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SYSTEMATIC REVIEW

Optimal Training Sequences to Develop Lower Body Force, Velocity, Power, and Jump Height: A Systematic Review with Meta-Analysis

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Abstract

Background Resistance training has been used to enhance a range of athletic abilities through correct manipulation of several variables such as training load, training volume, set configuration, and rest period.

Objective The aim of this systematic review and meta-analysis was to compare the acute and chronic responses of lower body cluster, contrast, complex, and traditional training across a range of athletic performance outcomes (1-repetition maximum squat strength, jump height, peak power, peak force, peak velocity, and sprint time).

Methods A database search was completed (SPORTDiscus, Medline and CINAHL) followed by a quality scoring system, which concluded with 41 studies being used in the meta-analysis. Effect sizes were calculated for acute and training intervention changes compared to baseline. For acute cluster training, effect sizes were used to represent differences between equated traditional and cluster sets.

Results Acutely, contrast and cluster training can be implemented to enhance and maintain velocity. Complex training does not acutely show a performance-enhancing effect on jump performance.

Conclusion When looking to develop exercise-specific force, the exercise should be completed closer to set failure with fewer repetitions still able to be completed, which can be achieved using complex or high-volume contrast training to pre-fatigue the lighter exercise. When the objective is to improve velocity for the target exercise, it can be combined with a heavier contrast pair to create a postactivation performance enhancing effect. Alternatively, cluster set designs can be used to maintain high velocities and reduce drop-off. Finally, traditional training is most effective for increasing squat 1-repetition maximum.

Key Points

It appears that completing training of an exercise close to the point of failure can provide a stimulus that increases the force component that is expressed at that load, whilst training an exercise at the fastest velocities possible can increase the velocity component.

Traditional, complex, and contrast training sequences may be used to specifically achieve velocity or force adaptations in either light or heavy exercise.

Cluster training variations can be used with all three of these training sequences to maintain exercise velocity, as well as enabling a higher load to be lifted.

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1 Introduction

Resistance training (RT) has been shown to be an effective strategy for developing several key athletic components such as strength, power, and speed [11, 27, 87, 91]. When designing a RT program, several variables must be considered, such as the type of movement, training load, training volume, set configuration, rest period between sets, movement intent, and exercise sequence, in order to achieve the desired training outcome. When performing RT, fatigue occurs in three main ways: (1) central fatigue, which is characterised by a decreased ability of the central nervous system to elicit motor-unit activation whilst the muscle is still capable of greater output [6, 56], (2) neuromuscular fatigue, which stems from biochemical changes at the neuromuscular junction that cause an attenuated contractile response to neural input [9], and (3) metabolic fatigue, which is related to impairment of muscle enzyme activity through local acidosis and the accumulation of metabolic by-products [21, 69, 104].

When traditional training sets are used (see Table 1), movement velocity and power output tend to decrease as more repetitions are performed [31, 37, 82, 98]. Based on previous research, completing exercise repetitions at maximum concentric velocity for a given load can lead to greater improvements in maximal strength and power when compared to repetitions that are completed at relatively slower speeds performed with less intent [28, 72]. Considering this, a method that has been suggested to mitigate this reduction in power output is cluster training [32]. Cluster sets as defined by Haff et al. [31] are "set structures inclusive of normal inter-set rest periods accompanied by pre-planned rest intervals within a set". These types of sets can have several different structures including basic cluster sets, inter-set rest redistribution, equal work-to-rest ratio, and the rest-pause method (full descriptions provided in Table 1). As well as facilitating superior maintenance of repetition velocity and power output compared to traditional sets [37, 98], cluster training has been shown to allow a higher number of repetitions to be performed if desired, resulting in a greater volume load than traditional set structures [43], which may contribute to superior hypertrophic and strength development [2, 28, 58]. A likely reason for these effects is that cluster training causes less metabolic fatigue than equivalent conventional sets [67], which would result in less feedback from type III and IV muscle afferents, and therefore, a smaller reduction in efferent neural drive from the CNS [4, 96]. With higher velocities maintained across a cluster set compared to a traditional set structure, it is theorised that greater improvements in strength and power may be achieved. Finally, one of the biggest benefits of cluster training is that it allows athletes to lift heavier loads more frequently [99]. This may lead to greater increases in strength as shown by Longo et al. [53], who had untrained

Table 1 Table of definitions and terms [24, 32, 76, 98]

Term	Definition
1-repetition maximum	The highest load at which an individual can correctly perform a chosen exercise movement
Basic cluster sets	A traditional set with additional short rest periods of typically 15–45 s inserted within each set
Cluster training	Set structures inclusive of normal inter-set rest periods accompanied by pre-planned rest intervals within a set
Complex training	Multiple sets of a heavy resistance exercise followed by sets of a lighter resistance exercise
Contrast training	A workout that involves the use of exercises of contrasting loads, that is, alternating heavy and light exercises set for set
Equal work-to-rest ratio	Equating the work-to-rest ratio for the entire exercise session based on a traditional set structure, then reprogramming to spread total rest between each repetition
Interrepetition rest	The recovery time taken between repetitions in cluster training variations
Inter-set rest redistribution	Long inter-set rest intervals that are divided into shorter but more frequent interest rest intervals, keeping the total rest time equal
Jump height	The maximal height attained during a jump activity
Peak force	The highest force recorded during the concentric portion of a movement
Peak power	The highest power recorded during the concentric portion of a movement
Peak velocity	The highest velocity recorded during the concentric portion of a movement
Post-activation performance enhancement	Enhancements in maximal strength, power, and speed following a conditioning activity
Rest-pause method	A method of performing single repetitions of an exercise with short rest periods between each repetition for 4–6 repetitions, allowing a near-maximal load to be lifted multiple times, and often performed to failure
Traditional sets	A straight set with no recovery until all repetitions are complete
Traditional training	Multiple sets of lighter resistances before heavy resistances

subjects perform three sets to failure of single-leg press at 80% of 1-repetition maximum (1RM) twice per week for 10 weeks under 1-min, 3 min, and volume-equated rest interval conditions. After 10 weeks, it was seen that longer and shorter inter-set rest intervals did not affect muscle strength increases when a higher intensity was maintained between the protocols, despite a greater volume load with longer rest. The authors concluded that intensity was likely the primary determinant of muscle strength increase within this group of subjects. However, to the authors' knowledge, this finding is yet to be investigated in resistance-trained populations and so cannot be confirmed as a major contributor to strength.

Another variable that can be manipulated in resistance training is the exercise sequence. Traditionally, it has been recommended to perform "power-type exercises" (e.g., weightlifting, ballistic, and plyometric exercises) at the start of a session so that movement velocity is less affected by fatigue, followed by multiple heavy RT sets [2, 41]. This sequencing has been challenged as a result of alternative training orders whereby the heavier lifts are sequenced at the start of a session and followed by a biomechanically similar, but lighter velocity-orientated exercise, which may be subsequently enhanced due to the heavier exercise or conditioning activity (CA) [23, 33, 80]. Postactivation potential (PAP) has recently been highlighted as a frequently misunderstood phenomenon within the literature, which is commonly used to explain the effects of this sequence because PAP refers to the increase in electrically evoked twitch force/torque following submaximal and maximal conditioning contractions [81]. The term "postactivation performance enhancement" (PAPE) has recently been proposed to describe any enhancements in maximal strength, power, and speed following a CA [76]. When PAPE is used within a practical setting, it can be utilised through two different types of training sequences known as complex and contrast training. Complex training involves performing multiple sets of heavy resistance exercise followed by sets of a lighter exercise [24]. Contrast training involves alternating heavy resistance sets with lighter sets in a set-by-set format [24]. PAPE has also been utilised within the same exercise using down sets, whereby the earlier sets start out heavy and get progressively lighter for subsequent sets [92]. An important point of discussion within the present systematic review is the need for clarification of definitions. Descriptions of certain terms that are used within the literature such as "complex pairs", "strength-power potentiation complexes", and "intra-complex recovery" seem to be more synonymous with contrast training but are sometimes referred to as complex training. This pattern is frequently seen throughout the PAPE literature and has likely led to some confusion amongst practitioners. Additionally, as new terms are introduced, more work should be done to clarify them amongst the strength and conditioning community. Clear definitions are described in Table 1.

Different recovery times have been proposed to provide the optimal length of time for eliciting PAPE with contrast and complex training protocols. Following a heavy CA, PAPE with jumping activities has been shown to occur at between 2 and 6 min, although individual variation is common [55, 66]. Furthermore, exercises utilising a higher load require longer recovery periods compared to exercises which use a lighter load [30, 57]. From a practical standpoint, the recovery time that creates the highest response in the subsequent lighter exercise may not necessarily be the best choice for coaches, given that they often have restrictions on the time allotted for athletes to perform resistance training. One factor that mitigates the recovery duration is the subject strength due to the fact that stronger individuals are able to show greater and earlier performance enhancements in the lighter exercise than their weaker counterparts [85, 88]. With this being the case, maximal strength development should be a pre-requisite for using complex and contrast training. A recovery period that can be utilised to maintain power output levels may be a sufficient option, especially when athletes can be restricted by the length of training sessions. In such a scenario, set recovery time that allows balance between the greatest performance enhancement in the light exercise, and overall training session time efficiency would appear to be most appropriate.

The current body of research has investigated the effectiveness of traditional, cluster, complex and contrast training protocols on various athletic performance measures. However, the effects of these four protocols have not been compared. Therefore, the purpose of this systematic review was to compare the acute and chronic responses to cluster, contrast, complex, and traditional training.

2 Methods

2.1 Literature Search Methodology

SPORTDiscus, Medline and CINAHL electronic databases were searched for both original and review journal articles related to specific search terms: "velocity based training", "cluster training", "complex training", "contrast training", and "rest periods". If the same article appeared on multiple search terms, the duplicates were eliminated. The next stage of elimination involved using a journal relevance function (a tool available with SPORTDiscus, Medline, and CINAHL) which eliminated articles from non-sport-related journals. If full-text articles could not be obtained through these database searches, articles were searched for on Google Scholar and ResearchGate™. Additional research studies that were deemed suitable were included after reading through the reference lists of the database-searched studies. Article titles and abstracts were then read to identify studies which fitted the inclusion criteria. To be included, articles were required to investigate the acute or chronic effects of lower body studies which investigated one or more of the following: cluster, complex, contrast, or traditional training involving resistance training protocols. Additionally, all studies were required to include a control group. The final search date was 13th July 2020 and Fig. 1 shows a schematic outline of the search process.

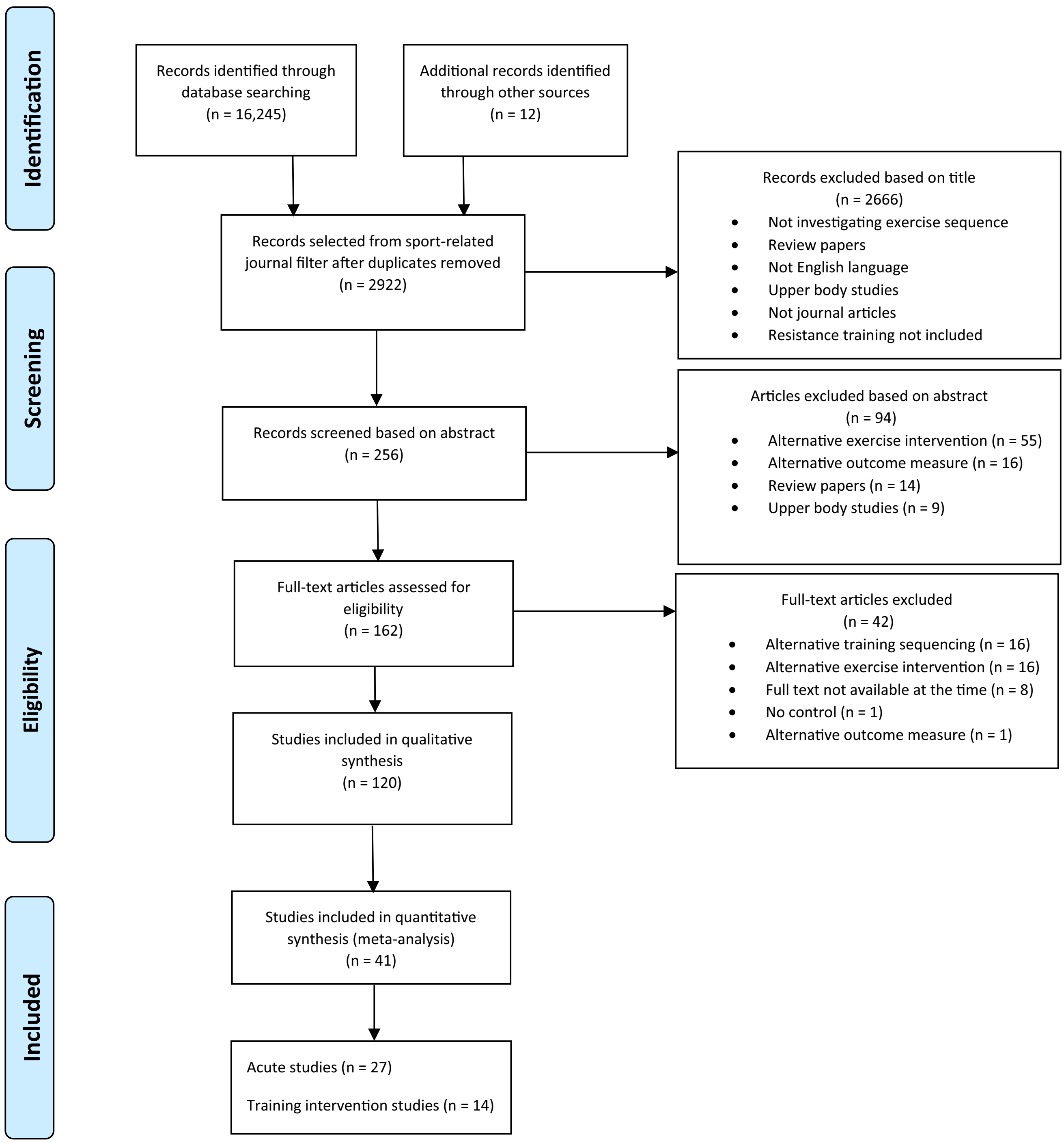


Fig. 1 PRISMA flow diagram showing the identification and selection of studies obtained for the present review

2.2 Grading Article Quality

A quality scoring system based on the same model used by Black et al. [10], was used to objectively measure the quality of each study. Studies were appraised using nine criteria (see Table 2) with the exception of studies investigating acute training effects, which used only eight criteria, because use of a practical training duration (criteria number 6) was not applicable. A scale of 0–2 (zero = no, one = maybe, and two = yes) was used for each answer, with a maximum score out of 18 (16 for acute studies) converted into a percentage ranging from 0–100% (see Tables 3 and 4). Articles were required to score > 80% to be involved in the final analysis. This maintained an acceptable level of quality. Two reviewers (JM and AT) conducted the searches, removed duplicates, screened all abstracts for eligibility and retrieved full-text versions of the eligible articles. Disagreements between reviewers' judgements were resolved by a third reviewer (CB).

2.3 Statistical Analysis

Review Manager (RevMan 5.2; Cochrane Collaboration, Oxford, United Kingdom) and Microsoft Excel (Microsoft Office 16; Microsoft Corporation, 2018) were used to carry out the meta-analysis. A random-effects meta-analysis was used to determine summary effect of both acute and training interventions for the following outcomes: Jump height (JH), peak force (PF), peak velocity (PV), peak power (PP), set 2 PP, 1RM and sprint time (for definitions see Table 1). Differences between acute cluster and traditional set maintenance, acute complex and contrast sets, and pre- and post-training intervention differences between cluster, complex, contrast and traditional training programs were expressed as effect sizes (ES) [Hedges' g [38] with 95% confidence intervals (CI)].

ES were classed in the following way: < 0.2 (trivial), 0.2–0.49 (small), 0.5–0.79 (moderate), and > 0.8 (large) according to the classifications set out by Cohen [19]. Heterogeneity between studies was evaluated with I^2 statistics [39] and between-study variance with the tau-square (Tau^2) [40]. The magnitude of heterogeneity for results was classified according to the following scale: < 25% (low), 25–75% (medium), and > 75% (high) [39]. If the p value for the chi-square was < 0.1, this indicated the presence of heterogeneity, with a Tau^2 value > 1 suggesting the presence of substantial statistical heterogeneity [40]. A p value of < 0.1 indicated whether statistically significant subgroup differences were present [79].

3 Results

3.1 Study Description

A total of 16,245 articles were initially returned with an additional 12 articles included from other sources. The titles and abstracts were then screened for relevance, followed by 162 articles being read to ensure that they were related to the inclusion criteria. Finally, 120 studies were graded according to the quality scoring system resulting in 41 studies scoring > 80% and being included in the systematic review.

These 41 studies were divided into acute ($n = 27$) and training intervention studies ($n = 14$). Acute studies were defined as studies lasting less than 1 week that investigated immediate effects, and training intervention studies were defined as those which lasted for 3 or more weeks and studied training adaptations. Within the acute study category, 13 studies investigated cluster sets using traditional set structures as controls, 1 study investigated complex training, 9 studies investigated contrast training, and 4 studies compared traditional, complex and contrast protocols with each other. Within the training intervention category, 5 studies compared cluster and traditional protocols, 1 study compared complex and traditional protocols, 5 studies compared contrast and traditional protocols, 1 study compared contrast, complex and traditional protocols, 1 study compared

Table 2 Study quality scoring system as used by Black et al. [10]

Criteria No	Item	Score
1	Inclusion criteria stated	0–2
2	Subjects assigned appropriately (randomized, ability level)	0–2
3	Intervention described (protocols equated)	0–2
4	Dependent variables defined (reliable outcome measures)	0–2
5	Assessments practical (easy to implement)	0–2
6	Training duration practical (only for intervention studies)	0–2
7	Appropriate statistics (normality, significant differences)	0–2
8	Results detailed (mean, standard deviation, percent change, effect size)	0–2
9	Conclusions concise (clear, concise, future directions)	0–2
Total		0–18

Table 3 Summary of acute studies investigating the effects of training sequence and inter/intra-set rest

Study	Subjects	Intervention	Outcome measure	Findings	Quality score (%)
Bauer et al. [8]	Resistance-trained males from American Football, track and field, weightlifting, powerlifting and martial arts ($n=60$)	3 protocols: control, three sets of back squats alternated with seven CMJs at 15 s, 1,3,5,7,11 min, using either 3×6 at 60% or 3×4 at 90% 1RM	CMJ height and relative PP	PAPE effect produced compared to control at 3,5 and 7 min following sets 1 and 2, and at 7 min following set 3 when relative PP was used as measure	93.75
Boullosa et al. [14]	Firefighters ($n=12$)	2 CA protocols: 5RM half squats to failure compared to same workload with 30-s IRR. CMJ measured before, and at various time points following CA	PP, PF, vertical stiffness, and vertical displacement of centre of mass	Cluster sets resulted in greater PP at 1 min compared to traditional set which potentiated less and at 9 min	93.75
Duthie et al. [24]	Resistance-trained women ($n=11$)	3 protocols: three sets of four jump squats before half squats (traditional), half squats then jump squats (complex), and alternating half squats and jump squats (contrast). Jump squats were completed after 5 min of recovery	Jump squat height, PP and PF	Contrast training is advantageous for increasing power output in athletes with high relative strength, though no protocols were significantly different to the traditional protocol	87.5
Garcia-Ramos et al. [26]	Resistance-trained soldiers ($n=16$)	3 protocols for half squat: optimal load, low load, and high load. For each, one set of continuous reps to failure, one set to failure with 6 s rest between reps	MP, PP and number of repetitions completed	6 s between reps is sufficient to induce partial recovery	87.5
González-Hernádez et al. [29]	Male sports science students ($n=11$)	6 protocols performing 30 squats at 10RM load and 5 min interset rest: 3×10, 6×5, 3×10 with 10-s IRR, 3×10 with 15-s IRR, 3×10 with 30-s IRR, and 1×30 with 15-s IRR	Mean propulsive velocity	Cluster protocols maintained mean propulsive velocity better than traditional protocols. In addition, longer IRR also caused reduced velocity loss	81.25
Haff et al. [31]	National track, field and Olympic weightlifters ($n=13$)	1 set of five reps in a cluster, traditional and undulating configuration for clean pull at 90 and 120% of power clean	PV, PD on set average	Significantly higher PV over cluster set. PD significantly higher for 120%	93.75
Hansen et al. [35]	Professional and semi-professional rugby players ($n=20$)	4×6 jump squats under four configurations: traditional with 3 min interset rests, 4×6 single reps with 12 s rests, 4×3 doubles with 30 s rests, 4×2 triples with 60 s rest	PP, PV, and PF of jump squat	Clusters appear to maintain PP and PV compared to traditional training. No significant differences between cluster set configurations. No differences in PF between protocols	81.25
Iglesias-Soler et al. [43]	Resistance-trained judo athletes ($n=9$)	2 protocols of parallel squats at 4RM: traditional 3xreps to failure and 3 min rest, or cluster with 36 s rest between reps	Mean propulsive velocity and number of repetitions completed	Cluster sets allowed for significantly more repetitions and a higher MPV	81.25

Table 3 (continued)

Study	Subjects	Intervention	Outcome measure	Findings	Quality score (%)
Jo et al. [44]	Resistance-trained males ($n=12$)	5 squat repetitions at 85% 1RM followed by a 30-s Wingate cycle test at 5,10,15 and 20 min	Wingate cycle PP	No significant differences compared to baseline	87.5
Jukic and Tufano [46]	Strength-trained men ($n=26$)	30 reps of back squat at 70% 1RM: traditional: 3 × 10 with 4 min rests, RR6: 5 × 6 with 2 min rests	PV and PP using GymAware	No difference between protocols for any variables	100
Jukic and Tufano [47]	Strength-trained men ($n=15$)	3 × 6 of clean pull at 80, 100 and 120% of power clean with 180 s interest rest or same weights with rest redistribution and 45 s every 2 reps	PV and PP using GymAware	RR maintains movement velocity and power output to a greater extent when compared to traditional sets at different loads, especially 100 and 120%	93.75
Kilduff et al. [50]	Professional rugby players ($n=20$)	3 × 3 squats at 87% with CMJ performed at before and at 15 s, 4,8,12,16,20,24 min after	JH and PP on force plate	CMJ performance significantly increased after 8 min rest	93.75
Koefoed et al. [51]	Non-elite resistance-trained subjects ($n=10$)	2 protocols of 4 × 6 loaded jump squats with 40% of body mass load added: Trad: 4 × 6 with 180 s rest. Clus: 4 × 6 with 20 s every 2 reps and 140 s interset rest	PP, PV, PF and JH	PF and PP significantly higher in the cluster protocol	87.5
Mola et al. [60]	Professional football players with resistance-training experience ($n=22$)	3RM squat with baseline CMJ, then again at 15 s, 4,8,12,16 and 20 min after	PP and JH	No overall difference between groups, although responders potentiated at 4,12 and 16 min	81.25
Naclerio et al. [64]	Resistance-trained male college athletes ($n=15$)	Protocols: 1 × 3 squats at 80%, 1 × 3 squats at 80% on vibration platform. 1 × 3 or 3 × 3, and 1 or 4 min recovery	JH, PF and PP for CMJ and drop jump	Both conditions improved CMJ after 4 min with low volume	87.5
Nickerson et al. [68]	Resistance-trained men ($n=12$)	4 protocols performing 1 set of 3 repetitions at 85% followed by vertical jumps: traditional set, traditional set with elastic bands, cluster set (30 s IRR), and cluster set with elastic bands. CMJ at 1,4,7 and 10 min post-CA	JH and PP	CS + bands elicited significant change in PP compared to baseline at 4 and 7 min and a significantly greater change than bands at 10 min. Bands caused significant change in PP at 10 min compared to 7 min	87.5
Oliver et al. [71]	12 resistance-trained and 12 non-trained men ($n=24$)	2 protocols completing back squats at 70% 1RM: Trad = 4 × 10 with 120 s interset rest. Clus = 4 × 10 with 30 s every 5 reps and 90 s interset rest	PF, PV and PP	Velocity maintained superiorly in cluster protocol compared to traditional	81.25

Table 3 (continued)

Study	Subjects	Intervention	Outcome measure	Findings	Quality score (%)
Robbins and Docherty [80]	Resistance-trained men ($n = 16$)	3 sets of 7-s maximal isometric squat alternated with 5 CMJs with 4 min recovery	PO and CMJ height	No significant differences between protocol and control condition	81.25
Schneiker et al. [83]	Sub-elite male Australian Rules players with resistance training experience ($n = 22$)	2 protocols: 6 squat jumps at 30%, or the same but with half squat contrast at 6 × 85%	PP and PF	No difference between groups but PP more enhanced in those with a lower power to strength ratio following contrast training	93.75
Seitz et al. [86]	Amateur rugby league players ($n = 14$)	Contrast protocol of 4 × 2 box squats with bands alternated with 2 standing broad jumps with a 90 s recovery between sets	Standing broad jump distance	Jump distance significantly greater after contrast protocols with 90 s rests. Increase was greater as sets went on. Stronger players displayed greater PAPE effect	93.75
Sotiropoulos et al. [89]	Resistance-trained male volleyball players ($n = 12$)	3 protocols: loaded squat jumps at max power, 70% of power max, 130% power max followed by 6 repeated squat jumps at 1, 3, 5, 7 and 10 min	JH and PP	No height change, mechanical power greater 5 min after 130% protocol	81.25
Talpey et al. [95]	Recreationally-trained males ($n = 18$)	4 protocols: Contrast protocols using heavy resistance at 3 × 4 reps of 5RM half squat, or contrast protocol using 5 s max isometric squat, complex conditions with the 2 above strength protocols. 4 min rest following heavy CA, 2 min following CMJ	PP during CMJ	Control protocol produced significantly greater PP than others except for dynamic complex and static contrast	93.75
Tufano et al. [99]	Strength-trained men ($n = 12$)	Using back squat, subjects performed 3 protocols: TS = 3 × 12 at 60% with 120 s interset rest, CS4 = 3 × 12 at 75% with 120 s interset rest and 30 s rest every 4 reps, CS2 = 3 × 12 at 80% and 120 s interset rest and 30 s rest every 2 reps	PF, PV and PP	Cluster protocols reduced fatigue-induced decreases in velocity compared to traditional training and allowed higher loads to be lifted without negatively effecting power, resulting in more work done	87.5
Tufano et al. [98]	Strength-trained men ($n = 12$)	Using back squat, subjects performed 3 protocols at 60% 1RM: TS = 3 × 12 at with 120 s interset rest, CS4 = 3 × 12 at with 120 s interset rest and 30 s rest every 4 reps, CS2 = 3 × 12 at and 120 s interset rest and 30 s rest every 2 reps	PF, PV and PP	Both cluster protocols maintained power and velocity over 3 sets compared to traditional. CS2 resulted in greater velocity and power values and less decrement compared to CS4	87.5

Table 3 (continued)

Study	Subjects	Intervention	Outcome measure	Findings	Quality score (%)
Wagle et al. [103]	Resistance-trained men ($n=11$)	2 protocols of 3×5 back squats at 80% 1RM and 3 min interset rest: traditional straight sets vs. cluster sets with 30 s IRR	PP and AV	Small positive effects observed for PP and moderate positive effects for AV when comparing the cluster protocol to the traditional	87.5
Weber et al. [105]	Male college track and field athletes ($n=12$)	5 back squats at 85% compared to 5 jump squats. Squat jump test performed before and 3 min after CA	JH and PF	Squat protocol caused increases in JH and GRF compared to decrease with jump squat protocol	87.5
Wetmore et al. [106]	Resistance-trained males ($n=11$)	2 protocols: 3×5 squats at 80% and 3 min interset rest or 3×5 at 80% with 30 s IRR and 3 min interset rest	PF, PV and PP	Cluster protocol produced higher PP outputs, average power outputs and velocities compared to traditional training	93.75

AV average velocity, *CA* conditioning activity, *CMJ* countermovement jump, *EMG* electromyography, *GRF* ground reaction force, *IRR* interrepetition rest, *JH* jump height, *PAPE* postactivation performance enhancement, *PD* peak displacement, PF peak force, *PP* peak power, *PV* peak velocity, *RM* repetition maximum, *SJ* squat jump

contrast and complex protocols, and 1 study investigated traditional training.

A wide range of outcome measures were used to assess the effect of the different set sequences and rest periods. Many of the review studies and the protocols/interventions within them used multiple outcome measures which included: PF ($n=22$), PP ($n=48$), PV ($n=11$), JH ($n=32$), 1 RM squat ($n=18$) and sprint time ($n=10$). Exercises included full, parallel, banded and isometric squats, countermovement, drop and squat jumps, and clean pulls. For study details, see Tables 2 and 3. Additionally, the authors felt that it would be useful to investigate the effects of contrast and complex sequences on later sets. Set 2 PP ($n=9$) was chosen as an outcome measure to demonstrate this. Unfortunately, too few studies reported the results of sets after set 2, so no further outcomes were investigated.

3.2 Meta-Analysis

3.2.1 Acute Cluster Results

When investigating PF in cluster and traditional set protocols (Fig. 2), low levels of heterogeneity were observed amongst studies ($I^2=0\%$, $Tau^2=0$). Compared to the traditional protocol, PF was higher in the cluster protocol with a trivial effect [ES: 0.14, 95% CI (−0.21, 0.48), $p=0.44$]. When investigating PV in cluster and traditional set protocols (Fig. 3), medium levels of heterogeneity were observed amongst studies ($I^2=74\%$, $Tau^2=0.47$). Compared to the traditional protocol, PV was higher in the cluster protocol with a large positive effect [ES: 1.07, 95% CI (0.58, 1.55), $p<0001$]. When investigating PP in cluster and traditional set protocols (Fig. 4), low levels of heterogeneity were observed amongst studies ($I^2=0\%$, $Tau^2=0$). Compared to the traditional protocol, PP was higher in the cluster protocol with a small positive effect [ES: 0.42, 95% CI (0.18, 0.65), $p=0.0005$].

3.2.2 Acute Contrast vs. Complex results

When investigating JH in contrast and complex protocols (Fig. 5), low levels of heterogeneity were observed amongst both studies ($I^2=0\%$, $Tau^2=0$). After examining the contrast studies, there was a small positive effect versus baseline [ES: 0.27, 95% CI (0.09, 0.45), $p=0.003$] compared to the complex studies which had a trivial effect [ES: −0.05, 95% CI (−0.59, 0.50), $p=0.86$] with no significant differences seen between the two types of training sequence ($p=0.74$).

When investigating PF in contrast and complex protocols (Fig. 6), low levels of heterogeneity were observed amongst contrast studies ($I^2=0\%$, $Tau^2=0$) and complex studies ($I^2=0\%$, $Tau^2=0$). After examining the contrast studies there was a small positive effect versus baseline [ES: 0.20,

Table 4 Summary of training intervention studies investigating the effects of training sequence and inter/intraset rest

Study	Subjects	Intervention	Outcome measure	Findings	Quality score (%)
Abade et al. [1]	Semi-pro male handball players ($n=20$)	2 groups over 12 weeks for leg press and half squat: Traditional group completed 4×6 at 80% and 4×8 at 30% on separate days. Contrast group performed 2×6 and 2×8 on both days. Contrast group contained worse performers based on CMJ test. Traditional group contained better jumpers	CMJ height, 10 and 20 m sprint	Greater CMJ height and 20 m improvements seen in contrast group	83.33
Alemdaroglu et al. [3]	Recreationally-trained students ($n=24$)	3 protocols over 6 weeks: plyometrics then resistance (traditional), resistance alternated with plyometrics (contrast), and resistance then plyometrics (complex)	Isokinetic leg strength, CMJ height and SJ height	No differences between protocols for any variables, but all improved compared to control	81.25
Arazi et al. [5]	Resistance-trained female volleyball players ($n=30$)	3 groups resistance training 3×per week over 8 weeks: Control, cluster and traditional	Squat and deadlift 1RM, 20 m sprint time, CMJ height and PP	Both groups improved in all areas with cluster showing slightly greater improvements overall	94.44
Dobbs et al. [22]	High school rugby players ($n=20$)	2 groups over 7 weeks: contrast group and complex control group with the same volume	Squat 4RM, CMJ, broad jump, and drop jump with force plate variables	Vertical and horizontal CMJ variables were improved significantly more in the contrast group. No difference in 4RM strength change	83.33
Freitas et al. [25]	Semi-professional male basketball players ($n=18$)	2 groups over 6 weeks: Optimal power load for half squat, bench press and hip thrust vs. contrast pairs of 80% of 1RM paired with optimal load sets	Anthropometrics, 1RM strength, CMJ, single leg jump, 10 m sprint and t-test	Optimal load group showed positive changes for lower body strength, 10 m sprint and t-test. Contrast group showed positive changes for lower body strength, CMJ PP, single leg jump, 10 m sprint and *t* test. Contrast appears superior for half squat and SLJ	88.9
Hammami et al. [34]	Elite 15–17 year old football players ($n=40$)	3 groups over 8 weeks: control, contrast = half squats contrasted with CMJ and 15 m sprint, plyometrics = hurdle and drop jumps	5 and 40 m sprint, 4×5 m direction change, anthropometry, leg muscle volume, CMJ and SJ force plate measures, 1RM half-squat, quadriceps EMG	Both experimental groups improved speed and change of direction performance significantly compared to control. Contrast group caused greater improvements in CMJ, 1RM and SJ	83.3
Hansen et al. [36]	Elite rugby players ($n=18$)	Traditional training group compared to cluster training over 8 weeks for half squat and jump squat at varying loads	Predicted 1RM for half squat and JS PP, PV and PF at 20,40 and 60 kg	Traditional training superior for maximal strength, some evidence that cluster training superior for PP due to moderate effect sizes	94.44

Table 4 (continued)

Study	Subjects	Intervention	Outcome measure	Findings	Quality score (%)
Loturco et al. [54]	Trained soldiers ($n=48$)	Traditional squat training group, and complex training group performed over 9 weeks	1RM squat, CMJ height, mean power and mean propulsive power in loaded SJ at 45% 1RM, and 20 m sprint	Although all variables improved compared to control group, traditional training lead to significantly higher improvements in sprint performance. Non-significant trend for complex training to be more effective for 1RM and CMJ than traditional	94.44
Morales-Artacho et al. [61]	Active males ($n=19$)	2 half squat protocols, two sessions a week for 3 weeks: traditional training (6×6 reps) vs. cluster training (6×3(2) squats)	Lower body force, velocity and power output during CMJ at 25,50 and 75% body mass	Cluster protocol more effective at inducing velocity and power adaptations specific to training load	83.33
Nicholson et al. [67]	Resistance-trained males ($n=46$)	4 squat protocols 2×per week for 6 weeks: strength (4×6 at 85%, 900 s rest), hypertrophy (5×10 at 75%, 360 s rest), cluster 1 (4×6/1 at 85%, 1400 s rest), and cluster 2 (4×6/1 at 90%, 1400 s rest)	1RM strength, maximal isometric squat, isokinetic flexion/extension, CMJ, surface EMG for quadriceps and gluteus maximus, blood lactate	Significantly greater increase in 1RM in strength and cluster 2 compared to hypertrophy group. No differences between jump variables. Cluster groups resulted in reduced metabolic demands compared to other groups	88.88
Ramirez-Campillo et al. [77]	Young football players ($n=54$)	3 groups training 2×per week for 7 weeks: 30 s, 60 s or 120 s recovery between plyometric sets	CMJ, 20 and 40 cm DJ, 20 m sprint, change of direction L-run and kicking performance	All rest periods improved test variables equally compared to control	94.44
Rial-Vázquez et al. [78]	Sports science students ($n=39$)	3 groups over 5 weeks training twice per week with a 10RM squat load: Control, traditional (4×8 with 5 min interset rest), and cluster (16×2 with 1 min interset rest)	1RM squat, PP at optimal load, maximum theoretical PV and PF when load is zero and velocity is zero, respectively	Small positive effects in both groups for 1RM squat (larger in cluster), increases in both groups for PV, PF, and PP but greater effects in cluster group	94.44
Spineti et al. [90]	Elite under 20 football players ($n=22$)	2 groups over 8 weeks 3×per week: Traditional weight training vs. contrast training with power exercises and plyometrics (different exercises)	Muscle architecture, repeat sprint ability, CMJ, 1RM Smith half squat	Contrast group: Significant improvements in 1RM, CMJ and repeat sprint ability % decrement. Traditional group: Significant improvements in 1RM, and muscle architecture	88.9

Table 4 (continued)

Study	Subjects	Intervention	Outcome measure	Findings	Quality score (%)
Talpey et al. [94]	Resistance-trained males ($n=20$)	2 groups over 9 weeks: complex group performed half squats prior to sets of jump squats, traditional group performed jump squats prior to half squats. 4 min recovery between squats, 3 min between jumps	CMJ variables at body weight, 10% and 20% of 1RM, 1RM, running vertical jump, sprint performance	Explosive muscle function and JH significantly improved in both groups. Complex group running vertical jump significantly higher than traditional. No difference in sprint performance. 1RM significantly improved in both groups but with no difference between them	83.33

AV average velocity, *CMJ* countermovement jump, *DJ* drop jump, *EMG* electromyography, *GRF* ground reaction force, *JH* Jump height, *PF* peak force, *PP* peak power, *PV* peak velocity, *RM* repetition maximum, *SJ* squat jump

95% CI (−0.1, 0.51), $p=0.19$] compared to the complex studies which had a small negative effect [ES: −0.25, 95% CI: (−0.8, 0.3), $p=0.37$] with no significant differences seen between the two types of training sequence ($p=0.15$).

When investigating PP in contrast and complex protocols (Fig. 7), low levels of heterogeneity were observed amongst contrast studies ($I^2=0\%$, $Tau^2=0$) and complex studies ($I^2=0\%$, $Tau^2=0$). After examining the contrast studies, there was a small positive effect versus baseline [ES: 0.25, 95% CI (0.09, 0.4), $p=0.002$] compared to the complex studies which had a trivial effect [ES: 0.02, 95% CI (−0.29, 0.32), $p=0.92$] with no significant differences seen between the two types of training sequence ($p=0.18$).

When investigating PP during set 2 of the explosive exercise in contrast and complex protocols (Fig. 8), low levels of heterogeneity were observed amongst contrast studies ($I^2=0\%$, $Tau^2=0$) and complex studies ($I^2=0\%$, $Tau^2=0$). After examining the contrast studies there was a trivial effect versus baseline [ES: 0.07, 95% CI (−0.13, 0.27), $p=0.51$] compared to the complex studies which had a trivial effect [ES: −0.07, 95% CI (−0.14, 0.22), $p=0.75$] with no significant differences seen between the two types of training sequence ($p=0.56$).

3.2.3 Training Intervention Results

When investigating differences between pre- and post-training intervention JH for cluster, complex, contrast and traditional training (Fig. 9), low levels of heterogeneity were observed amongst cluster, complex and traditional studies ($I^2=0\%$, $Tau^2=0$) and medium levels amongst contrast studies ($I^2=70\%$, $Tau^2=0.54$). After examining the cluster studies there was a small positive effect [ES: 0.39, 95% CI (−0.10, 0.88), $p=0.12$), compared to the complex studies which had a moderate positive effect [ES: 0.61, 95% CI (−0.08, 1.31), $p=0.08$], the contrast studies which had a large positive effect [ES: 1.10, 95% CI (0.40, 1.80), $p<0.01$], and the traditional group which had a small positive effect [ES: 0.41, 95% CI (0.12, 0.70), $p<0.01$]. No significant differences were seen between any of the four training types ($p>0.1$) with the exception of traditional versus contrast ($p=0.07$).

When investigating differences between pre- and post-training intervention 1 RM for cluster, complex, contrast and traditional training (Fig. 10), low levels of heterogeneity were observed amongst cluster, complex, and contrast studies ($I^2=0\%$, $Tau^2=0$) and medium levels with traditional studies ($I^2=44\%$, $Tau^2=0.17$). After examining the cluster studies, there was a moderate positive effect [ES: 0.68, 95% CI (0.24, 1.12), $p<0.01$] compared to the complex studies which had a large positive effect [ES: 0.93, 95% CI (0.25, 1.60), $p<0.01$], the contrast group which had a large positive effect [ES: 1.16, 95% CI (0.70, 1.62), $p<0.01$], and the

Study or Subgroup	Cluster training Mean	SD	Total	Traditional training Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Hansen et al. [36]	2,422	534	20	2,384	400	20	31.0%	0.08 [-0.54, 0.70]
Koefoed et al. [52]	2,786	629	10	2,642	507	10	15.4%	0.24 [-0.64, 1.12]
Tufano et al. [100]	2,605	250	12	2,464	257	12	17.9%	0.54 [-0.28, 1.35]
Tufano et al. [99]	3,012	465	11	3,002	504	11	17.1%	0.02 [-0.82, 0.86]
Wetmore et al. [107]	2,526	238	12	2,559	248	12	18.6%	-0.13 [-0.93, 0.67]
Total (95% CI)			**65**			**65**	**100.0%**	**0.14 [-0.21, 0.48]**

Heterogeneity: Tau² = 0.00; Chi² = 1.51, df = 4 (P = 0.82); I² = 0%
Test for overall effect: Z = 0.78 (P = 0.44)

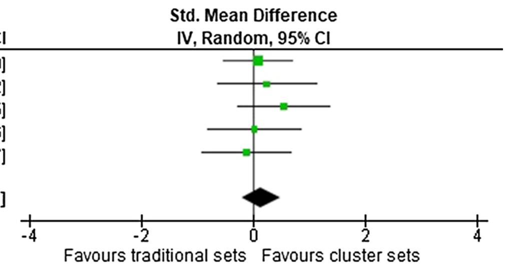


Fig. 2 Acute effects of cluster set structures on peak force (Newtons) compared to traditional sets. Each plotted point represents the standard error and effect sizes between cluster sets and traditional sets

Study or Subgroup	Cluster training Mean	SD	Total	Traditional training Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
González-Hernádez et al. [30]	0.75	0.03	11	0.61	0.03	11	5.0%	4.49 [2.80, 6.18]
Haff et al. [32]	1.72	0.06	13	1.59	0.06	13	8.4%	2.10 [1.11, 3.09]
Hansen et al. [36]	-0.02	0.15	20	-0.12	0.14	20	10.6%	0.68 [0.04, 1.31]
Iglesias-Soler et al. [44]	0.44	0.08	9	0.36	0.04	9	8.2%	1.20 [0.18, 2.23]
Jukic & Tufano [47]	0.63	0.25	26	0.62	0.25	26	11.1%	0.04 [-0.50, 0.58]
Jukic &Tufano [48]	91.57	2.44	15	87.79	3.42	15	9.6%	1.24 [0.45, 2.03]
Koefoed et al. [52]	2.49	0.21	10	2.46	0.26	10	9.1%	0.12 [-0.76, 1.00]
Oliver et al. [72]	0.73	0.04	24	0.68	0.05	24	10.7%	1.09 [0.48, 1.70]
Tufano et al. [99]	0.8	0.08	12	0.72	0.05	12	9.1%	1.16 [0.28, 2.03]
Wagle et al. [104]	0.55	0.07	11	0.49	0.07	11	9.1%	0.82 [-0.05, 1.70]
Wetmore et al. [107]	0.541	0.072	11	0.489	0.071	11	9.1%	0.70 [-0.17, 1.57]
Total (95% CI)			**162**			**162**	**100.0%**	**1.07 [0.58, 1.55]**

Heterogeneity: Tau² = 0.47; Chi² = 38.07, df = 10 (P < 0.0001); I² = 74%
Test for overall effect: Z = 4.33 (P < 0.0001)

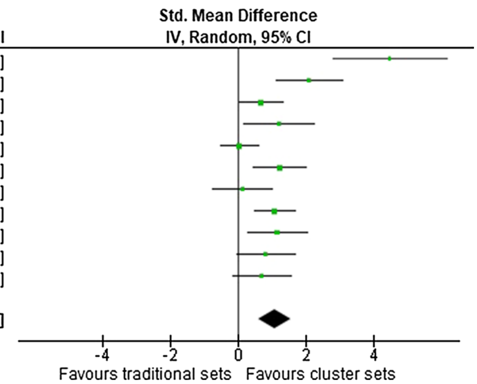


Fig. 3 Acute effects of cluster set structures on peak velocity (meters per second) compared to traditional sets. Each plotted point represents the standard error and effect sizes between cluster sets and traditional sets

Study or Subgroup	Cluster training Mean	SD	Total	Traditional training Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Garcia-Ramos et al. [27]	1,390.7	269.8	16	1,271.8	236	16	11.1%	0.46 [-0.25, 1.16]
Haff et al. [32]	2,957	191	13	2,768	200	13	8.2%	0.94 [0.12, 1.75]
Hansen et al. [36]	-120	380	20	-400	460	20	13.4%	0.65 [0.01, 1.29]
Iglesias-Soler et al. [44]	1,197	611	26	1,156	611	26	18.5%	0.07 [-0.48, 0.61]
Jukic &Tufano [48]	85.55	4.02	15	82.79	8.67	15	10.4%	0.40 [-0.33, 1.12]
Koefoed et al. [52]	5,060	1,254	10	4,882	1,283	10	7.1%	0.13 [-0.74, 1.01]
Tufano et al. [100]	2,170	413	12	2,121	354	12	8.5%	0.12 [-0.68, 0.92]
Tufano et al. [99]	2,563	403	12	2,208	243	12	7.4%	1.03 [0.17, 1.89]
Wagle et al. [104]	2,836.39	993.46	11	2,526.1	786.41	11	7.7%	0.33 [-0.51, 1.18]
Wetmore et al. [107]	2,834	982	11	2,518	784	11	7.7%	0.34 [-0.50, 1.19]
Total (95% CI)			**146**			**146**	**100.0%**	**0.42 [0.18, 0.65]**

Heterogeneity: Tau² = 0.00; Chi² = 6.61, df = 9 (P = 0.68); I² = 0%
Test for overall effect: Z = 3.49 (P = 0.0005)

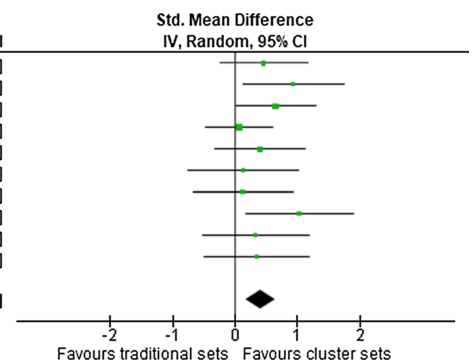


Fig. 4 Acute effects of cluster set structures on peak power (Watts) compared to traditional sets. Each plotted point represents the standard error and effect sizes between cluster sets and traditional sets

traditional group which had a large positive effect [ES: 1.19, 95% CI (0.76, 1.63), $p<0.01$]. No significant differences were seen between any of the four training types ($p>0.1$).

When investigating differences between pre- and post-training intervention PF for contrast, complex, cluster and traditional training (Fig. 11), low levels of heterogeneity were observed amongst all training programs ($I^2=0\%$, $\mathrm{Tau}^2=0$). After examining the contrast studies, there was a moderate positive effect [ES: 0.64, 95% CI (0.06, 1.23), $p=0.03$], the complex studies had a trivial effect [ES: 0.14, 95% CI (−0.50, 0.78), $p=0.67$], the cluster studies had a trivial effect [ES: −0.04, 95% CI (−0.47, 0.39), $p=0.84$], and the traditional studies had a trivial effect [ES: 0.14, 95% CI (−0.24, 0.52), $p=0.48$]. No significant differences were seen between the training types ($p>0.1$) with the exception of contrast versus cluster training ($p=0.08$).

When investigating differences between pre- and post-training intervention PV for contrast, cluster and traditional training (Fig. 12), low levels of heterogeneity were observed

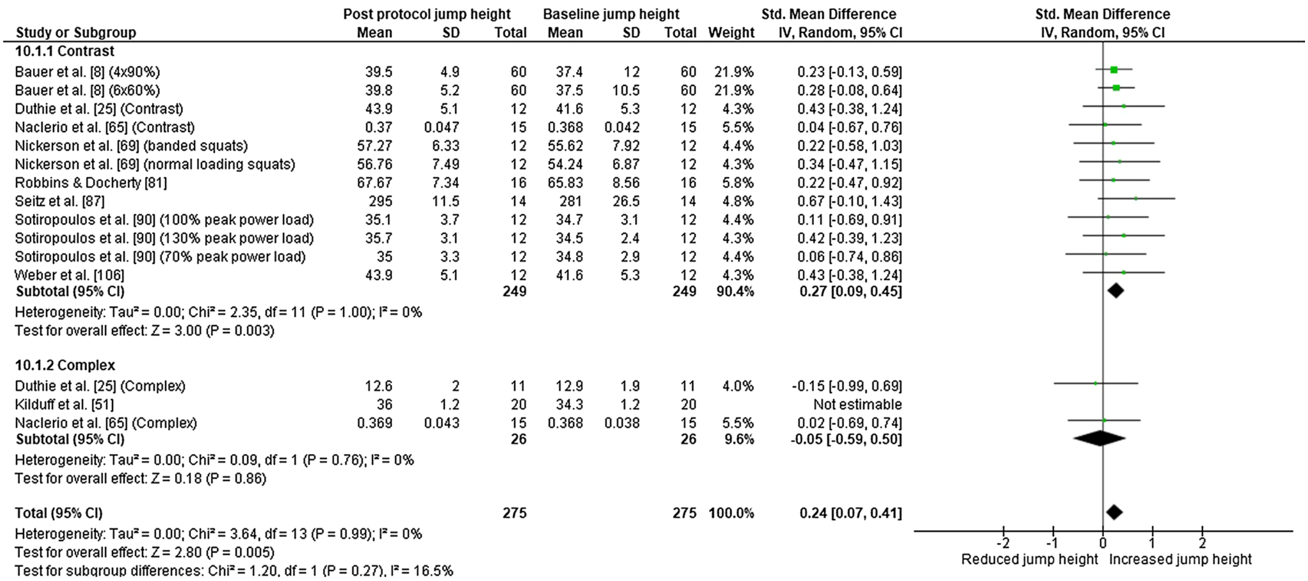


Fig. 5 Acute effects of contrast and complex training on jump height (centimetres). Each plotted point represents the standard error and effect sizes between baseline and post-protocol results

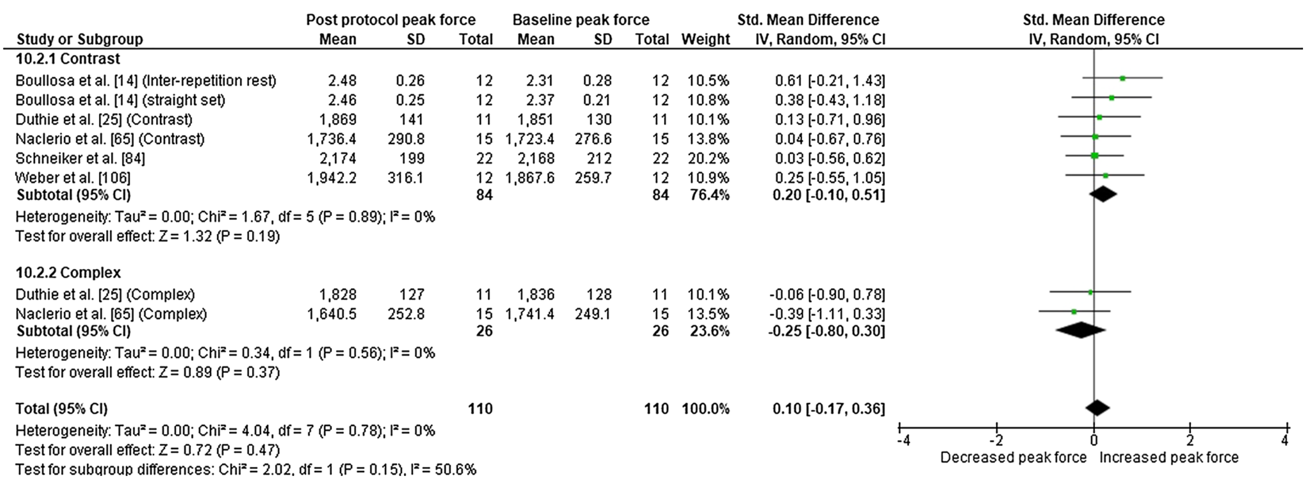


Fig. 6 Acute effects of contrast and complex training on peak force (Newtons). Each plotted point represents the standard error and effect sizes between baseline and post-protocol results

amongst all training programs ($I^2=0\%$, $\text{Tau}^2=0$). After examining the contrast studies, there was a large positive effect [ES: 1.01, 95% CI (0.4, 1.62), $p<0.01$], the cluster studies had a small positive effect [ES: 0.33, 95% CI (−0.31, 0.97), $p=0.32$], and the traditional studies had a small positive effect [ES: 0.24, 95% CI: (−0.28, 0.76), $p=0.36$]. The contrast studies showed significantly greater improvements compared to traditional studies ($p=0.06$). Aside from this, no significant differences were observed between training types ($p>0.1$).

When investigating differences between pre- and post-training intervention PP for cluster, contrast and traditional training (Fig. 13), low levels of heterogeneity were observed amongst all training programs ($I^2=0\%$, $\text{Tau}^2=0$). After examining the cluster studies, there was a small positive effect [ES: 0.36, 95% CI (0.01, 0.72), $p=0.04$] compared to the contrast studies which had a moderate effect [ES: 0.67, 95% CI (0.20, 1.13), $p<0.01$], and the traditional group which had a moderate effect [ES: 0.52, 95% CI (0.24, 0.80), $p<0.01$]. No significant differences were seen between any of the three training types ($p>0.1$).

When investigating differences between pre- and post-training intervention sprint time for contrast and traditional training (Fig. 14), low levels of heterogeneity were observed

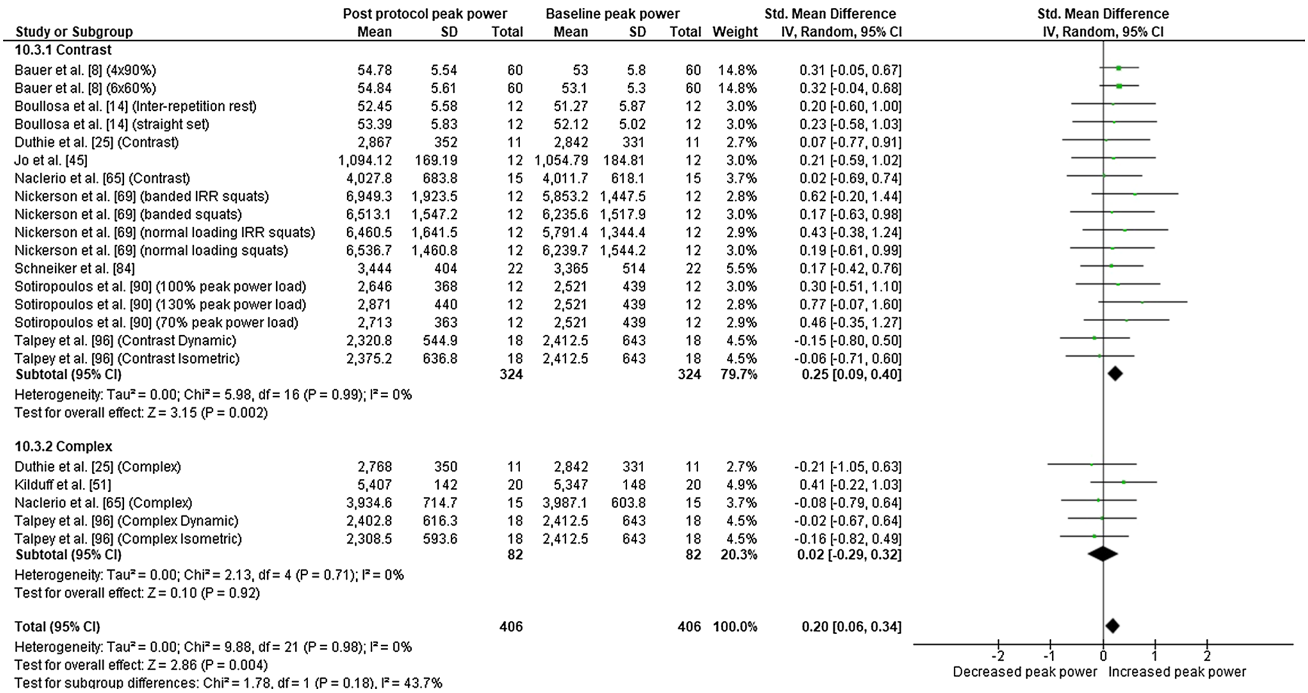


Fig. 7 Acute effects of contrast and complex training on peak power (Watts). Each plotted point represents the standard error and effect sizes between baseline and post-protocol results

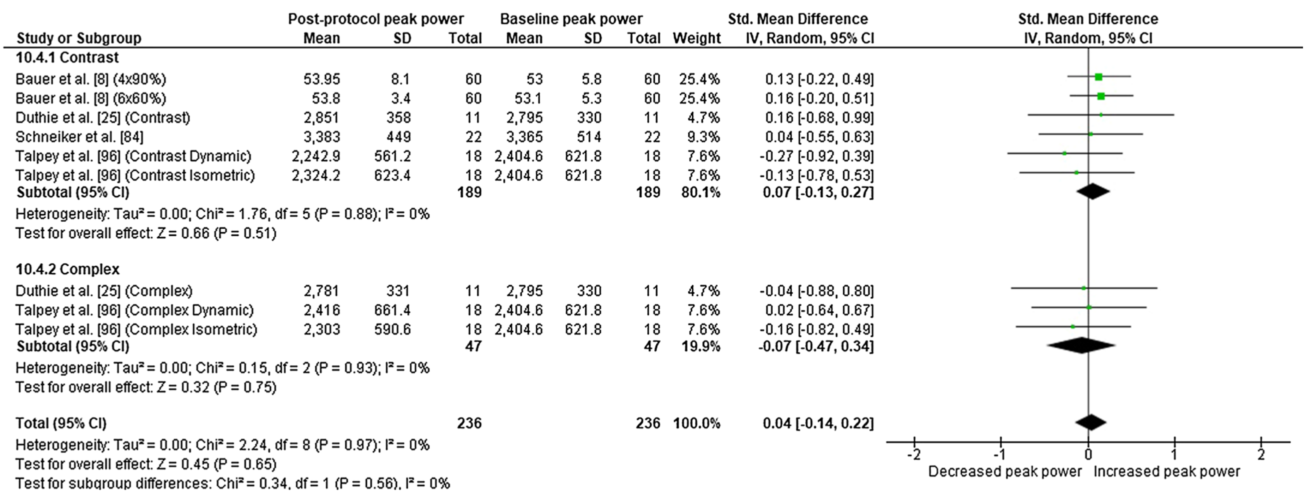


Fig. 8 Acute effects of contrast and complex training on set 2 peak power (Watts). Each plotted point represents the standard error and effect sizes between baseline and post-protocol results

in the contrast training programs ($I^2=0\%$, $Tau^2=0$), and moderate levels in the traditional training programs ($I^2=58\%$, $Tau^2=0.26$). After examining the contrast studies, there was a large negative effect [ES: −2.10, 95% CI (−2.67, −1.53), $p<0.01$] compared to the traditional studies which had a small negative effect [ES: −0.45, 95% CI (−0.94, 0.05), $p=0.08$]. Significant differences were seen between the training types ($p<0.01$).

4 Discussion

The purpose of this systematic review was to compare the acute and chronic responses of cluster, contrast, complex, and traditional training and to identify which of these training types may be used to target a particular training adaptation most optimally. When designing a RT session, the order of the chosen exercises and the intra-set recovery may have

Study or Subgroup	Post jump height Mean	SD	Total	Pre jump height Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
11.1.1 Cluster								
Arazi et al. [3] (Cluster)	35.8	6.1	10	33.5	6.3	10	5.1%	0.36 [-0.53, 1.24]
Nicholson et al. [68] (85% Cluster)	0.36	0.05	12	0.34	0.05	12	5.7%	0.39 [-0.42, 1.20]
Nicholson et al. [68] (90% Cluster)	0.36	0.04	11	0.34	0.05	11	5.4%	0.42 [-0.42, 1.27]
Subtotal (95% CI)			**33**			**33**	**16.1%**	**0.39 [-0.10, 0.88]**
Heterogeneity: Tau² = 0.00; Chi² = 0.01, df = 2 (P = 0.99); I² = 0%								
Test for overall effect: Z = 1.56 (P = 0.12)								
11.1.2 Complex								
Alemdaroglu et al. [3] (Complex)	143.3	25.3	8	129.1	31	8	4.4%	0.47 [-0.52, 1.47]
Talpey et al. [95] (Complex)	46.6	5	9	43.1	3.9	9	4.6%	0.74 [-0.22, 1.71]
Subtotal (95% CI)			**17**			**17**	**8.9%**	**0.61 [-0.08, 1.31]**
Heterogeneity: Tau² = 0.00; Chi² = 0.14, df = 1 (P = 0.70); I² = 0%								
Test for overall effect: Z = 1.73 (P = 0.08)								
11.1.3 Contrast								
Abade et al. [1] (Contrast)	31.02	3.84	10	27.24	2.89	10	4.6%	1.07 [0.11, 2.02]
Alemdaroglu et al. [3] (Contrast)	133.3	27.1	8	130.8	35.4	8	4.5%	0.07 [-0.91, 1.06]
Freitas et al. [26] (Contrast)	37.2	3.6	9	36.4	4.2	9	4.8%	0.19 [-0.73, 1.12]
Hammami et al. [35] (Contrast)	47	5.9	14	38.2	2.1	14	4.8%	1.93 [1.01, 2.85]
Loturco et al. [55] (Contrast)	40	4.7	15	29.1	4.8	15	4.7%	2.23 [1.29, 3.17]
Spineti et al. [91] (Contrast)	36.4	4.7	10	31.4	4.2	10	4.6%	1.07 [0.12, 2.03]
Subtotal (95% CI)			**66**			**66**	**28.1%**	**1.10 [0.40, 1.80]**
Heterogeneity: Tau² = 0.54; Chi² = 16.59, df = 5 (P = 0.005); I² = 70%								
Test for overall effect: Z = 3.07 (P = 0.002)								
11.1.4 Traditional								
Abade et al. [1] (Traditional)	36.6	5.6	10	36.2	5.6	10	5.1%	0.07 [-0.81, 0.95]
Alemdaroglu et al. [3] (Traditional)	139.6	26.3	8	125.7	31.6	8	4.4%	0.45 [-0.54, 1.45]
Arazi et al. [5] (Traditional)	34.6	4.1	10	33	4.2	10	5.1%	0.37 [-0.52, 1.25]
Freitas et al. [26] (Traditional)	37.9	7.5	9	36.5	7.2	9	4.8%	0.18 [-0.74, 1.11]
Hammami et al. [35] (Plyometrics)	42.1	6	14	36.9	3.9	14	5.8%	1.00 [0.21, 1.79]
Loturco et al. [55] (Traditional)	37.3	2.75	18	28.2	2.6	18		Not estimable
Nicholson et al. [68] (Traditional)	0.41	0.07	11	0.39	0.07	11	5.4%	0.27 [-0.57, 1.12]
Ramirez-Campillo et al. [78]	23.5	5.4	11	21.7	4.4	11	5.4%	0.35 [-0.49, 1.20]
Spineti et al. [91] (Traditional)	31.6	4.9	12	31.1	5.5	12	5.7%	0.09 [-0.71, 0.89]
Talpey et al. [95] (Traditional)	45.9	4.3	11	41.9	5.2	11	5.1%	0.81 [-0.07, 1.68]
Subtotal (95% CI)			**96**			**96**	**46.9%**	**0.41 [0.12, 0.70]**
Heterogeneity: Tau² = 0.00; Chi² = 4.45, df = 8 (P = 0.81); I² = 0%								
Test for overall effect: Z = 2.77 (P = 0.006)								
Total (95% CI)			**212**			**212**	**100.0%**	**0.62 [0.36, 0.87]**
Heterogeneity: Tau² = 0.13; Chi² = 30.41, df = 19 (P = 0.05); I² = 38%								
Test for overall effect: Z = 4.77 (P < 0.00001)								
Test for subgroup differences: Chi² = 3.50, df = 3 (P = 0.32), I² = 14.4%								

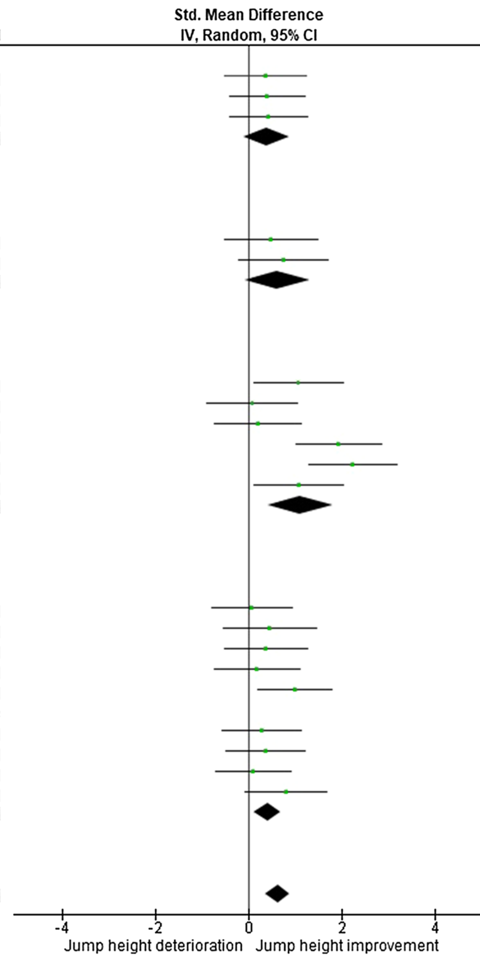


Fig. 9 Training intervention effects of cluster, complex, contrast and traditional training on jump height (centimetres). Each plotted point represents the standard error and effect sizes between post-intervention and pre-intervention

significant effects on both acute variables and long-term training adaptations. The information in this meta-analysis will have important implications for practitioners when planning sessions and training blocks for their athletes.

4.1 Traditional

The findings of the present meta-analysis suggest that following traditional training, small positive effects on JH (ES: 0.41, 95% CI [0.12, 0.70], $p < 0.01$) and PV (ES: 0.24, 95% CI [−0.28, 0.76], $p = 0.36$), moderate positive effects on PP (ES: 0.52, 95% CI [0.24, 0.80], $p < 0.01$), a large positive effect on squat 1RM (ES: 1.19, 95% CI [0.76, 1.63], $p < 0.01$), a trivial effect on jump PF (ES: 0.14, 95% CI [−0.24, 0.52], $p = 0.48$), and a small negative effect on sprint time (ES: −0.45, 95% CI [−0.94, 0.05], $p = 0.08$) can be obtained (Figs. 9, 10, 11, 12, 13, 14). Traditional training resulted in the greatest increases in back squat 1 RM compared to the other training methods. With this method, the multiple sets of low load exercises performed before the heavy sets are likely to have created a small amount of fatigue. When the time came to perform the heavy sets afterwards, these sets would have had a closer proximity to failure relative to the other three types of training. This may have activated more higher order motor units which could lead to greater improvements in strength [63]. Interestingly, traditional training did not have the greatest effects on jump PF (ES: 0.14, 95% CI [−0.24, 0.52], $p = 0.48$), despite having the greatest effects for 1 RM (ES: 1.19, 95% CI [0.76, 1.63], $p < 0.01$), which suggests that force and velocity adaptations are specific to the loads used in training. Traditional training had a small positive effect on jump PV (ES: 0.24, 95% CI [−0.28, 0.76], $p = 0.36$). Though this effect was smaller than that of contrast training (ES: 1.01, 95% CI [0.4, 1.62], $p < 0.01$), it is likely that greater improvements in jump PV following traditional training interventions would be seen compared to complex training, had enough complex training studies with this as an outcome measure been

Study or Subgroup	Post 1RM Mean	Post 1RM SD	Post 1RM Total	Pre 1RM Mean	Pre 1RM SD	Pre 1RM Total	Weight	Std. Mean Difference IV, Random, 95% CI
11.2.1 Cluster								
Arazi et al. [3] (Cluster)	48.2	0.59	10	44.6	0.7	10		Not estimable
Hansen et al. [37] (Cluster)	216.4	25.3	9	191.1	25	9	4.7%	0.96 [-0.03, 1.95]
Nicholson et al. [68] (85% Cluster)	150.56	23.78	12	134.72	21.88	12	6.7%	0.67 [-0.16, 1.50]
Nicholson et al. [68] (90% Cluster)	138.61	20.85	11	121.39	21.36	11	6.0%	0.78 [-0.09, 1.66]
Rial-Vázquez et al. [79] (Cluster)	199.42	43.4	11	182.92	38.52	11	6.4%	0.39 [-0.46, 1.23]
Subtotal (95% CI)			**43**			**43**	**23.8%**	**0.68 [0.24, 1.12]**
Heterogeneity: Tau² = 0.00; Chi² = 0.82, df = 3 (P = 0.84); I² = 0%								
Test for overall effect: Z = 3.03 (P = 0.002)								
11.2.2 Complex								
Dobbs et al.[23] (Complex)	148.4	18.1	10	132.5	17.1	10	5.4%	0.86 [-0.06, 1.79]
Talpey et al. [95] (Complex)	181.1	35.3	9	145.6	32.6	9	4.7%	1.00 [0.00, 1.99]
Subtotal (95% CI)			**19**			**19**	**10.1%**	**0.93 [0.25, 1.60]**
Heterogeneity: Tau² = 0.00; Chi² = 0.04, df = 1 (P = 0.85); I² = 0%								
Test for overall effect: Z = 2.68 (P = 0.007)								
11.2.3 Contrast								
Dobbs et al. [23] (Contrast)	155.4	17.9	10	138	17.2	10	5.3%	0.95 [0.01, 1.89]
Freitas et al. [26] (Contrast)	178.2	14.5	9	154.8	33.3	9	4.8%	0.87 [-0.11, 1.85]
Hammami et al. [35] (Contrast)	135	7	14	92	7	14		Not estimable
Loturco et al. [55] (Contrast)	89	11.8	15	72	11.5	15	6.9%	1.42 [0.61, 2.23]
Spineti et al. [91] (Contrast)	155.5	29.4	10	121.7	19.6	10	4.8%	1.30 [0.31, 2.28]
Subtotal (95% CI)			**44**			**44**	**21.8%**	**1.16 [0.70, 1.62]**
Heterogeneity: Tau² = 0.00; Chi² = 1.00, df = 3 (P = 0.80); I² = 0%								
Test for overall effect: Z = 4.93 (P < 0.00001)								
11.2.4 Traditional								
Arazi et al. [5] (Traditional)	47.4	1.8	10	44.1	1.2	10	3.7%	2.07 [0.94, 3.20]
Freitas et al. [26] (Traditional)	165.4	27.9	9	149.1	23	9	5.1%	0.61 [-0.34, 1.56]
Hansen et al. [37] (Traditional)	240.1	25	9	203.2	16.6	9	3.8%	1.66 [0.55, 2.76]
Loturco et al. [55] (Traditional)	87	9.3	18	71	8.9	18	7.5%	1.72 [0.94, 2.50]
Nicholson et al. [68] (Traditional)	135.83	13.64	11	120.56	13.96	11	5.6%	1.06 [0.16, 1.97]
Rial-Vázquez et al. [79] (Traditional)	210	50.52	13	197.41	51.53	13	7.6%	0.24 [-0.53, 1.01]
Spineti et al. [91] (Traditional)	146	21.8	12	120	10.5	12	5.4%	1.47 [0.55, 2.39]
Talpey et al. [95] (Traditional)	170.9	26.1	11	138.6	31.5	11	5.6%	1.07 [0.17, 1.98]
Subtotal (95% CI)			**93**			**93**	**44.3%**	**1.19 [0.76, 1.63]**
Heterogeneity: Tau² = 0.17; Chi² = 12.49, df = 7 (P = 0.09); I² = 44%								
Test for overall effect: Z = 5.38 (P < 0.00001)								
Total (95% CI)			**199**			**199**	**100.0%**	**1.02 [0.80, 1.24]**
Heterogeneity: Tau² = 0.01; Chi² = 17.84, df = 17 (P = 0.40); I² = 5%								
Test for overall effect: Z = 9.13 (P < 0.00001)								
Test for subgroup differences: Chi² = 3.30, df = 3 (P = 0.35), I² = 9.0%								

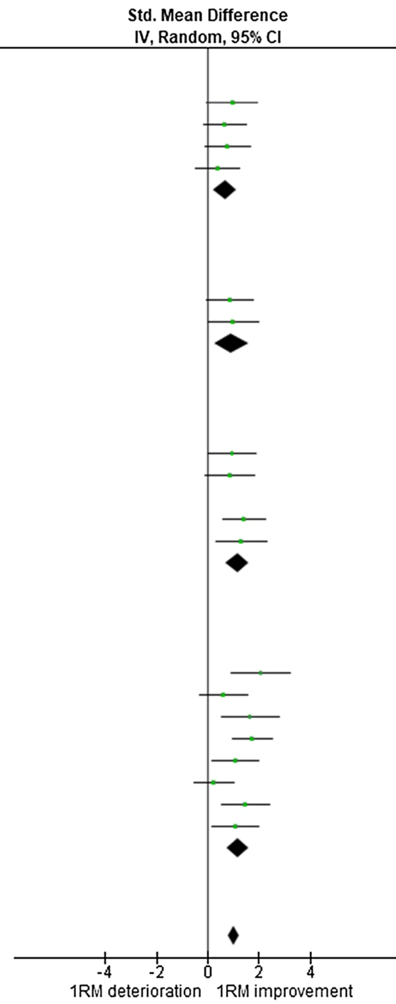


Fig. 10 Training intervention effects of cluster, complex, contrast and traditional training on 1-repetition maximum (kilograms). Each plotted point represents the standard error and effect sizes between post-intervention and pre-intervention

identified for analysis. This was partially supported by the single complex intervention study that measured CMJ (countermovement jump) PV showing a non-significant 0.5% ± 6.4 decrease [22]. The reason for this is likely explained by the fact that with no fatigue from prior heavy RT sets, the jump sets completed with traditional training were performed at higher velocities than the complex training jump sets, which has been shown to lead to superior velocity adaptations [73].

Finally, although a small reduction was observed for sprint time (ES: − 0.45, 95% CI [− 0.94, 0.05], $p = 0.08$), these improvements were significantly smaller than those seen with contrast training interventions (ES: − 2.10, 95% CI [− 2.67, − 1.53], $p < 0.01$). As described previously, traditional training appears to be superior for developing squat 1RM, whereas contrast training shows greater improvements in all jump outcome measures. When transferring these different improvements to sprinting, it is useful to observe that jumping activities are closer to sprinting than 1RM squatting is on the force–velocity curve [100]. Additionally, closer relationships have been shown with CMJ variables and sprinting compared to 1RM squat performance [18, 62, 93].

4.2 Cluster Training

When examining the results of acute cluster protocols compared to traditional sets, a trivial effect was seen for PF (ES: 0.14, 95% CI [− 0.21, 0.48], $p = 0.44$), a large positive effect for PV (ES: 1.07, 95% CI [0.58, 1.55], $p < 0.01$), and a small positive effect for PP (ES: 0.42, 95% CI [0.18, 0.67], $p = 0.0007$), all in favour of cluster sets (see Figs. 2, 3, 4). These results were expected as fatigue has been shown to decrease velocity to a greater extent than force during RT [15, 49]. Additionally, as power is the product of force and velocity, there is no surprise that the larger PP effect is approximately halfway between the PF and PV effect sizes. Similar findings were observed in a recent meta-analysis by

Study or Subgroup	Post peak force Mean	Post peak force SD	Post peak force Total	Pre peak force Mean	Pre peak force SD	Pre peak force Total	Weight	Std. Mean Difference IV, Random, 95% CI
11.4.1 Contrast								
Dobbs et al. [23] (Contrast)	2,559	629	10	2,243	551	10	7.1%	0.51 [-0.38, 1.41]
Hammami et al. [35] (Contrast)	1,408	228	14	1,226	247	14	9.5%	0.74 [-0.03, 1.51]
Subtotal (95% CI)			**24**			**24**	**16.6%**	**0.64 [0.06, 1.23]**
Heterogeneity: Tau² = 0.00; Chi² = 0.15, df = 1 (P = 0.70); I² = 0%								
Test for overall effect: Z = 2.17 (P = 0.03)								
11.4.2 Complex								
Dobbs et al.[23] (Complex)	2,335	599	10	2,243	551	10	7.3%	0.15 [-0.73, 1.03]
Talpey et al. [95] (Complex)	1,997	370	9	1,951	342	9	6.6%	0.12 [-0.80, 1.05]
Subtotal (95% CI)			**19**			**19**	**13.9%**	**0.14 [-0.50, 0.78]**
Heterogeneity: Tau² = 0.00; Chi² = 0.00, df = 1 (P = 0.96); I² = 0%								
Test for overall effect: Z = 0.43 (P = 0.67)								
11.4.3 Cluster								
Hansen et al. [37] (Cluster)	2,329	221.9	9	2,280	279.8	9	6.6%	0.18 [-0.74, 1.11]
Morales-Artacho et al. [62] (Cluster)	50.33	9.22	10	51.87	14.3	10	7.3%	-0.12 [-1.00, 0.75]
Nicholson et al. [68] (85% Cluster)	23.63	2.19	12	23.24	1.67	12	8.8%	0.19 [-0.61, 1.00]
Nicholson et al. [68] (90% Cluster)	24.29	1.99	11	25.08	1.55	11	7.9%	-0.43 [-1.27, 0.42]
Subtotal (95% CI)			**42**			**42**	**30.5%**	**-0.04 [-0.47, 0.39]**
Heterogeneity: Tau² = 0.00; Chi² = 1.38, df = 3 (P = 0.71); I² = 0%								
Test for overall effect: Z = 0.20 (P = 0.84)								
11.4.4 Traditional								
Hammami et al. [35] (Plyometrics)	1,264	150	14	1,216	206	14	10.2%	0.26 [-0.49, 1.00]
Hansen et al. [37] (Traditional)	2,410.6	144.1	9	2,358.6	140.2	9	6.5%	0.35 [-0.58, 1.28]
Morales-Artacho et al. [62] (Traditional)	50.59	19.19	9	47.97	10.44	9	6.6%	0.16 [-0.76, 1.09]
Nicholson et al. [68] (Traditional)	24.54	1.98	11	25.68	2.67	11	7.8%	-0.47 [-1.32, 0.38]
Talpey et al. [95] (Traditional)	1,898	246	11	1,797	267	11	7.9%	0.38 [-0.47, 1.22]
Subtotal (95% CI)			**54**			**54**	**39.0%**	**0.14 [-0.24, 0.52]**
Heterogeneity: Tau² = 0.00; Chi² = 2.56, df = 4 (P = 0.63); I² = 0%								
Test for overall effect: Z = 0.70 (P = 0.48)								
Total (95% CI)			**139**			**139**	**100.0%**	**0.17 [-0.07, 0.40]**
Heterogeneity: Tau² = 0.00; Chi² = 7.62, df = 12 (P = 0.81); I² = 0%								
Test for overall effect: Z = 1.37 (P = 0.17)								
Test for subgroup differences: Chi² = 3.53, df = 3 (P = 0.32), I² = 15.1%								

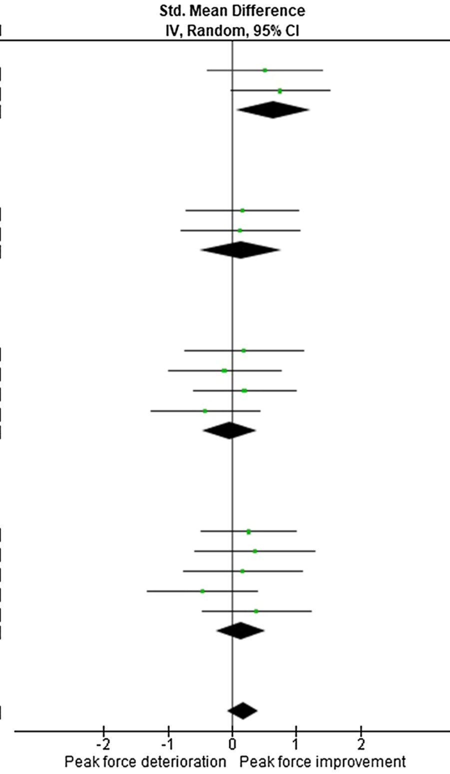


Fig. 11 Training intervention effects of contrast, complex, cluster and traditional training on peak force (Newtons). Each plotted point represents the standard error and effect sizes between post-intervention and pre-intervention

Study or Subgroup	Post peak velocity Mean	Post peak velocity SD	Post peak velocity Total	Pre peak velocity Mean	Pre peak velocity SD	Pre peak velocity Total	Weight	Std. Mean Difference IV, Random, 95% CI
11.5.1 Cluster								
Hansen et al. [37] (Cluster)	2.3	0.17	9	2.22	0.2	9	12.9%	0.41 [-0.53, 1.35]
Morales-Artacho et al. [62] (Cluster)	6.08	1.34	10	5.73	1.3	10	14.5%	0.25 [-0.63, 1.13]
Rial-Vázquez et al. [79] (Cluster)	3.21	0.75	11	2.31	0.99	11		Not estimable
Subtotal (95% CI)			**19**			**19**	**27.4%**	**0.33 [-0.31, 0.97]**
Heterogeneity: Tau² = 0.00; Chi² = 0.06, df = 1 (P = 0.81); I² = 0%								
Test for overall effect: Z = 1.00 (P = 0.32)								
11.5.2 Contrast								
Dobbs et al. [23] (Contrast)	2.84	0.18	10	2.69	0.17	10	13.3%	0.82 [-0.10, 1.74]
Hammami et al. [35] (Contrast)	2.72	0.19	14	2.53	0.12	14	17.2%	1.16 [0.35, 1.97]
Subtotal (95% CI)			**24**			**24**	**30.5%**	**1.01 [0.40, 1.62]**
Heterogeneity: Tau² = 0.00; Chi² = 0.30, df = 1 (P = 0.59); I² = 0%								
Test for overall effect: Z = 3.26 (P = 0.001)								
11.5.3 Traditional								
Hansen et al. [37] (Traditional)	2.19	0.15	9	2.18	0.16	9	13.2%	0.06 [-0.86, 0.99]
Morales-Artacho et al. [62] (Traditional)	5.94	1.6	9	5.51	1.23	9	13.0%	0.29 [-0.64, 1.22]
Rial-Vázquez et al. [79] (Traditional)	2.94	0.73	13	2.61	0.6	13		Not estimable
Talpey et al. [95] (Traditional)	2.46	0.28	11	2.35	0.32	11	15.9%	0.35 [-0.49, 1.20]
Subtotal (95% CI)			**29**			**29**	**42.1%**	**0.24 [-0.28, 0.76]**
Heterogeneity: Tau² = 0.00; Chi² = 0.22, df = 2 (P = 0.90); I² = 0%								
Test for overall effect: Z = 0.91 (P = 0.36)								
Total (95% CI)			**72**			**72**	**100.0%**	**0.50 [0.16, 0.84]**
Heterogeneity: Tau² = 0.00; Chi² = 4.54, df = 6 (P = 0.60); I² = 0%								
Test for overall effect: Z = 2.92 (P = 0.004)								
Test for subgroup differences: Chi² = 3.97, df = 2 (P = 0.14), I² = 49.6%								

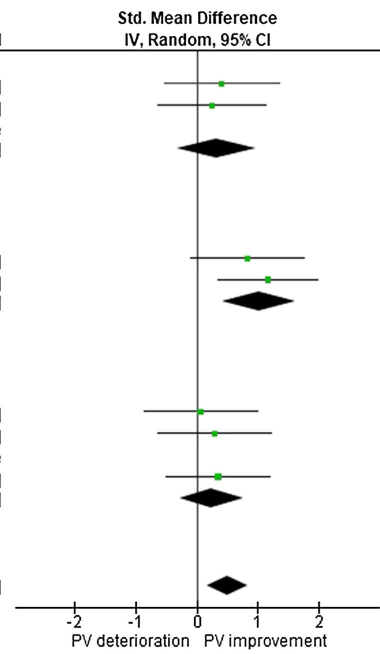


Fig. 12 Training intervention effects of contrast and traditional training on peak velocity (meters per second). Each plotted point represents the standard error and effect sizes between post-intervention and pre-intervention

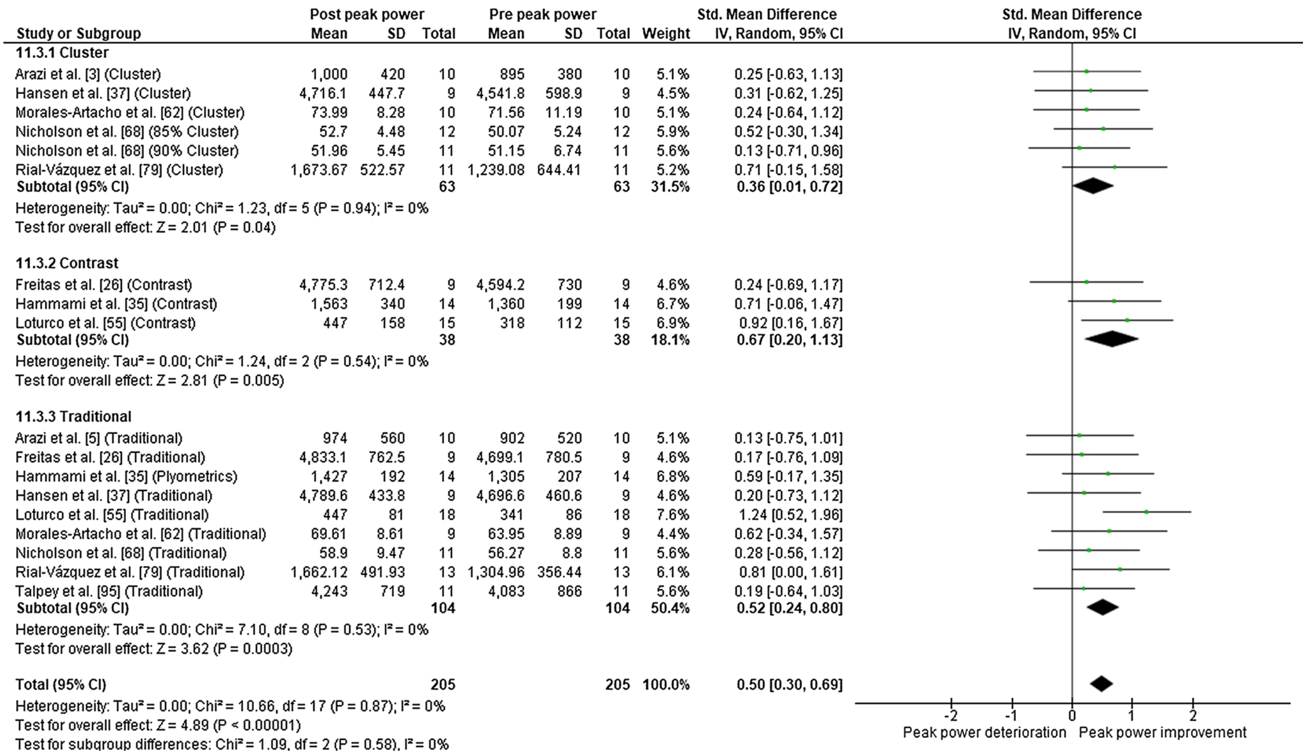


Fig. 13 Training intervention effects of cluster, contrast and traditional training on peak power (Watts). Each plotted point represents the standard error and effect sizes between post-intervention and pre-intervention

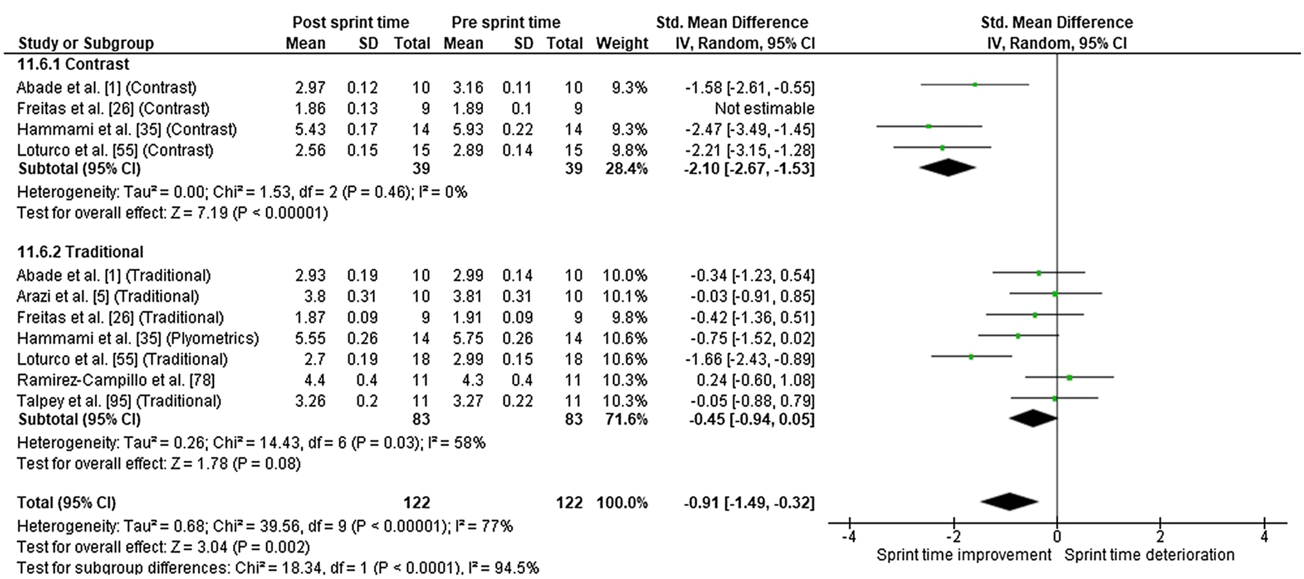


Fig. 14 Training intervention effects of contrast and traditional training on sprint time (seconds). Each plotted point represents the standard error and effect sizes between post-intervention and pre-intervention

Latella et al. [52], which reported that cluster sets were an effective method for attenuating velocity and power loss, particularly during heavy and moderate loads.

The exercises used in the studies within the present meta-analysis included different squat and jump squat variations as well as clean pulls, all of which utilise a stretch–shortening cycle. Different responses to cluster training may be seen when the stretch–shortening cycle is not involved, as observed by Moir et al. [59] who compared cluster and traditional sets using a 4RM deadlift, and found that the traditional set maintained power output to a significantly higher level than a cluster set with 30 s of interrepetition rest (IRR). Further research investigating the effect of cluster training with exercises utilising the stretch–shortening cycle is required to confirm this finding.

Considering the training intervention effects of cluster training, a moderate positive effect was seen in 1RM squat (ES: 0.68, 95% CI [0.24, 1.12], $p<0.01$), a trivial effect in PF (ES: −0.04, 95% CI [−0.47, 0.39], $p=0.84$), and small positive effects in PP (ES: 0.36, 95% CI [0.01, 0.72], $p=0.04$), JH (ES: 0.39, 95% CI [−0.10, 0.88], $p=0.12$), and PV (ES: 0.33, 95% CI [−0.31, 0.97], $p=0.32$) (Figs. 9, 10, 11, 12, 13). An interesting difference between cluster and traditional training interventions is that traditional training showed slightly greater effects for PF improvements with jump activities (ES: 0.14, 95% CI [−0.24, 0.52], $p=0.48$), whereas cluster training showed slightly greater effects for PV improvements (ES: 0.33, 95% CI [−0.31, 0.97], $p=0.32$). An explanation for the PF finding could be that the traditional sets were closer to the point of failure compared to cluster sets which caused superior force adaptations and activated more higher order motor units [63]. Related to the closer proximity to set failure, greater force producing adaptations may have been achieved through greater increases in muscle cross sectional area [74]. When addressing the trend towards greater PV improvements with cluster training, this could be explained by the fact that training at higher velocities stimulates greater velocity improvements [73]. In addition, the higher velocities seen with cluster training may enhance motor unit firing frequency [101].

In agreement with the results seen in the present meta-analysis, a recent study by Rial-Vazquez et al. [78] compared a rest-redistribution cluster structure to a traditional training program and found cluster sets were superior for increasing the velocity component of the subjects' force–velocity profile compared to traditional sets, which tended to impact force contribution to the profile. Morales-Artacho et al. [61] used a loaded CMJ as an intervention with 20% of body weight, and the major difference between cluster and traditional training interventions was also in velocity improvements for the cluster group compared to PF improvements in the traditional group. These findings support those of the present meta-analysis. Overall, CMJ PP actually showed greater improvements in the cluster group, although this may be attributed to the lighter, ballistic training intervention used.

An important consideration with cluster training prescription is how to manipulate the intra-set rest to target different training outcomes. For example, higher volumes can be achieved compared to traditional sets with the same load. This could have implications for both strength and hypertrophy adaptations [99]. Within the present meta-analysis, all cluster studies equated the cluster set volume to the traditional protocol comparison, meaning that many of the benefits of cluster training (e.g., higher volume load, higher set velocities, reduced metabolic fatigue) could not be investigated properly. However, one study investigated the effect of using higher loads that this type of structure enables. Nicholson et al. [67] compared four different back squat training interventions over a 6-week period: strength (4 × 6 at 85% 1RM, 5 min inter-set rest), hypertrophy (5 × 10 at 70% 1RM, 90 s inter-set rest), cluster one (4 × 6/1 at 85% 1RM, 25 s IRR, 5 min inter-set rest), and cluster two (same as cluster one but with a 90% 1RM load). This type of cluster design would be the rest-pause method (see Table 1). Following the intervention, back squat 1RM for the strength and cluster 2 groups increased significantly more than for the hypertrophy group (15.28 kg ± 1.95, ES = 1.106, and 17.22 kg ± 2.32, ES = 0.816, respectively). No significant differences were observed between the groups for CMJ jump variables. The results of the present meta-analysis found larger positive effects on squat 1RM in the traditional group than the cluster group. Similar results were seen with this study with larger effects observed in the traditional strength group compared to the cluster two group (ES: 1.106 vs. 0.816). It should be noted that only 34 out of 46 participants completed all sessions which may well have affected the results. It is likely that maximal strength benefits may be achieved with cluster training if this method is used to its full potential. Cluster training can even be combined with contrast training to great effect [14, 68].

In summary, equated cluster sets can be used to acutely limit reductions in PP and PV compared to traditional training sets. Following this approach as part of a training intervention, superior improvements in PV may be observed compared to traditional training; however, reductions in PF capabilities may be seen alongside this, which may be avoided if the cluster set is performed with a closer proximity to failure, and not just with equated loads and volumes.

4.3 Contrast

The results of the present meta-analysis regarding acute contrast sets revealed small positive effects in JH (ES: 0.27, 95% CI [0.09, 0.45], $p=0.003$), PF (ES: 0.2, 95% CI [−0.1, 0.51], $p=0.19$) and PP (ES: 0.25, 95% CI: [0.09, 0.4], $p=0.002$), and a trivial effect in set 2 PP (ES: 0.07, 95% CI [−0.13, 0.27], $p=0.51$) compared to baseline (see Figs. 5, 6, 7, 8). These results seem to suggest that PAPE is present during the lighter exercises in contrast training. PAPE is thought to occur as a result of phosphorylation of myosin regulatory light chains and increased recruitment of higher order motor units [97]. Considering set 2 PP, a trivial effect

(ES: 0.07, 95% CI [− 0.13, 0.27], $p = 0.51$) can still be seen but seems to be smaller than set 1 (ES: 0.25, 95% CI [0.09, 0.4], $p = 0.002$). This suggests that potentiation-fatigue balance is different at this point with more fatigue present. When seeking to understand how this effect may work as more contrast pairs are completed, it can be helpful to draw similarities with the fitness–fatigue model [7] where performance or the potentiated change in performance, is the sum of two curves, one representing the fatigue effect, and the other representing the fitness or potentiated improvement. The fitness or potentiation effect in PAPE responders [85, 88] can only be observed when the fatigue has dissipated, despite the fact that fitness has actually been improving from immediately after the end of the initial heavy set. When the second heavy set is completed with contrast training, the same amount of fitness created after the first set could well be present; however, a greater amount of fatigue is present than before, which reduces the overall expression of PAPE.

When assessing the small positive effects seen for PP (ES: 0.25, 95% CI [0.09, 0.4], $p = 0.002$) and PF (ES: 0.2, 95% CI [− 0.1, 0.51], $p = 0.19$) of the lighter contrast paired exercise, it is important to consider whether PV improved to a greater extent than PF as PP is a product of the two measures. Only one study used PV as an outcome measure with acute contrast sets [83]. When compared to baseline results, squat jumps with 30% of 1RM following a set of six squats at 85% showed significantly higher PV values (ES = 0.29, 95% CI [0.17, 0.42]), whereas PF values showed trivial and non-significant increases (ES = 0.03, 95% CI [− 0.56, 0.62]). Though more research is needed to support the results of this study, it can be surmised that contrast training acutely improves PP of the lighter exercise through improved PV.

When designing contrast pairs, other considerations are necessary. For example, Bogdanis et al. [12] showed superior PAPE effects on CMJ when using isometric squats as the CA. However, in another meta-analysis by Wilson et al. [107], it was concluded that isometric actions produced lower ES when compared to dynamic contractions (ES: 0.35 CI [− 0.19, 0.89]) vs. ES: 0.42 CI [0.22, 0.61]). A more promising option could be to use resistance bands. As well as causing lower levels of fatigue than traditional weight training [75] and therefore allowing shorter rests between sets and more efficient training sessions, this type of training overloads the outer range of exercises which may be more specific for most jumping tasks as this tends to be the chosen range used for jumps. In terms of overloading this specific range, Scott et al. [84] compared the PAPE effects of 3 repetitions of trapbar deadlifts and back squats at 93% 1RM on subsequent CMJ performance and found that the trapbar deadlift group exhibited significantly greater increases in CMJ PP at 2, 4, and 6 min post-CA compared to the back squat group ($p < 0.01$). The ranges of movement used during the trapbar deadlift resemble those seen in the CMJ to a greater extent than the back squat exercise. Overloading similar ranges of movement to those used in the lighter contrast exercise appears to be an important consideration when using this type of training sequence. Indeed, there is evidence that banded sets may have superior PAPE effects on jump performance when compared to non-banded [68, 86]. Another potential option for contrast pair design is the form of cluster training. Interestingly, Nicolson et al. [67] found that a conventional strength set of six squats at 85% 1RM produced significantly higher levels of blood lactate than a heavier cluster set of six squats at 90% 1RM with 25 s IRR. Assuming that the same level of PAPE was produced as the conventional set, it appears that lower levels of fatigue are present with cluster training, allowing performance increases in the lighter jump set to be expressed both earlier and with a greater magnitude as seen in the two studies within the present analysis [14, 68]. When referring back to the comparisons with the fitness-fatigue model [7], these set structures lead to a reduced masking of the PAPE or fitness effect.

It appears that exercises requiring high levels of force have a performance-enhancing effect on lighter, velocity-dependent exercises in a contrast pair, with this effect being more pronounced in individual responders [85, 88]. What is less understood (and researched) is whether the light exercise has any effects on the heavy exercise. Bullock and Comfort [16] found that when carrying out a 1RM squat assessment, inserting either 2, 4 or 6 depth jumps before 1RM attempts led to significantly higher 1RM results (ES: 0.26) with no differences observed between number of depth jump repetitions. If these results are repeatable, it could be useful to identify the mechanism by which this effect occurs and to measure both the light and heavy-set variables of PF and PV.

Considering the training intervention effects of contrast training, the present meta-analysis revealed large positive effects on JH (ES: 1.01, 95% CI [0.40, 1.80], $p = 0.01$), squat 1RM (ES: 1.16, 95% CI [0.70, 1.62], $p < 0.01$), and PV (ES: 1.01, 95% CI [0.4, 1.62], $p < 0.01$), a large negative effect on sprint time (ES: − 2.10, 95% CI [− 2.67, − 1.53], $p < 0.01$), and moderate positive effects on PP (ES: 0.67, 95% CI [0.20, 1.13], $p < 0.01$) and PF (ES: 0.64, 95% CI [0.06, 1.23], $p = 0.03$), (see Figs. 9, 10, 11, 12, 13, 14), with higher ES seen for all outcome measures compared to the other groups with the exception of 1RM squat, where traditional training showed a larger ES (ES: 1.19, 95% CI [0.76, 1.63], $p < 0.01$). It may be expected that PV and sprint performance improved the most with contrast training compared to the other three methods, because the biggest stimulus for improved velocity is to train at the highest velocities possible for a given resistance [65]. Unlike cluster training, which did show small improvements in PV (ES: 0.33, 95% CI [− 0.31, 0.97], $p = 0.32$) and would have likely shown superior improvements in PV for the individual clustered exercise (and load) used in the training intervention, contrast training does not simply maintain the high relative velocities seen at the beginning of an exercise set, but it allows supramaximal velocities for the light exercise through PAPE mechanisms. As previously mentioned, ES were larger for improvements in 1RM squat with traditional training (ES: 1.19, 95% CI [0.76, 1.63], $p < 0.01$) but higher for improvements in jump PF with contrast training interventions (ES: 0.64, 95% CI [0.06, 1.23], $p = 0.03$). With traditional training, the multiple sets of low load exercises performed before the heavy sets created some fatigue. When the time came to perform the heavy sets afterwards, these sets would have had a closer proximity to failure than any of the other three types of training. This may have activated more higher order motor units [63]. Whether this is what caused the greater improvement effects in 1RM squat or not, proximity to failure appears to be a mechanism for improving 1RM squat [17]. This is likely achieved through increases in PF of high-load squats. With this trend, it would seem strange that PF improvements in various jump test outcomes showed the largest effects with contrast training (ES: 0.64, 95% CI [0.06, 1.23], $p = 0.03$). This finding could be explained by the theory of velocity-specific training, whereby force producing adaptations are specific to the velocity or movement that training occurs at [65]. The lighter jump exercise sets completed at the start of a traditional training sequence would be free of fatigue compared to the lighter jump sets in contrast training that are alternated with the heavy sets. Although the velocity component of the contrast jump exercise is increased by PAPE [83], there is still a higher level of fatigue than that seen with the traditional setup, meaning that the jump exercise again has a closer proximity to failure. With this in mind, it may be prudent to change the previous statement that "proximity to failure appears to be a mechanism for improving 1RM", and instead conclude that proximity to failure appears to be a major mechanism for improving PF with the trained exercise load. Indeed, this would also explain the larger ES for improvements in 1RM squat following contrast training (ES: 1.16, 95% CI [0.70, 1.62], $p < 0.01$) compared to complex training (ES: 0.93, 95% CI [0.25, 1.60], $p < 0.01$), where the heavy sets would be performed with no preceding element of fatigue compared to the contrast heavy sets which would have a small element of extra fatigue from the light jump exercises. With contrast training interventions showing the greatest effects in the four jump variables (JH, PF, PV, and PP), it would be expected that contrast training also showed larger effects (ES: −2.10, 95% CI [−2.67, −1.53], $p < 0.01$) than traditional training (ES: −0.45, 95% CI [−0.94, 0.05], $p = 0.08$) for improving sprint time since close relationships have previously been identified between vertical jump and sprint performance [18, 93].

Cormier et al. [20] recently carried out a meta-analysis comparing the training intervention effects between contrast and complex training. Specifically, they investigated 1RM, CMJ, sprint times, and change of direction performance. Although no significant differences were observed between the two types of training, contrast training resulted in larger positive effects for 1RM, CMJ and sprint time (ES = 2.01, 0.88, −0.94, respectively) compared to complexes (ES = 1.29, 0.55, −0.27, respectively). These results are supported by the present meta-analysis, although it is important to note that the meta-analysis by Cormier et al. [20] used the opposite definitions to the present review, defining contrast training as complex and vice-versa. Readers are once again directed to the original definitions described by Duthie et al. [24] to avoid confusion.

4.4 Complex

For complex training, the results of this meta-analysis found that when acutely compared to baseline, a trivial effect was seen on JH (ES: −0.05, 95% CI [−0.59, 0.50], $p = 0.86$), a small negative effect on PF (ES: −0.25, 95% CI [−0.8, 0.3], $p = 0.37$), a trivial effect on PP (ES: 0.02, 95% CI [−0.29, 0.32], $p = 0.92$), and a trivial effect on set 2 PP (ES: −0.07, 95% CI [−0.14, 0.22], $p = 0.75$) (Figs. 5, 6, 7, 8). These findings suggest that although PAPE may be present during a complex sequence, this is likely heavily masked by fatigue caused from the initial heavy sets as previously observed by Verkhoshansky and Tatyan [102]. Although the neural PAPE effect dissipates more slowly than fatigue, the effect is not seen after the first light set as evidenced by set 2 PP (ES: −0.07, 95% CI [−0.14, 0.22], $p = 0.75$). No acute complex studies included within the present analysis investigated the response of PV within the light jump sets. It was felt that this was important information to obtain and so the two studies which reported both PP and PF [24, 64] had the PV calculated (PP/PF) to gain some more insight into this effect. Duthie et al. [24] investigated the effect of athletes performing three sets of 3RM half squats followed by three sets of four jump squats with 30% 1RM load. Contrast and traditional protocols were also completed with the same volumes. Though no significant differences were seen between complex and traditional sets for PF, PP was significantly higher during set 1 of the traditional protocol. Based on the available data, an estimated ~ 2.6% reduction was seen in complex set 1 for PV compared to the corresponding traditional set. Naclerio et al. [64] investigated the effect of 1 × 3 full squats at 80% 1RM load (contrast) compared to 3 × 3 squats under the same conditions (complex), followed by a CMJ 4 min later. No significant differences were seen for PP or PF. Following our calculations of PV, estimated increases of ~ 4.6% were seen with complex training compared to ~ 0.4% reductions in the contrast condition. These two studies have very different findings; however, this could be explained by the fact that the former study [24] performed the heavy sets very close to failure and used half squats which more closely matched the jumping activity range, compared to the latter study [64] which performed the heavy sets with a load that was approximately five repetitions away from failure. Considering these findings, it could be concluded that performance enhancement could indeed be obtained with complex training as long as the volume of the heavy CA is low, thus reducing the interfering effect of fatigue with PAPE. In support of this, Wilson et al. [107] conducted a meta-analysis and found that complex sets produced greater performance enhancement when loads of 60–85% were used. However, although load and volume were investigated, proximity to failure was not investigated in relation to PAPE. More research should be completed to improve understanding in this area.

The results of the present analysis reported a trivial effect on acute JH (ES: −0.05, 95% CI [−0.59, 0.50], $p=0.86$). Just three studies were used in the ES calculation of this outcome [24, 50, 64], and one of these was removed from the analysis because the results were regarded as an outlier [50]. Interestingly, the volume was the same as that used in the other two studies (3 × 3 squats), although the load chosen was 87%—approximately halfway between the two other protocols. However, the statistically significant increase in JH compared to baseline was at 8 min (ES: 0.34). The other studies performed jumps at 4- and 5-min post-CA and if we consider the JH results recorded at 4 min by Kilduff et al. [50], increases of < 0.5 cm (ES: 0.12) were seen which were not statistically significant. This trivial change fits the same pattern as the other studies. It is interesting to observe a significant increase in JH at 8 min, likely due to fatigue dissipating at a faster rate than PAPE [102]; however, rest periods of this length are practically unrealistic. Furthermore, diminished effects will be seen as more jump sets are completed causing more fatigue combined with the PAPE effect of multiple heavy sets wearing off. For this reason, the place of complex training within a program may be questioned, though elements of the training intervention findings discussed below may provide a rationale.

Following complex training interventions, a moderate positive effect on JH (ES: 0.61, 95% CI [−0.08, 1.31], $p=0.08$), a large positive effect on squat 1RM (ES: 0.93, 95% CI [0.25, 1.60], $p<0.01$), and a trivial effect on jump activity PF (ES: 0.14, 95% CI [−0.50, 0.78], $p=0.67$) were seen in the present analysis (see Figs. 9, 10, 11). When compared to traditional training, complex sequences reported smaller ES for 1RM strength (ES: 0.93, 95% CI [0.25, 1.60], $p<0.01$). As alluded to earlier, this can likely be explained by the observation that increased fatigue caused closer subsequent proximity to failure which seems to drive greater force-generating adaptations. In this example, the jump sets completed first with traditional training caused some fatigue for the heavier sets performed afterwards, whereas the complex heavy sets were performed with no prior fatigue.

It has previously been mentioned that velocity adaptations are dependent upon performing repetitions for a given load at the highest velocities possible [65, 73]. Since velocity is reduced more by fatigue than force is [15, 49], it would seem likely that complex training would have the smallest effect on the PV of jump activities of any of the investigated training types. Indeed, this was observed in a study by Dobbs et al. [22] who compared contrast and complex training programs over 7 weeks. At the end of the intervention, the complex group actually showed small reductions in CMJ PV compared to the contrast group (−0.5% ± 6.4 vs. 5.6% ± 4.9, ES = 0.84 ± 0.66, respectively), whereas PF increased in both groups, albeit to a lesser extent with the complex group compared to the contrast (4.1% ± 8.7 vs. 14.1% ± 14.1, ES = 0.40 ± 0.37, respectively). PP was not reported in this study but was calculated from the results reported. The complex group showed a 3.7% improvement from pre to post compared to the contrast group improvement of 20.5%. Talpey et al. [94] found similar trivial increases in CMJ PP following a 9-week complex training program (3.9%, ES = 0.18). It has previously been shown that when fatigued, athletes will adopt different strategies with the CMJ exercise [48]. Due to greater reductions in velocity, athletes will often increase their total movement duration to express force, which undergoes smaller reductions as a result of fatigue [48]. Athletes using complex training appear to improve their jumping performance as a result of force improvements driven by closer proximity to failure. In a way, complex training can even be compared to pre-fatiguing muscle training where isolation work is completed on one muscle group in an effort to place more focus on another muscle group during a compound exercise [42]. Strategies that aim to develop CMJ PF may be warranted as this variable has shown significant correlations with 5, 10 and 20 m sprint performance [62], as well as maximum isometric squat PF, CMJ PP, and squat and power clean 1RM in comparison to CMJ PV [70]. Nevertheless, CMJ PV still had a much higher correlation to CMJ JH than CMJ PF [70].

5 Conclusions

To conclude, the results of this meta-analysis have reaffirmed the idea that force is developed by completing sets in a semi-fatigued state to bring about a closer proximity to failure, whereas velocity is developed through performing repetitions at the highest velocity possible. Either way, maximal intent should be used with every repetition. Additionally, practitioners should note that training in this way should be task-specific, for example, if the aim is to improve an athlete's bodyweight CMJ performance

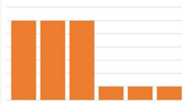
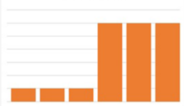
Training type	Description	Time point	Jump height	1RM Squat	Peak power	Peak force	Peak velocity	Sprint time
Cluster 	Traditional sets with additional short rest periods typically 15-45 seconds inserted within each set	Acute maintenance effect compared to traditional	N/A	N/A	++ 0.42 [0.18, 0.65]	+ 0.14 [-0.21, 0.48]	++++ 1.07 [0.58, 1.55]	N/A
		Following training intervention	++ 0.39 [-0.10, 0.88]	+++ 0.68 [0.24, 1.12]	++ 0.36 [0.01, 0.72]	- -0.04 [-0.47, 0.39]	++ 0.33 [-0.31, 0.97]	N/A
Complex 	Multiple sets of a heavy resistance exercise followed by sets of a lighter resistance exercise	Acute effect	- -0.05 [-0.59, 0.50]	N/A	+ 0.02 [-0.29, 0.32]	- -0.25 [-0.80, 0.30]	N/A	N/A
		Following training intervention	+++ 0.61 [-0.08, 1.31]	++++ 0.93 [0.25, 1.60]	+++ 0.67 [0.20, 1.13]	+ 0.14 [-0.50, 0.78]	N/A	N/A
Contrast 	A workout that involves the use of exercises of contrasting loads, that is, alternating heavy and light exercises set for set	Acute effect	++ 0.27 [0.09, 0.45]	N/A	++ 0.25 [0.09, 0.40]	++ 0.20 [-0.10, 0.51]	N/A	N/A
		Following training intervention	++++ 1.10 [0.40, 1.80]	++++ 1.16 [0.70, 1.62]	N/A	+++ 0.64 [0.06, 1.23]	++++ 1.01 [0.40, 1.62]	---- -2.10 [-2.67, -1.53]
Traditional 	Multiple sets of lighter resistance followed by sets of a heavy resistance exercise	Acute effect	N/A	N/A	N/A	N/A	N/A	N/A
		Following training intervention	++ 0.41 [0.12, 0.70]	++++ 1.19 [0.76, 1.63]	+++ 0.52 [0.24, 0.80]	+ 0.14 [-0.24, 0.52]	++ 0.24 [-0.28, 0.76]	-- -0.45 [-0.94, 0.05]

Fig. 15 Summary and descriptions of acute and training intervention effects of cluster, complex, contrast, and traditional training sequences. Summary of effect sizes with confidence intervals. Effects grouped according to Cohen (19): + + + + = large positive effect, + + + = moderate positive effect, ++ = small positive effect, + = trivial positive effect, − = trivial negative effect, − − = small negative effect, − − − = moderate negative effect, − − − − = large negative effect

with PP as the major outcome measure, the athlete should complete bodyweight CMJs. If the aim is to improve an athlete's 1RM squat, power could still be used as the outcome measure with mean power being a more appropriate measure in line with recommendations for force-dominant movements [45], and the athlete should complete squats at near maximal intensities.

Different exercises fall on different areas of the force–velocity continuum but improving either force or velocity will have a positive effect on PP so long as the other component is maintained. The major finding of the present meta-analysis is that cluster, contrast, complex and traditional training can all be used to specifically target athletic components. When looking to develop the force component, the exercise should be completed with an increased level of fatigue subsequent to training at a close proximity to failure which can be brought about by performing multiple sets of a similar lighter exercise before the heavy exercise sets i.e. traditional training to optimally improve force development and, therefore, 1RM in the heavy exercise. When the objective is to improve velocity of the lighter exercise, it can be combined with a heavier exercise in a contrast pair to create a PAPE effect. Contrast training can be adjusted to optimally develop the force component of the lighter exercise as well, if both the heavy and light sets involved are completed close to the point of failure. Cluster set designs can be used to maintain velocities and reduce drop-off. The contrast and cluster methods may even be combined with the initial heavy set being performed as a cluster using heavier loads at the same volume as a traditional set and working to the same proximity to failure, with the lighter set also being clustered to reduce velocity drop-off. For a full summary, please see Fig. 15. When discussing the limitations of this study, further subgroup analysis might have been considered to investigate factors such as intervention durations, periodisation models, athlete level, or athlete age. These areas may be a useful direction for future research.

Finally, a small amount of evidence exists which suggests that high velocity sets can potentiate high force sets [16]. It may be possible to potentiate heavy exercise sets with even heavier sets using various set patterns such as flat pyramid, wave loading or double stimulation loading [13], but if this can indeed be achieved with light, high-velocity sets, it is certainly another interesting avenue for future research.

Declarations

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Conflict of interest James Marshall, Chris Bishop, Anthony Turner and Gregory Haff declare that they have no conflicts of interest relevant to the content of this review.

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Author contributions JM drafted the manuscript. CB, AT and GH edited and revised the manuscript. All authors approved the final version before submission.

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