented in this review suggests that cluster sets may be effective where the development of muscular strength, power, hypertrophy, movement velocity and/or endurance is of importance.

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Compliance with Ethical Standards

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