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Review

Combining higher-load and lower-load resistance training exercises: A systematic review and meta-analysis of findings from complex training studies

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ABSTRACT

Objectives: The aim of the present meta-analytical review was to determine the effectiveness of training programmes combining higher-load and lower-load exercises in one workout (i.e. complex training [CT]) on lower-body performance.
Design: Systematic review and meta-analysis.
Methods: A search of five electronic databases (PubMed, Web of Science, SportDiscus, CINAHL and Scopus) was conducted to identify all publications up to 7 March 2018. Meta-analyses were performed using a random-effects model with the dependent variables countermovement jump (CMJ) height, squat jump (SJ) height, one-repetition maximum (1-RM) squat performance and sprint time for 5 m, 10 m, 20 m, 30 m and 40 m, respectively.
Results: The analysis comprised 33 studies and a total of 1064 healthy participants. The meta-analysis revealed that CT is effective in improving CMJ (95% confidence interval [CI] 5.6%–12.3%), SJ (95% CI 8.0%–17.4%), 1-RM squat (95% CI 16.4%–30.7%) and sprint performance (5 m = 95% CI −14.8% to −0.9%, 10 m = 95% CI −6.0% to −2.1%, 20 m = 95% CI −7.4% to −1.4%, 30 m = 95% CI −8.0% to −0.6%). However, when directly compared to traditional training methods, only 1-RM squat strength performance and 20 m sprint time were superior following CT interventions (95% CI 0.2%–13.7% and 95% CI −1.6% to −0.1%, respectively)
Conclusions: CT is an acceptable method for improving jump, strength and sprint performance in athletes. Compared to traditional training methods, CT seems to produce superior training effects only for 1-RM squat and 20 m sprint performance; however, these findings were influenced by single studies and should be therefore interpreted with circumspection.

Practical implications

- Complex training consistently and notably improves vertical jump, strength and sprint performance in athletes from various sport disciplines.
- No significant differences could be found between complex and alternative training methods, except for 1-RM squat and 20 m sprint performance, which could possibly benefit more from complex training interventions.
- Complex training may offer organizational benefits which could be of importance for practitioners.

1. Introduction

Performance and success in sports strongly rely on the capacity to produce maximal neuromuscular power.[1] For this purpose, athletes need to reach relatively high levels of strength and maximize its transfer to performance. It is suggested that resistance training programmes should therefore consist of both higher-loads (and thus lower-velocity) and lower-loads (and thus higher-velocity) exercises to reach maximal performance.[1–3] However, the specific pattern how these methods should be combined has been subject

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of debate for decades.[1,4,5] More recently, there has been significant practical interest in the idea that higher and lower-load resistance training exercises can be combined in one training session. This coupling is often referred to as complex training (CT).[6] It is suggested that athletes and coaches can save time by training higher and lower-load exercises in the same workout and can additionally benefit from a phenomenon called post-activation potentiation (PAP).[7] PAP refers to the acute improvements in skeletal muscle performance capacities after the completion of a conditioning activity[8] and has been attributed to the phosphorylation of the myosin regulatory light chains[9–11] and an increased recruitment of higher order motor units.[12] Although the precise mechanism is still under debate, there is considerable literature advocating that higher-load resistance training exercises can acutely increase the power production in subsequent lower-load exercises through PAP.[13] However, the results of studies investigating the long-term adaptations of combining higher-load and lower-load exercises in one workout (i.e. CT) have yielded conflicting results: superior[14–16] and equal[17–20] performance improvements have been observed longitudinally compared to more traditional or alternative resistance training methods (i.e. higher-load strength training, lower-load training or other training methods combining higher-load and lower-load training).

Thus, the purpose of this review and meta-analysis was to determine the effectiveness of CT interventions on jump, sprint and strength performance and compare it to alternative resistance training methods. The results from this analysis may provide strength and conditioning practitioners with reliable evidence to better inform their programming.

2. Methods

This meta-analytical review was conducted and reported in accordance with the guidelines outlined in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement.[21]

The literature search and study selection were independently conducted by two researchers (PB and FUE) and disagreements were resolved by a third reviewer (LBS). Five databases (PubMed, Web of Science, SportDiscus, CINAHL and Scopus) were screened to identify relevant studies published up to 7 March 2018. The following search terms were used to source pertinent peer-reviewed articles: "combined training" OR "complex training" OR "contrast training" OR "compound training" OR ("light loads" AND "heavy loads") OR" contrast load" OR "complex pair" OR (("strength training" OR "weight training" OR "resistance training" OR "weight lifting" OR "weightlifting") AND ("plyometric" OR "explosive" OR "explosive performance" OR "explosive training" OR "ballistic performance" OR "ballistic training")). The search was supplemented by manually cross-matching reference lists, key author searches, and citation searching of all retrieved studies. The authors of published papers were also contacted directly if crucial data were not reported in original papers. Duplicates were removed, and the remaining studies underwent a detailed manual screening procedure by searching (1) titles, (2) abstracts and (3) full-texts. Irrelevant articles were excluded. Studies were deemed eligible for inclusion if they met the following criteria: (1) participants were healthy and older than 14 and younger than 50 years; (2) full-text article was published in English or German in a peer-reviewed journal; (3) training intervention was required to be a minimum of 4 weeks in duration with at least 8 training sessions in total; (4) one intervention group performed CT. CT was defined as a combination of higher-load and lower-load resistance training exercises in one training session with a passive rest period less than 15 min between higher and lower-load exercises. The higher-load exercises had to be carried out before the corresponding lower-load exercises. Higher-load resistance training exercises were defined as exercises using an average load >40% of 1-RM (i.e. strength training exercises), whereas lower-load resistance training exercises were defined as explosive exercises using an average load <30% of 1-RM (i.e. plyometric and ballistic exercises). Additionally, sprint and change of direction exercises were also defined as lower-load resistance training exercises; (5) CT was compared to a control group or an alternative training method (i.e. lower-load resistance training, higher-load resistance training and other training strategies combining higher- and lower-load resistance training); (6) outcome measures were countermovement jump (CMJ) height, squat jump (SJ) height, one-repetition maximum (1-RM) squat performance or sprint time (5 m, 10 m, 20 m, 30 m or 40 m); (7) relevant data was available. The review and selection processes for the studies in the systematic review are summarized in Fig. 1.

Data were scanned by two independent researchers (PB and FUE) and transferred to an Excel spreadsheet. Differences in opinion were resolved through discussion and consensus with a third reviewer (LBS). Physical performance values were extracted as original values, such as jump height (cm), sprint time (s) and squat 1-RM (kg). In studies where the relevant data were shown in figures or graphs the corresponding author was contacted to get the numerical data or, if applicable, data were measured manually from the figures or graphs to extract the necessary data. Relevant study information regarding author, year, sample description, number of participants, intervention characteristics (experimental and control groups, duration and frequency) and training characteristics (training duration and frequency, volume, intensity and exercise selection) are reported in electronic Supplementary material (Appendix A).

Study quality of the included trials was assessed based on the Physiotherapy Evidence Database (PEDro) scale. The PEDro scale is used to identify the external (item 1) and internal validity (criteria 2–9), and the amount of statistical information provided to make the results interpretable (criteria 10–11). Each satisfied item contributes 1 point to the overall PEDro score. The maximum score for the PEDro scale is 10 points, since item 1 is not included in the calculation of the total PEDro score. Studies were rated independently by two researchers (PB and FUE). In case of disagreement between both researchers, a third independent researcher (LBS) was consulted to achieve final consensus (see ESM 1).

Statistical analyses were performed using R version 3.3[22] with the library 'metafor'.[23] The level of statistical significance was set at 0.05. Outcome data of the included studies are presented for each training group in terms of the pre- to post-training % mean change $\frac{\bar{Y}_{post} - \bar{Y}_{pre}}{\bar{Y}_{pre}} * 100$, where $\bar{Y}_{pre}$ and $\bar{Y}_{post}$ are pre- and post-training mean values. Importantly, the sprint improvement means a reduced time, thereby giving rise to the negative % change. For 1-RM squat, CMJ and SJ performance a positive % change indicates an improvement. The standard error (SE) of the % mean change was calculated using the equation $SE = \sqrt{\left(\frac{s_{post}^2}{\bar{Y}_{pre}^2} + \frac{s_{pre}^2 \bar{Y}_{post}^2}{\bar{Y}_{pre}^4} - 2\rho s_{pre} s_{post} \frac{\bar{Y}_{post}}{\bar{Y}_{pre}^3}\right) \frac{1}{n}} * 100$, which is derived using the delta method. Here n is the sample size, s_{pre}^2 and s_{post}^2 are reported pre- and post-training sample variances and ρ is the correlation between pre- and post-training values. The correlation could be determined for one study[16] reporting t-statistics for pre- to post-training comparisons, four studies[24–27] reporting the standard deviation of percent changes and one study[20] where subject level data was available. The average correlation in these studies was 0.91 for CMJ height, 0.90 for SJ height, 0.93 for 1-RM squat performance and 0.85 for sprint times. These average values were used to calculate SEs for % mean changes when no other information on the correlation was avail-

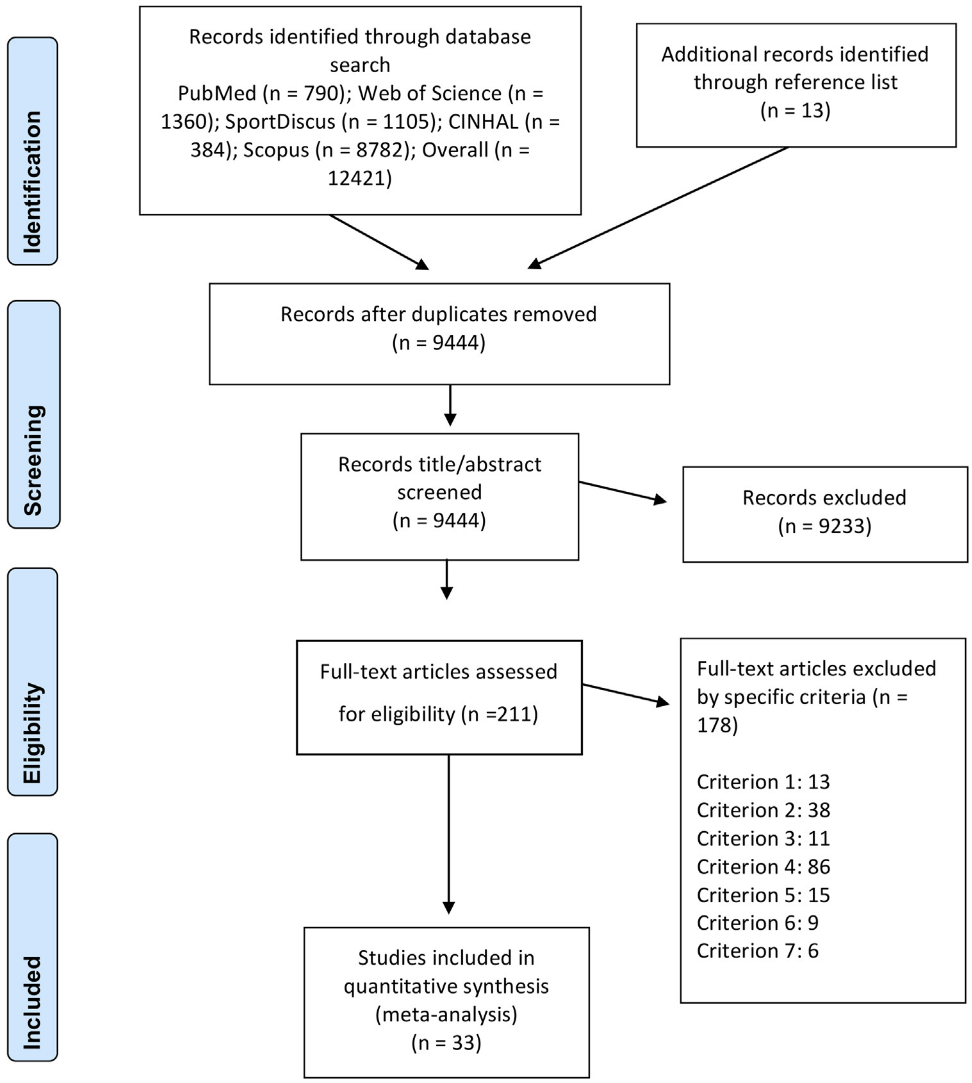

Fig. 1. Flowchart of study screening and selection. *Criterion 1–7* for details see Section 2.

able. Random-effects meta-analysis models for the between-group differences in % mean change were fit using the restricted maximum likelihood method with inverse variance weights. Confidence intervals for the overall difference between training groups in % mean change and p-values for the null hypothesis of this difference being zero were calculated using the Knapp and Hartung adjustment.[28] I^2 values are reported to assess the heterogeneity between studies. A potential publication bias was assessed using funnel plots (ESM 2 and ESM 3). Sensitivity analyses was performed by excluding (1) one study at a time (2) studies using upper-body exercises (3) studies using an average load of under 60% of 1-RM as a conditioning activity in the strength-power potentiation complex (i.e. lower-load CT studies) (4) studies reporting extreme results (i.e. outliers) and evaluating the impact of removing these studies on the summary results (ESM 4-7).

3. Results

In the literature search, we identified 12421 publications in databases and 13 in reference lists. After removing duplicates and reviewing titles and abstracts, we read 211 articles in their entirety. Of these 178 articles were excluded because they did not meet the selection criteria. At the end of the search, 33 studies were included in the systematic review (see Fig. 1).

The study quality (PEDro score) of the included trials ranged from 2 to 5, with a median score of 4, indicating poor to moderate methodological quality (ESM 1). Although 29 of the 33 trials were randomized, none stated that the allocation process was concealed. None of the trials blinded participants, supervisors or testing personnel, except the study by Juarez et al.[29], where testing personnel was blinded. However, blinding within exercise interventions is often not plausible or even impossible to establish. Therefore, a lack of blinding of athletes and coaches was not considered to be a source of bias.

Included study characteristics are summarized in Appendix A. More than two thirds of the included studies (n = 28) were published in the last decade of 2009–2018. The mean sample size was 33 participants per study, ranging from 12[20] to 65.[30] All articles were written in English, except the study by Wallenta et al.[20] which was published in German. Trials comprised various study arms: control condition (total number of participants, n = 250), CT (n = 430), lower-load resistance training (n = 155), higher-load resistance training (n = 210) and other training strategies combining higher-load and lower-load exercises (n = 74). Studies using other training strategies alternated higher-load and lower-load exercises in reverse order[17,31,32] (lower-load exercises before the corresponding higher-load exercise), on separate days[18,25,33] (higher-load exercises on one day and lower-load exercises on the other) or separated higher-load and lower-load exercises in distinct training phases[20,29] (higher-load exercises in the first half and lower-load exercises in the second half of the training intervention). We grouped lower-load training, higher-load training and other strategies combining higher- and lower load exercises under the heading "alternative training methods" (n = 439). Thus, 1064 healthy participants from various sporting disciplines (soccer, futsal, basketball, volleyball, rugby, football, water polo, track and field) with a mean age of 19.8 years were involved in the 33 trials. Most studies involved males (27 out of 33 studies), two studies[33,34] referred only to females, and four studies included both male and female participants.[17,18,30,35]

A brief description of the exercise interventions is given in Appendix A. The duration of interventions varied from 4 to 18 weeks, with a median duration of 7 weeks. Most of the intervention groups trained twice a week (26 out of 33 studies). Higher-load strength exercises in CT and alternative training groups mainly focused on lower limb muscles, with 4 studies[25,26,34,36] adding upper-body strength training exercises to their programme. The median number of strength exercises was two per study. These exercises were repeated for 1–5 sets (median = 3) and 1–10 repetitions per set (median = 5.5). Intensity of the strength exercises ranged from 40% to 90% of 1-RM. Lower-load exercises in experimental groups similarly focused on lower limb muscles, with two studies[25,26] adding upper-body plyometrics to their programme. All authors except Kotzamanidis et al.,[16] Torres-Torrelo et al.[37] and Tsimachidis et al.[24] included jumps in their lower-load exercise routine, whereas 14 out of the 33 studies implemented sprints, change of direction exercises or running drills.[33,38,14–16,20,24,29,37,39–42] Interestingly, only one study explicitly mentioned the use of external resistance (i.e. ballistic exercises) in their lower-load exercise programme.[25] The median number of lower-load exercises was also two per study. These exercises were repeated for 1–6 sets (median = 3) and 1–11 repetitions per set (median = 5). Rest periods between the strength and the lower-load exercises were reported for 20 of the 33 studies[16–20,24,25,27,29,31–33,35,37,40,42–46] and ranged from 10 s to 5 min (mean ∼ 2 min).

The effects of CT versus control and CT versus alternative training methods, on the lower-body performance outcomes are summarized in Figs. 2 and 3 and reported below.

The random-effects model suggested significant improvements after CT in all lower-body performance measures compared to control condition, except for 40 m sprint performance (−4.2%, 95% CI −8.9 to 0.5, p = 0.068, I^2 = 94.7%). The highest performance gains could be found in 1-RM squat strength with an increase of 23.6% (95% CI 16.4–30.7, p < 0.001, I^2 = 96.6%). Data analysis from studies in which CMJ height was tested revealed an increase of 8.9% (95% CI 5.6–12.3, p < 0.001, I^2 = 86.6%). Similarly, SJ height increased by 12.7% (95% CI 8.0–7.4, p < 0.001, I^2 = 82.8%) compared to con-

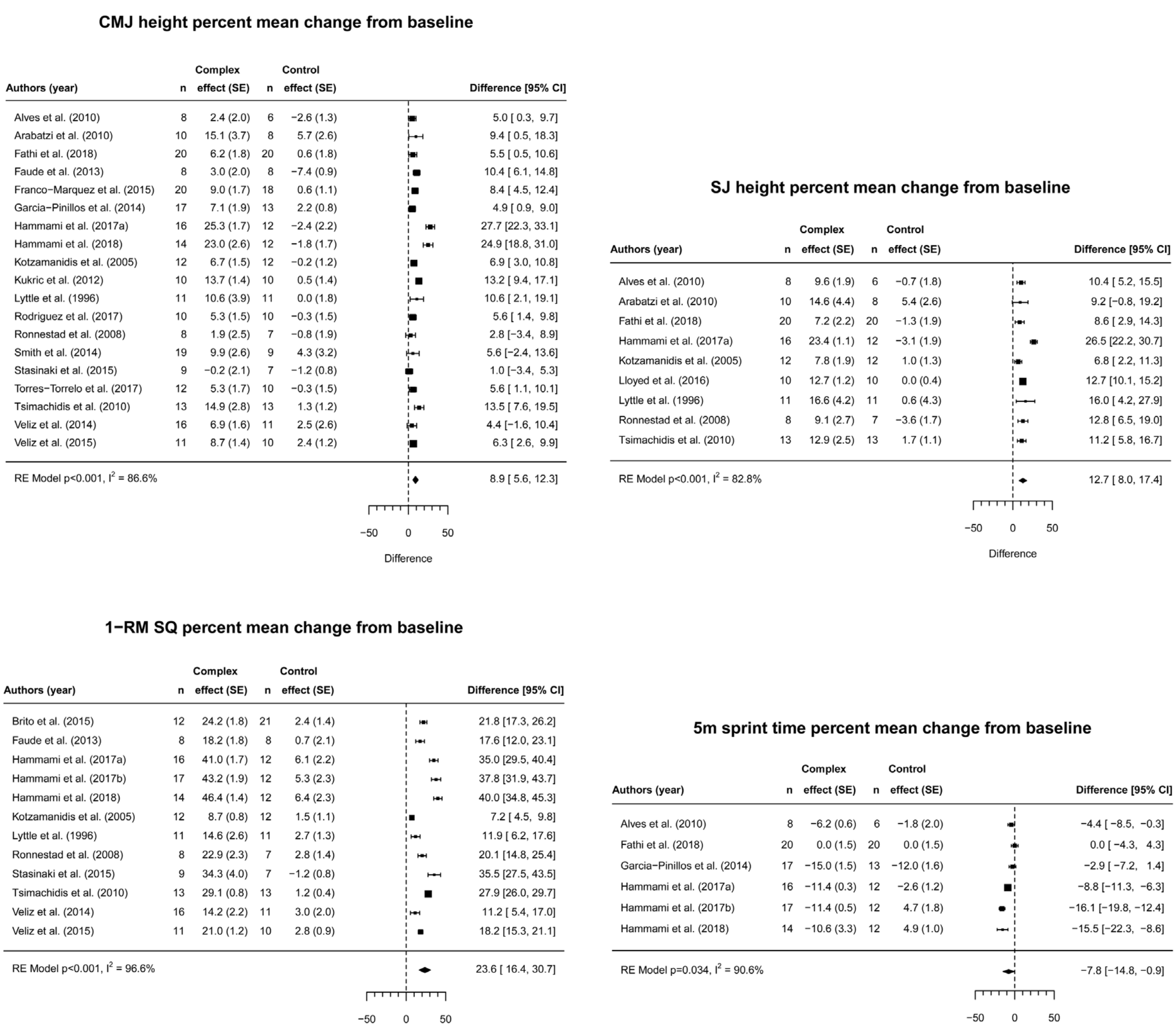

Fig. 2. Effects of complex training vs. control on CMJ height, SJ height, 1-RM squat and sprint performances. *CI* confidence interval, *SE* standard error, *RE* random-effects model.

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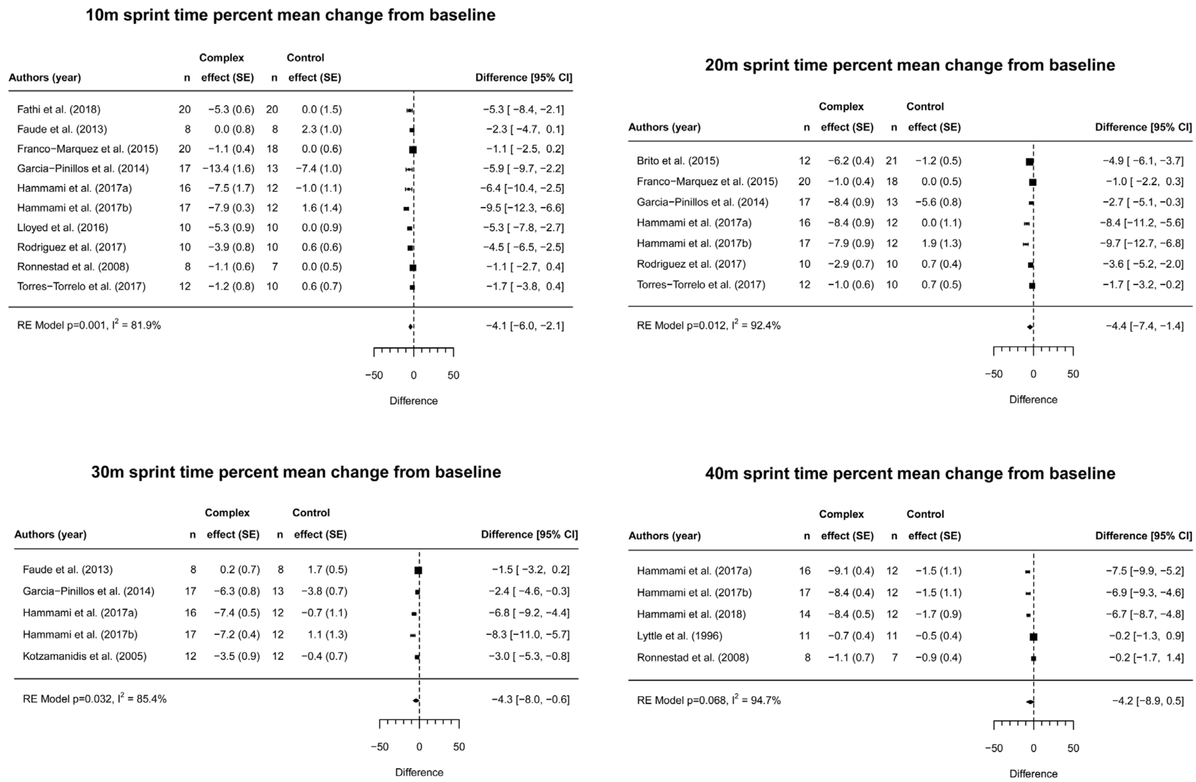

Fig. 2. (*Continued*)

trol condition. Reductions in 5 m, 10 m, 20 m and 30 m sprint times were −7.8% (95% CI −14.8 to −0.9, p = 0.034, I^2 = 90.6%), −4.1% (95% CI −6.0 to −2.1, p = 0.001, I^2 = 81.9%), −4.4% (95% CI −7.4 to −1.4, p = 0.012, I^2 = 92.4%) and −4.3% (95% CI −8.0 to −0.6, p = 0.032, I^2 = 85.3%), respectively (Fig. 2), suggesting that sprint performance improved following CT. The sensitivity analysis did not change the statistical significance in most performance variables. However, with exclusion of some or more studies independently, the differences of 5 m and 30 m sprint improvements were no longer significant (see ESM 4).

When compared to alternative training methods, the random-effects model did not detect significant advantages or disadvantages of CT on performance outcomes, except 1-RM squat and 20 m sprint performance changes, which were significantly greater following CT (7.0%, 95% CI 0.2–13.7, p = 0.044, I^2 = 94.2% and −0.9%, 95% CI −1.6 to −0.1, p = 0.028, I^2 = 0.0%, respectively). Changes in CMJ height, SJ height, 5 m, 10 m, 30 m and 40 m sprint times were 1.2% (95% CI −1.2 to 3.6, p = 0.303), 2.7% (95% CI −2.3 to 7.7, p=0.252), −0.7% (95% CI −2.3 to 1.0, p = 0.323), −0.8% (95% CI −2.4 to 0.9, p = 0.325), −1.1% (95% CI −4.9 to 2.8, p = 0.357) and −2.3% (95% CI −4.7 to 0.2, p = 0.061), respectively (Fig. 3). The sensitivity analysis suggested that the primary analysis was not robust. Exclusion of specific studies independently changed the statistical significance for all variables except for CMJ height and 10 m sprint performance. In particular, the sensitivity analyses revealed that the estimated advantage of CT to improve 1-RM performance was substantially influenced by studies reporting extreme improvements.[14,15] After removing these studies, the combined estimate was reduced to 2.6% (95%CI −0.5 to 5.7, p = 0.096).

4. Discussion

The purpose of this meta-analysis was to determine the effects of CT in comparison to control conditions and alternative training methods on lower-body performance. Therefore, we meta-analysed data from 33 studies involving 1063 athletes in which CT was directly compared to either control and/or alternative training methods. We found that CT can be employed to improve performance in 1-RM squat, CMJ, SJ, 5 m, 10 m, 20 m, and 30 m sprint performance compared to control conditions. These findings are consistent with a recent meta-analysis by Freitas et al.,[47] demonstrating that CT is an appropriate training stimulus to improve vertical jump and sprint performance compared to control conditions. Additionally, we found that the benefits of CT can be realized after only few weeks and with relatively low training frequency. CT workouts seem to be effective with only few exercises and relatively low overall training volume, although the heterogeneity observed among the studies was high. However, this may be of interest for coaches and athletes seeking a more time-efficient way to incorporate lower-load and higher-load exercises in their training program. To the best of the authors' knowledge, only one study published in German meta-analysed the effects of CT on jump and sprint performance in comparison to alternative training methods[48] and reported only trivial effects favouring CT. In fact, the larger number of trials in the current meta-analysis reinforces the findings reported by Lesinski et al.[48] and strengthens the evidence for no differences between CT and alternative training methods to improve jump and sprint performance. Therefore, based on current available evidence, coaches and athletes should individually determine whether implementing CT instead of alternative training methods is a worthwhile undertaking. To our knowledge, this is the first comprehensive systematic review and meta-analysis examining the effects of CT and alternative training methods on strength performance. We found that improvements in 1-RM squat strength were significantly higher following CT interventions. It is well established that greater muscular strength is associated with enhanced general sport performance, with the ability to take advantage of potentiation effects and with decreased injury risk.[3] Therefore, the presence of superior 1-RM squat performance gains could further reinforce the importance of considering CT as a viable

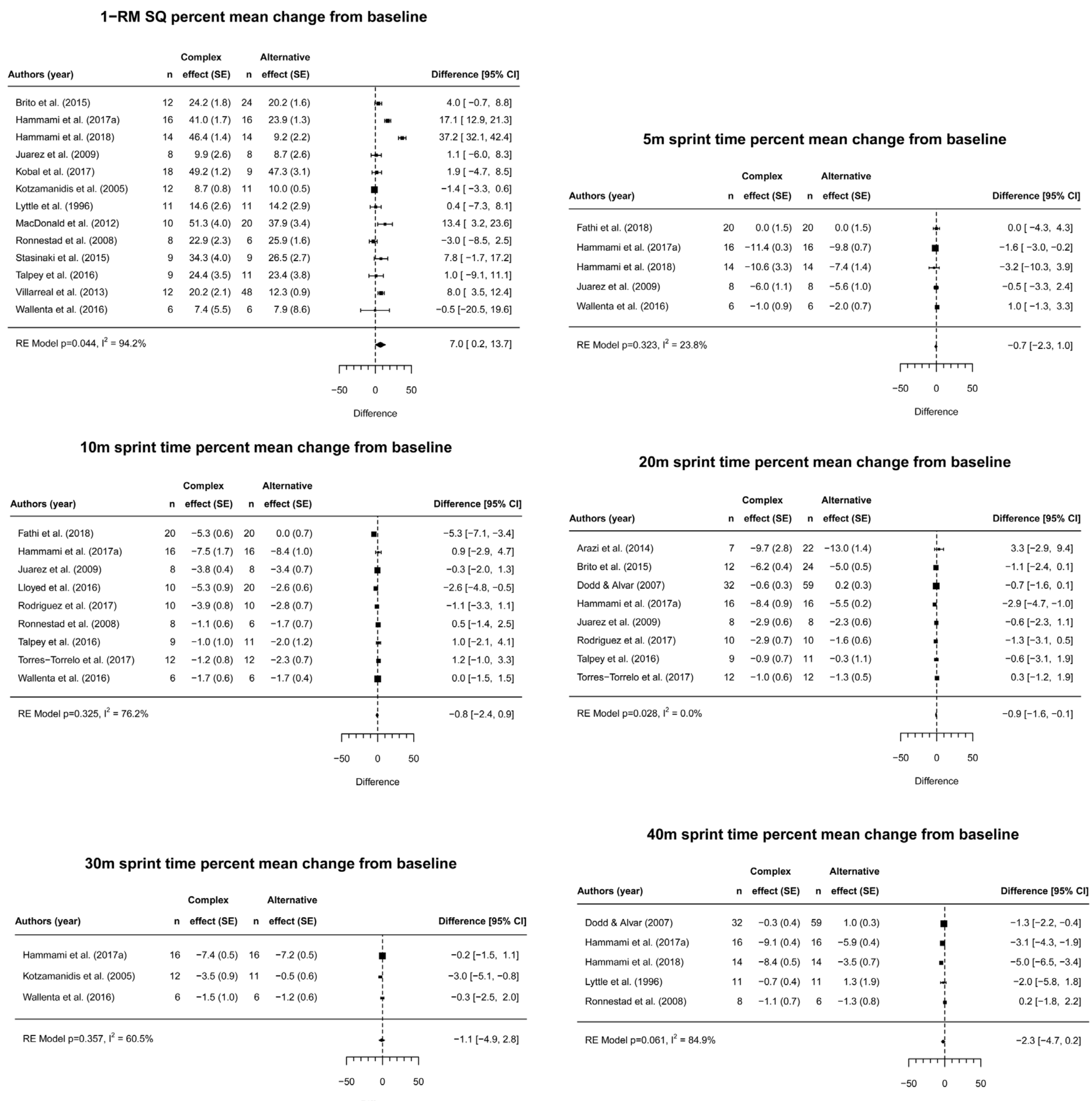

Fig. 3. Effects of complex training vs. alternative training methods on CMJ height, SJ height, 1-RM squat and sprint performances. *CI* confidence interval, *SE* standard error, *RE* random-effects model.

training strategy. However, it should be noted that most of the included studies used relatively weak athletes actively involved in sports which typically involve jumping and sprinting. It could be assumed that the relatively novel higher-load strength training stimulus could have produced a strong adaptation response, although explicit testing of this hypothesis is required. Additionally, it should be noted that the sensitivity analysis of the data showed that the positive findings were influenced by single studies reporting extreme improvements of more than 40%[14,15] casting doubt as to whether CT is truly superior in improving 1-RM performance compared to alternative training methods.

There are several limitations that warrant further discussion. First and most important, a major limitation is that CT studies vary significantly in the training programmes used, creating a level of heterogeneity that makes comparison difficult. As mentioned above, lower-load training, higher-load strength training and other training strategies combining higher-and lower-load training were grouped under the heading "alternative training". However, there is evidence to suggest that adaptations to resistance training are load-specific.[1] Therefore, it could be speculated that performance variables not specifically trained in lower-load (i.e. 1-RM squat) or higher-load (i.e. jumps and sprints) training programmes are naturally much higher following CT or other mixed training strategies targeting both ends of the load-velocity spectrum. Future meta-analysis with higher sample sizes for each of the sub-groups could address this problem.

Furthermore, careful inspection of the scientific literature reveals that there is no consent in how to define and more importantly how to organize higher-load and lower-load exercises in CT programmes. In the included studies of this review we identified at least three different sequential patterns of combining higher and lower-load exercises: (1) studies alternating higher-load and lower-load exercises set-by-set[14,15,17,20,24,25,31,33,35,38–41,44,46,49]; (2) studies alternating multiple sets of higher-load with multiple sets of lower-load exercises[17,18,27,31,32,37,50] and (3) studies performing all sets of higher-load prior to all sets of lower-load exercises.[16,19,26,29,30,34,36,42,43,45,51,52] Given the evidence that the magnitude of PAP is highly dependent on organizational factors of the strength-power potentiation complex,[13] it remains to be determined whether employing different sequential patterns in CT is influencing the outcomes. However, it should be noted that authors such as Alemdaroğlu et al.[17] and Kobal et al.[31] directly compared different forms of CT and did not show any significant differences in long-term performance improvements.

Beside the organizational factors of the strength-power potentiation complex other factors influencing the level of potentiation have been identified.[13] This includes the performance level of the athlete, the load and volume of the strength exercises (i.e. conditioning activity) and the rest period between the conditioning activity and the subsequent lower-load exercise.[13] However, after careful inspection of the studies in this review we concluded that many of the CT protocols do not comply with recommendations from acute PAP research. For example, there is compelling evidence to suggest that performance of the lighter-load exercise is decreased immediately after the higher-load exercise and that recovery periods of 5–7 min are optimal to benefit from PAP.[13] However, we found that studies in this review used average rest periods of about 2 min (ranging from 10 s to 5 min) or did not report rest period between exercises at all.[14,15,26,30,34,36,38,39,41,49–52] Additionally, a recent meta-analysis suggests that higher-load exercises with loads at or above 85% of 1-RM induce a larger PAP effect than exercises with loads ranging between 30% and 84% of 1-RM.[13] It therefore remains questionable whether loads of the included studies (ranging from 40% to 90% of 1-RM) were sufficient in eliciting PAP. However, it should be noted that excluding studies using very low-loads as a potentiation stimulus did not influence our overall conclusions (ESM 6 and ESM 7).

Furthermore, it should be noted that there is strong evidence to suggest that stronger and more experienced athletes show considerably larger PAP effects than their weaker and less experienced counterparts.[13] This is important because most athletes of the included studies have limited or no resistance training experience. Therefore, athletes potentially elicited lower levels of PAP, which in turn could have been limiting their potential to adapt to CT interventions.

Future research should therefore endeavour to explore if and how PAP influences chronic adaptations following CT and therefore potentially optimize CT protocols. Additionally, future studies on trained athletes with a high training age are warranted to determine whether adaptations following CT are dependent on resistance training experience and/or strength level.

While the limitations above may exist, the information gathered from the current meta-analysis may benefit strength and conditioning practitioners from an exercise prescription standpoint but may also serve as a hypothesis generating analysis for future research.

5. Conclusion

The present meta-analysis confirms that CT has a significant beneficial effect on lower-body performance compared to control conditions. Furthermore, this analysis provides evidence that CT is superior in improving 1-RM squat strength and 20 m sprint performance compared to alternative training methods. However, these findings could be potentially influenced by single studies and should therefore be interpreted with circumspection. Jump and 5 m, 10 m, 30 m, 40 m sprint performances showed no significant differences between CT and alternative training methods. However, this finding is particularly of importance for practitioners as the organizational benefits of combining higher and lower-load resistance training exercises in one training session could still remain, even without the presence of a significant increase in lower-body performance compared to alternative training methods. Coaches and athletes can potentially save time and resources by training different parts of the load-velocity spectrum in one workout and bring greater variety to their training programmes. In conclusion, more high-quality research on CT should be conducted to confirm and possibly extend the promising results of this systematic meta-analytical review. We recommend that future studies should focus on resistance trained athletes. Further work is also needed to understand specific CT variables like intensity, volume and training duration. Moreover, it should be elucidated if PAP is present and how it can be maximized in CT interventions. Collectively, our findings support the promotion of CT as a strategy to improve lower-body performance of athletes.

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Appendix A. Summary of characteristics of all studies meeting the inclusion criteria

Authors and year	Population		Training program					
	Sample size (n), sex and age (years) [mean ± SD]*	Sample description	Training type (n)	Higher-load resistance training	Lower-load resistance training	Frequency (times/ week)	Training duration (weeks)	Study quality (PEDro)
Alemdaroğlu et al. (2013)	24 MF (21.6 ± 2.3)[a]	Recreational trained students with experience in resistance and plyometric training	CT (16)[b] ALT [MIX] (8)	CT and ALT [MIX] groups 3 × 6 reps of split squats, leg-press and leg-curls at 85–90% of 1-RM	CT and ALT [MIX] groups 3 × 6–12 reps of split jumps, SJs and front tuck jumps	2	6	3
Maio Alves et al. (2010)[c]	14 M (17.4 ± 0.6)	Portuguese elite soccer players	CT (8) CTRL (6)	CT group 3 × 6 reps of squats, calf raises, and knee extensions at 80–100% of 1-RM	CT group 5 m skipping and 5 m sprint, 8 CMJs plus 3 ball headers, 8 SJs from seated position, 3 DJs with ball headers	2	6	3
Arabatzi et al. (2010)	36 M (20.3 ± 2.0)	Active physical education students with experience in resistance and plyometric training	CT (10) ALT[PLYO] (9) ALT [ST] (9) CTRL (8)	CT and ALT [ST] groups 4–6 × 4–6 reps of snatches from a squat position, high pulls, power cleans and squats at 75–90% of 1-RM, whereas CT group	CT and ALT [PLYO] 4–6 × 6 reps of double-leg hurdle hops, alternated single-leg hurdle hops, double-leg hops, half-squats	3	8	3
Arazi et al. (2014)	29 F (20.7 ± 0.7)[a]	Untrained women with experience in resistance and plyometric training	CT (7) ALT [PLYO] (8) ALT [ST] (7) ALT [MIX] (7)	CT, ALT [ST], ALT [MIX] 3 × 6 reps of squats, knee-extensions, knee-flexions, single-leg lunges at 60% of 1-RM	3 × 6 reps of DJs, CMJs, 10m zigzag drill, lunge jumps	2	6	3
Brito et al. (2014)	57 M (20.3 ± 1.6)	College students engaged in different local soccer clubs	CT (12) ALT [PLYO] (12) ALT [ST] (12) CTRL (21)	CT and ALT [ST] groups 1 × 6 reps of squats, calf extensions and leg extensions at 80–90% of 1-RM	CT and ALT [PLYO] groups 5 m skipping, 5 m sprint, 8 CMJs plus 3 ball headers, 85 m skipping and 5 m sprint, 8 CMJs plus 3 ball headers, 8 SJs from seated position, 3 DJs with ball headers	3	9	4
De Villarreal et al. (2011)	65 MF (20.0 ± 2.7)[a]	Physical education students with no specific strength training experience	CT (14) ALT [ST] (39)[b] ALT [PLYO] (12)	CT group 3 × 3–6 reps of squats at 60–86% of 1-RM and additional lower-body exercises with diverse intensities ALT [ST] consist of 3 different strength training groups (traditional strength, power-oriented and ballistic) which performed 3–4 × 2–6 reps of lower body exercises with different intensities[e]	CT and ALT [PLYO] groups 4–8 × 5 reps of CMJs	3	7	4

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De Villarreal et al. (2013)	60 M (20.4 ± 2.1)	Physical education students with no specific strength training experience	CT (12) ALT [ST] (36)[b] ALT [PLYO] (12)	Same training program as de Villarreal et al.[30][e]	Same training program as de Villarreal et al.[30]	3	7	4
Dodd and Alvar (2017)[d]	45 M (18–23)	Division II junior college baseball players with at least 1 year resistance training experience	CT (32) ALT [PLYO] (28) ALT [ST] (31)	CT group 2 × 6 reps and ALT [RT] group 4 × 6 reps of squats, lunges and split squats at 80–90% of 1-RM	CT group 2 × 6 reps and ALT [PLYO] group 4 × 6 reps of box jumps, DJs, and split squat jumps	2	4	3
Fathi et al. (2018)	60 M (14.6 ± 0.6)	First division Tunisian volleyball players with lack of plyometric training experience	CT (20) ALT [PLYO] (20) CTRL (20)	CT group 1–2 × 8–12 reps of half squat, Bulgarian split squats, bench press, behind the neck press at 40–70% of 1-RM	CT group 2–3 × 6–8 reps and ALT [PLYO] 3–5 × 8–10 reps of hurdle jumps and DJs	2	16	5
Faude et al. (2013)	16 M (22.5 ± 2.5)	Third Swiss league soccer players	CT (8) CTRL (8)	CT group 4 × 4 reps of unilateral squats at 90% of 1-RM on day 1 and 2–3 × 5–8 reps from two of four exercises (squats, calf raises, lateral squats and step-ups) at 50–60% of 1-RM on day 2	CT group 4 × 5 reps of single-leg hurdle jumps on day 1 and 2–3 times two of four pairs (5 DJs + 5 m sprint, 5 CMJs + 1 header, 8 lateral jumps + 10 zig-zag sprints, 4 bounding jumps + 3 headers) on day 2	2	7	3
Franco-Marquez et al. (2015)	38 M (14.7 ± 0.5)	Spanish first division soccer players with no experience in resistance training	CT (20) CTRL (18)	CT group 2–3 × 4–8 reps of squats at 45–60% of 1-RM	CT group 6 × 6–12 reps of step phase triple jumps, 3 × 5 reps of CMJs, 3–5 × 10 s CODs, 3–4 × 20 m sprints, whereas CODs and sprints were alternated every training session.	2[c]	6	2
Garcia-Pinillos et al. (2014)	30 M (15.9 ± 1.4)	Semi-professional soccer academy players	CT (17) CTRL (13)	CT group 4–6 × 40–80 s of isometric half squats	CT group 4–6 × 6 reps of SJs and single-leg jumps	2	12	5
Hammami et al. (2017a)	44 M (16.0 ± 0.5)	Soccer players with strength training experience	CT (16) ALT [ST] (16) CTRL (12)	CT and ALT [ST] groups 3–5 × 3–8 reps of squats at 70–90% of 1-RM (ascending and descending sets)	CT group 3–5 × 3 reps of CMJs in the first four weeks and 3–5 × 1 CMJ followed by a 15m sprint in the second four weeks	2	8	4
Hammami et al. (2017b)	29 M (16.3 ± 0.4)	Professional soccer players	CT (17) CTRL (12)	CT group 3–5 × 3–8 reps of squats at 70–90% of 1-RM (ascending and descending sets)	CT group 3–5 × 3 reps of CMJs in the first four weeks and 3–5 × 1 CMJ followed by a 15 m sprint in the second four weeks	2	8	3
Hammami et al. (2018)	40 M (15.8 ± 0.4)	Elite-level soccer players	CT (14) ALT [PLYO] (14) CTRL (12)	CT group 3–5 × 3–8 reps of squats at 70–90% of 1-RM (ascending and descending sets)	CT group 3–5 × reps CMJs in the first four weeks and 3–5 × 1 CMJ followed by a 15m sprint in the second four weeks ALT [PLYO] group 5–10 × 7–10 reps of hurdle jumps in the first four weeks and 4 × 7–10 reps of DJs in the second four weeks	2	8	4

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Juarez et al. (2009)	16 M (19.7 ± 1.7)[a]	Active undergraduate students with no specific strength training experience	CT (8) ALT [MIX] (8)	CT group 2 × 4 reps of squats at 70–85% of 1-RM ALT [MIX] group 4–5 × 4–8 reps of squats at 70–85% of 1-RM in the first four weeks	CT group 2 × 5 reps of CMJs, hurdle jumps or DJs combined with 2 × 20 m sprints ALT [MIX] group 4–5 × 5 reps of CMJs, DJs or box jumps combined with 4–5 × 2 reps of 20 m sprints in the second four weeks	2	8	4
Kobal et al. (2017)	27 M (18.9 ± 0.6)	Brazilian first division soccer players with no experience in resistance or plyometric training	CT (18)[b] ALT [MIX] (9)	CT and ALT [MIX] groups 3–5 × 6–10 reps of squats at 60–80% of 1-RM	CT and ALT [MIX] groups 3–5 × 10–12 reps of DJs	2	8	4
Kotzamanidis et al. (2005)	35 M (17.3 ± 1.0)[a]	Soccer players in the intervention groups and physical education students in the control group	CT (12) ALT [ST] (11) CTRL (12)	CT and ALT [ST] groups 4 × 8RM in the first three weeks, 4 × 6RM in the second three weeks and 4 × 3RM in the third three weeks of squats, step-ups and leg curls	CT group 4 × 4, 5, and 6 reps of 30m sprints in the first, second and third subperiod respectively	2	9	4
Kukrić et al. (2012)	23 M (16–17)	Junior basketball players of the first division of Republika Srpska	CT (10) ALT [PLYO] (10) CTRL (10)	CT group 3 × 5–8 reps of calf raises, leg press, split squats and squats at 80% of 1-RM	CT group 3 × 8 reps of single-leg jumps, hurdle jumps, jump lunges ALT [PLYO] 3 × 10 reps of SJs, hurdle jumps, CMJs, one-leg jumps, box jumps and DJs	2	10	3
Lloyd et al. (2016)	40 M (16.2 ± 0.3)[a]	School children (post-peak height velocity) with no experience in strength and conditioning training	CT (10) ALT [PLYO] (10) ALT [ST] (10) CTRL (10)	CT and ALT [ST] 3 × 10RM of squats and lunges ALT [ST] group additionally performed step ups and leg press with 3 × 10RM	CT and ALT [PLYO] groups 2–4 × 3–10 reps of different plyometric drills	2	6	4
Lyttle et al. (1996)	33 M (22.8 ± 5.3)[a]	Regional level athletes with no specific strength or plyometric training in the previous year	CT (11) ALT [PLYO] (11) CTRL (11)	CT group 1–3 × 6–10RM of bench press and squats	CT group 1–2 × 4 reps medicine ball throws and DJs ALT [PLYO] group 2–6 × 8 reps of bench press throws and SJs at 30% of 1-RM	2	8	3
MacDonald et al. (2012)	30 M (21.7 ± 3.4)	Recreational athletes with resistance training experience of at least 6 months	CT (10) ALT [PLYO] (9) ALT [ST] (11)	CT and ALT [RT] groups 3 × 3–6 reps of squats, Romanian deadlifts and calf raises at 45–90% of 1-RM	CT and ALT [PLYO] groups 3 × 3–7 reps of lateral jumps, DJs and box jumps	2	6	4
Mihalik et al. (2008)	31 MF (20.6 ± 2.3)[a]	Division 1 volleyball athletes	CT (15) ALT [MIX] (16)	CT and ALT [MIX] groups 3 × 6 reps of squats, single-leg lunges and deadlifts at 60% of 1-RM	CT and ALT [MIX] groups 3 × 6 reps of DJs, split squat jumps and double-leg bounds	2	4	3
Rodriguez-Rosell et al. (2017)	30 M (25.4 ± 3.4)	Spanish third division semi-professional soccer players with no experience in strength training	CT (10) ALT [ST] (10) CTRL (10)	CT and ALT [ST] groups 2–3 × 4–6 reps of squats at 45–58% of 1-RM	CT group 3 × 5 reps CMJs, 3 × 20 s CODs and 3 × 20 m sprints every second training session	2	6	4

Ronnestad et al. (2008)	21 M (22.7 ± 2.0)[a]	Norwegian premier league soccer players with experience in strength training	CT (8) ALT [ST] (6) CTRL (7)	CT and ALT [ST] groups 3–5 × 4–6RM squats, and hip flexion exercise	CT group 2–4 × 10 reps of alternate leg bounds, 2 × 5 reps of double-leg hurdle jumps and single-leg forward hops	2	7	4
Smith et al. (2014)	28 MF (20–29)	Recreational athletes	CT (19)[b] CTRL (9)	CT group 3 × 4–6RM squats or kettlebell swings	CT group 3 × 5 reps of CMJs	3	6	4
Stasinaki et al. (2015)	23 M (21.9 ± 1.9)	Moderately trained physical education students with modest resistance training experience	CT (9) ALT [MIX] (9) CTRL (7)	CT group 2 × 6 reps of leg press, bench press and squats at 85% of 1-RM ALT [MIX] group 4 × 6 reps of reps of leg press and squats at 85% of 1-RM every second training session	CT group 2 × 8 reps of leg press throws and bench press throws with 30% of 1-RM, 2 × 8 reps of SJs and 3 × 8 reps of DJs ALT [MIX] group 4 × 8 reps of leg press throws and bench press throws with 30% of 1-RM, 4 × 8 reps of SJs and 3 × 8 reps of DJs every second training session	3	6	4
Talpey et al. (2016)	20 M (21.1 ± 3.5)[a]	Recreational athletes involved, football, rugby, basketball with a minimum of one year resistance training experience	CT (9) ALT [MIX] (11)	CT and ALT [MIX] group 3–4 × 3–8RM of squats	CT and ALT [MIX] group 3–4 × 4 reps of SJs	2	9	4
Torres-Torrelo et al. (2017)	34 M (23.7 ± 4.1)[a]	Spanish third division futsal players with no experience in resistance training	CT (12) ALT [ST] (12) CTRL (10)	CT and ALT [ST] groups 2–3 × 4–6 reps of squats at 45%–58% of 1-RM[e]	CT group 2–5 × 10 s CODs	2	6	5
Tsimachidis et al. (2010)	26 M (18.0 ± 1.0)[a]	Junior basketball players without background in strength or plyometric training	CT (13) CTRL (13)	CT group 5 × 8RM of squats in the first five weeks and 5 × 5RM in the second five weeks	5 × 30 m sprints	2	10	3
Veliz et al. (2014)	27 M (20.4 ± 5.1)	Spanish national level water polo players with no experience in strength or plyometric training	CT (16) CTRL (11)	CT group 3–4 × 4–10 reps of bench press, squats, military press, pull ups and loaded CMJs at 60–86% of 1-RM	CT group 3 × 5 reps of CMJs	2	18	4
Veliz et al. (2015)	21 F (26.4 ± 4.3)	Spanish national level water polo players with no experience in strength or plyometric training	CT (11) CTRL (10)	CT group 3–4 × 4–6 reps of squats, split squats and loaded CMJs at 60–80% of 1-RM	CT group 3–6 × 5 reps of CMJs	2	16	4

Wallenta et al. (2016)	12 M (18.3 ± 1.4)[a]	German youth soccer players	CT (6) ALT [MIX] (6)	CT group 3×5 reps of squats, at 60–70% of 1-RM ALT [MIX] group 6×5 reps of squats at 60–70% of 1-RM in weeks 1–3	CT group 3×3 hurdles jumps followed by a 20 m submaximal sprint ALT [MIX] group 6×3 hurdle jumps followed by a 20 m submaximal sprint in weeks 4–6	2	6	3

1-RM one repetition maximum, *ALT* alternative training methods, *CMJ* countermovement jump, *COD* change of direction, *CT* complex training, *CTRL* control group, *DJ* drop jump, *F* female only, *M* male only, *MF* male and female together, *MIX* mixed strength and plyometric training, *PEDro* physiotherapy evidence database scale, *PLYO* plyometric training, *reps* repetitions, *SD* standard deviation, *SJ* squat jump, *ST* strength training

[a]For studies not reporting pooled estimates for the sample mean and sample standard deviation, the respective values were calculated using the sample sizes (n1, n2), means (m1, m2) and standard deviations (sd1, sd2) reported for the individual groups. The according equations are pooled mean = (m1 × n1 + m2 × n2)/(n1 + n2) and pooled sample standard deviation = sqrt [(n1 – 1) × sd1$\hat{2}$ + (n2 – 1) × sd2$\hat{2}$ + n1 × (m1 – m)$\hat{2}$ + n2 × (m2 – m)$\hat{2}$) / (n1 +n2 – 1)].

[b]Data from groups carrying out the same training type were combined

[c]Maio Alves et al.[38] analysed two CT groups, whereas one group performed CT once and the other twice a week. We excluded the group with a training frequency of once a week according to criterion 3. Additionally, we were not able to obtain age values for the separate groups, therefore mean ± SD age values for the all subjects are shown.

[d]Dodd & Alvar used a crossover study design.

[e]Torres-Torrelo et al.,[37] Villarreal et al.[30] and Villarreal et al.[51] prescribed strength training intensity according to an associated mean propulsive velocity derived from a cable-extension linear velocity transducer.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2019.01.006.

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