Network Meta-analysis of Combined Strength and Power Training for Countermovement Jump Height

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ABSTRACT

Combined strength and power training in a training program is considered to improve the vertical jump, which is frequently quantified using the countermovement jump height. It is not yet clear whether one of the different training set structures, such as complex training, contrast training, compound training and traditional training, is superior to another. The aim of this review is to describe and assess the comparative effects of the set structures on countermovement jump height in healthy subjects. A systematic review and network meta-analysis (NMA) was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Network Meta-Analyses. Three databases were systematically searched. Risk of bias was assessed using the Risk of Bias 2 tool. NMAs were performed using a random-effects model. Twenty-four studies were included. All interventions were superior to control (no intervention) with mean differences ranging from 2.87 [95 % confidence interval (CI): 1.99 to 3.74] for complex training to 3.43 (95 % CI: 2.61 to 4.26) for traditional training. None of the training interventions were superior compared to each other in strength and/or power trained subjects, as well as in non-strength and/or power trained subjects. The findings support the combination of strength and power training to improve countermovement jump height.

Background

Stronger athletes can generate increased ground reaction forces, which are related to faster sprint times [1–3], change of direction speed [4], and vertical jump height [3]. Movements in field games are characterized by changes in velocity and these changes are determined by a produced impulse [5]. For example, a strong predictor of jump height is the body's ability to generate maximal vertical impulse [6, 7]. Maximal neuromuscular efforts aim at maximizing the impulse generated, because this is decisive for the subsequent velocity and, therefore, performance outcome. Vertical jump ability, frequently quantified using the countermovement jump (CMJ) [8, 9], is associated with higher level performers across a range of team sports, such as volleyball, football, rugby, or basketball [10–13], as well as individual sports, like track and field [3, 14]. Continuous athlete improvement depends on the amount of the trainability of numerous performance variables in athletic populations, respectively [15].

To enhance the maximal neuromuscular performance, strength training (ST) and/or power training (PW) are recommended [16]. For PW, low-load, high-velocity movements are performed (e. g. plyometrics, ballistics, sprinting). This is done with body weight or loads < 30 % of 1 repetition maximum (1-RM) [17, 18]. For ST, higher loads are moved at lower velocities during exercise (e. g. squats, leg presses, split squats, leg extensions, leg curls) compared to PW [18–20]. In untrained individuals, recent literature suggests intensities of > 60 % of 1-RM to achieve strength gains [21]. A specific form of ST is weightlifting (e. g. power cleans, clean and jerks, high pulls). These exercises require an athlete to move heavy loads as quickly as possible. It is suggested that 75 to 80 % of 1-RM should be used for this type of strength training [22]. Meanwhile, it is well established that a combination of higher and lower loads during exercises improves maximum strength, sprinting speed, and jump height [17, 23, 24]. When incorporated into a strength training program, weightlifting exercises are believed to improve force production characteristics and athletic performance, including jumping, to a greater extent than resistance or plyometric training alone [25]. Four main set structures of combining high and low loads in a training program exist. They are complex training (CPX), contrast training (CT), compound training (CP), and traditional training (TT) [26–28]:

- CPX: Multiple sets of a heavy resistance exercise are carried out prior to performing sets of a lighter resistance exercise [28]
- CT: The training is characterized by using exercises of contrasting loads, i. e. varying heavy and light exercises set for set
- CP: Strength and plyometric exercises are conducted on separate days [17, 29]
- TT: Multiple sets of lighter resistances with high velocity are carried out before performing sets of heavy resistances with low velocity [28], because power training is considered most effective, when exercises are performed in a fatigue-free state where the body can produce the peak power output [30]

Power exercises should therefore be completed before ST (TT) or on another day (CP). CPX and CT utilize a phenomenon called post-activation performance enhancement (PAPE). PAPE occurs when one or more high-intensity voluntary conditioning contractions results in an increased voluntary muscular performance in a subsequent test without concurrent sign of typical post-activation potentiation (PAP) [31]. While PAP is principally attributed to the phosphorylation of myosin light chains in type II fibers, PAPE arises as a higher rate of force development that can mainly be elucidated by physiological responses, such as increased muscle temperature, accumulation of intracellular water and further mechanisms [31–33]. Based on this theory, CPX uses a block-wise approach where several sets of ST alternate with several sets of PW, while CT switches between higher load and lower load exercises in each set [26, 34]. Currently, there is no evidence that one of the training set structures is superior to another. However, this may be necessary because athletes engaged in a similar competitive environment may need different ST schemes aimed at improving the physical status of weaker athletes and sustaining stronger athletes' capacities during in-season [35].

The aims of this research are thus to (1) determine the effectiveness of CPX, CT, CP, and TT interventions on countermovement jump performance, (2) compare their effects to each other, (3) to ST alone, (4) to PW alone, (5) to ST and PW combined (ST/PW), and (6) to control (CTRL), i. e. no intervention. In addition, the aim is to examine whether the training experience or status of the participants is associated with the intervention effects from CPX and CT, as well as CP and TT, because experienced or trained subjects may have less potential for adaptation [36]. The results of this analysis may provide strength and conditioning practitioners evidence to help them design their training programs more effectively.

Materials and Methods

This review was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Network Meta-Analyses (PRISMA-NMA) [37].

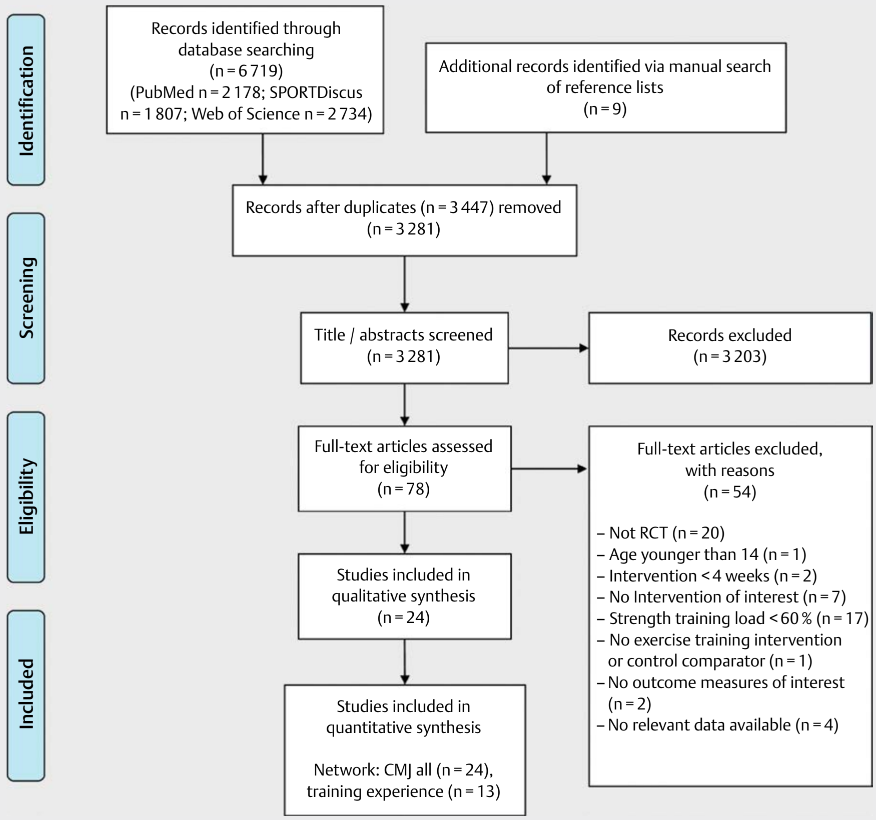
Literature search and study selection

The databases Web of Science, Medline (PubMed), and SPORTDiscus were systematically searched until November 30, 2020, using the subsequent search strings: ((((combined training OR compound training OR contrast training OR complex training OR strength training OR weight training OR resistance training OR weight lifting OR weightlifting OR Olympic weightlifting))) AND ((plyometric OR plyometric training OR explosive OR explosive training OR explosive performance OR ballistic performance OR ballistic training))). Additional publications were obtained from reference lists of potentially eligible articles.

Inclusion criteria

Eligible studies were randomized trials investigating the influence of ST and/or PW on vertical jump performance in healthy subjects, published in English or German language in a peer-reviewed journal. Specifically, studies were included if they met the following criteria: (1) participants (male or female) were healthy, older than 14, and younger than 50 years; (2) the training intervention lasted at least four weeks including at least eight training sessions in total; (3) one intervention group performed CPX, CT, CP or TT; (4) ST was considered as training that efficiently induces a measurable growth in muscle strength or/and hypertrophy [38]. An increase of muscular strength depends on the training load employed, i. e. the heavier the training load the larger the maximal strength adaptation [39]. Furthermore, the greater the % 1-RM, the greater is the response of hypertrophy, with a maximal increase between loads of 80 to 95 % of 1-RM. However, athletes may have different training backgrounds and, therefore, experience different muscle hypertrophy in response to the same amount and type of ST [38]. It was reported that subjects with no experience in ST make the most of their strength gains with mean intensities of 60 % of 1-RM [21]. To consider subjects of various levels of ST experience, studies were included that reported the effects of different training set structures incorporating the lower extremity using an average load > 60 % of 1-RM. Furthermore, moderate loads (60 to 84 % 1-RM) revealed an increased power enhancement in subsequent potentiation tasks compared to heavy loads (> 85 % 1-RM), with an effect size of 1.06 versus 0.31, respectively [40].

PW was defined as explosive exercises (plyometrics, ballistic, sprint and change of direction exercises) using an average load < 30 % of 1-RM [17]; (5) CPX, CT, CP, and TT were compared to each other, a control condition, an alternative training method such as ST or PW alone or ST and PW combined. In this regard, a combined



▶ **Fig. 1** Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of study identification and selection according to the PRISMA guidelines [104]. CMJ, countermovement jump; RCT, randomized controlled trial.

training does not fit to the definitions of CPX, CT, CP, TT, because combined ST and PW is characterized by dividing ST and PW into two separate phases, e. g. four weeks of ST using external weights for four sets, each with six repetitions, followed by four weeks of PW using plyometric exercises [41]; (6) outcome measure was CMJ height; (7) relevant data were available.

Exclusion criteria

Studies were excluded if they (1) were non-randomized trials, (2) were trials that examined the effect of CPX, CT, CP, TT on an underlying pathology, (3) were trials that combined CPX, CT, CP, and TT, e. g. in a cross-over design, and (4) reported insufficient data precluding inclusion in a network meta-analysis.

Implementation of search

Titles and abstracts of studies were reviewed initially by two authors (MB, SB) to screen if they might be relevant. Then, duplicates were removed (▶ **Fig. 1**). All potential articles were assessed against the eligibility criteria and reviewed in full text by two authors (MB, SB) independently to determine their final relevance. If a difference of opinion occurred, the third/senior author (MA) helped to find a consensus.

Quality assessment of included studies and treatment effect

The Cochrane Risk of Bias 2 (RoB 2) tool for randomized trials was used to assess the included studies' internal validity [42]. RoB 2 contains five domains that cover the main types of bias, including randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. A predefined algorithm is given with each domain, which contains several questions that can be answered using one of four given answer choices. These algorithms provide a guided approach to making an informed decision about the potential risk of bias in each study. The choices of answers are (1) "yes"; (2) "probably yes"; (3) "probably no"; (4) "no"; and (5) "no information". Based on the answers provided, each domain is rated as (1) "low risk of bias"; (2) "some concerns"; or (3) "high risk of bias". Studies were rated independently by two researchers (MB, SB). If disagreements occurred between the two researchers, resulting in no consensus, the third author (MA) was consulted to clear the disagreement. The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach was used for rating the quality of treatment effect estimates from network meta-analysis (NMA) [43].

Outcome measures and data extraction

After quality assessment, relevant data were extracted from the studies. Extracted outcome data were the mean change from baseline CMJ heights and its standard deviation (SD) in each trial arm. When the respective mean change was not available, or the data were presented in a different way, for example median values or another measure, the mean change of mean (± SD) CMJ heights between preintervention and postintervention were calculated, or the available data were converted to mean (± SD), as suggested by the Cochrane Handbook for Systematic Reviews of Interventions (Version 6.0) [44, 45].

When only figures were presented in the studies, the authors were first contacted and the missing numerical information was requested. If no response was given, the data from the figures were extracted using ImageJ (V.1.50i, https://imagej.nih.gov/ij/). ImageJ is an image processing program that was used to first calibrate the axis length of the relevant figures in pixels. Then, the calibration was used to measure the relevant axis that contained the data points of interest. This method was applied to four studies [46–49]. If none of those aforementioned methods were applicable for determining the SD, a correlation coefficient of 0.6 was used to substitute the missing values between baseline and follow-up CMJ. This method was applied to one study [50]. Different correlation coefficients were applied to evaluate findings' sensitivity and confirm the consistency of the results. In addition, relevant study information regarding author, year, sample description, number and gender of participants, intervention characteristics (experimental and control groups, duration, and frequency), and training characteristics (training duration and frequency, volume, intensity, and exercise selection) were reported by the researchers. Rest periods were reported in 18 out of 24 studies (▶ **Table 1**). After the extraction, the data included were peer-reviewed and confirmed by the senior researcher (MA). The overall agreement on data extraction and RoB 2 assessment between the researchers, which was calculated using the kappa statistics (κ) [51], was excellent (κ = 0.81).

Statistical analysis

Network plots for outcome were developed using R software (V.4.0.2) to illustrate the corresponding amount of available evidence on the different training set structures [52]. Next, to compare the effects of CPX, CT, CP, and TT interventions on CMJ performance with each other, to ST or PW alone, to ST/PW as well as to control, network meta-analyses (NMA) were performed [53]. In NMA, comparisons between three or more interventions are possible. Furthermore, they rely on a combination of direct and indirect comparisons, which leads to an improvement of the precision of the treatment effect estimates [54, 55]. Direct comparisons refer to interventions directly compared in individual studies, whereas statistics calculates indirect comparisons. The effects in two sets of analyses were compared: (1) different exercise interventions on CMJ height and (2) different exercise interventions on CMJ height in subjects, who were specifically described as strength and/or power trained. According to recommendations from previous literature [36, 56, 57], participants were defined strength and/or power trained if they have been classified as individuals with strength and/or plyometric training experience by the respective study authors or if they participated in regular structured training programs for at least 3 months prior to the intervention period.

From initial scanning, a meta-analytical approach to the data of different exercise interventions on CMJ height in non-strength and/or power trained subjects was considered inappropriate for the analysis, given the low number of studies (n = 6) [49, 58–62] as well as the lack of sufficient study population characteristics based on the training experience (n = 5) [48, 50, 63–65]. Similar to previous studies [36, 56, 57], participants were defined non-strength and/or power trained, if they were reported to be individuals with no strength and/or plyometric training experience by the respective study authors or if they reported no involvement in regular physical activity for at least 3 months prior to the intervention period. If the study authors failed to provide sufficient information on training status of the participants in their studies, or classification of participants was unclear, the respective study was not included into the subgroup analyses.

The network meta-analyses were completed using a random-effects model. Random-effect models consider the variability of studies and do not require between-study homogeneity. Therefore, they allow for differentiating the true intervention effect between each included study [66]. With possible different true intervention effects from each study, random-effect models give a summary effect, representing an estimation of the mean of this distribution of true effect sizes. Mean difference (MD) and its 95 % confidence intervals (95 % CI) were outlined for every intervention compared to each other and control. Participants were defined as controls when they served as control persons without performing any intervention in the respective studies [67]. Following the evaluation of the interventions' comparative effect, each one was ranked to identify if one intervention was superior to another. The ranking was performed by applying P-scores. P-scores are based solely on the point estimates and standard errors of the network estimates. They compare all different interventions and measure the probability to which extent a specific treatment is better than another one [68].

A critical tool to determine the applicability of NMA results is testing for consistency. Consistency assumes that the treatment effects estimated from direct comparisons do not differ from those effect estimates of indirect comparisons. To assess each network's consistency assumption, a global approach that calculates the regression coefficient of each study design's inconsistency model was used first. Then, the Wald test, which tests the regression coefficients' linearity for all models, was applied [69]. If there was agreement (p-value > 0.05), a local approach was used and side-splitting was applied to further assess the inconsistency of each treatment. The probability of "small study bias", where smaller studies contribute different or greater treatment effects than more extensive trials, was evaluated using comparison-adjusted funnel plots. This procedure was applied to comparisons, where at least ten studies were obtainable. A frequentist framework using the R package "netmeta" (V.1.2–1) was applied to all NMA models. In a frequentist method, the available data are repeated infinitely based on a general statistical theory, and the probability of significance, known as the p-value, and the CI is calculated. Based on this statistic method, the research hypothesis is discarded or accepted. Furthermore, the frequentist approach is independent of external information,

▶ **Table 1** Study characteristics of included studies.

Author and year	Population		Training program					
	Sample size (n), sex and age (years) [mean ± SD]	Subjects	Set structure (number of subjects per set structure)	Strength training	Power training	Frequency (times/week)	Training duration (weeks)	Results CMJ height (cm) pre-/postintervention [mean ± SD]
Alemdaroglu et al. (2013)	24 MW (21.6 ± 2.3)[a]	Recreational trained students with experience in resistance and plyometric training	CPX (8)	CPX, CT and TT: 3 × 6 reps of split squats, leg-press and leg-curls at 85–90 % of 1-RM; rest periods of 1 min between sets and 2 min between exercises	CPX, CT and TT: 3 × 6–12 reps of split jumps, SJs and front tuck jumps	2	6	CPX (33.6 ± 1.2/36.2 ± 1.1)
			CT (8)					CT (29.5 ± 1.3/32.5 ± 1.2)
			TT (8)					TT (31.2 ± 1.1/35.2 ± 1.0)
Ali et al. (2019)	36 M (21,4 ± 0.3)[a]	Soccer players (students) with experience in resistance training	CPX (12)	CPX: 3 × 12 reps of squats, barbell lunges, lateral lunges, and calf raises at 80 % of 1-RM ST 3 × 12 reps of squats, barbell lunges, lateral lunges, and calf raises at 40–80 % of 1-RM; rest periods of 1 min between sets	CPX: 3 × 12 reps of DJs, split squat jumps, lateral hops and calf jumps	3	6	CPX (46.9 ± 4.8/50.7 ± 4.9)
			ST (12)					ST (41.9 ± 4.6/45.1 ± 4.7)
			CTRL (12)					CTRL (43.9 ± 6.9/44.3 ± 6.9)
Arabatzi et al. (2010)	36 M (20.3 ± 2.0)	Active physical education students with experience in resistance and plyometric training	CPX (10)	CPX and ST: 4–6 × 4–6 reps of snatches from a squat position, high pulls, power cleans, and squats at 75–90 % of 1-RM; rest periods of 3 min between sets in CPX and ST, not reported for PW	CPX and PW: 4–6 × 6 reps of double-leg hurdle hops, alternated single-leg hurdle hops, double-leg hops, and half-squats	3	8	CPX (34.4 ± 8.3/39.6 ± 8.6)
			PW (8)					PW (31.5 ± 6.3/36.1 ± 6.4)
			ST (9)					ST (34.6 ± 7.5/39.8 ± 6.8)
			CTRL (8)					CTRL (33.3 ± 5.2/35.2 ± 5.8)
Arazi et al. (2014)	24 W (20.7 ± 0.7)[a]	Untrained women with experience in resistance and plyometric training	CPX (7)	CPX, ST and CP: 3 × 6 reps of squats, knee-extensions, knee-flexions and single-leg lunges at 60 % of 1-RM; rest periods of 1 min between sets	CPX and PW, CP: 3 × 6 reps of DJs, CMJs, 10 m zigzag drill and lunge jumps	2	6	CPX (25.6 ± 4.5/30.2 ± 4.4)
			PW (8)					PW (26.1 ± 3.0/31.2 ± 3.3)
			ST (7)					ST (23.1 ± 4.3/27.8 ± 5.3)
			CP (7)					CP (24.8 ± 3.8/31.8 ± 2.5)

▶ **Table 1** Continued.

Author and year	Population		Training program					
	Sample size (n), sex and age (years) [mean ± SD]	**Subjects**	**Set structure (number of subjects per set structure)**	**Strength training**	**Power training**	**Frequency (times/week)**	**Training duration (weeks)**	**Results CMJ height (cm) pre-/postintervention [mean ± SD]**
Caterisano et al. (2018)	28 M (18.8 ± 0.4)	College footballer (NCAA Division I) with experience in resistance training	TT (14)	TT: 2–4 × 3–12 reps of back squats, front squats power snatches, power cleans, bench press and medicine ball throws at 50–65 % of 1-RM (ST) 4–8 × 3–9 reps of back squats, cleans and presses, bench press and jammers with 56,82 kg; rest periods not reported	TT: 3 × 5 reps of box jumps	4	5	TT (57.9 ± 8.9/64.5 ± 7.9)
			ST (14)					ALT [ST] (68.1 ± 6.9/74.9 ± 6.6)
De Villarreal et al. (2011)	65 MW (20.0 ± 2.7)[a]	Physical education students	CPX (14)	CPX: 3 × 3–6 reps of squats at 60–86 % of 1-RM and additional lower-body exercises with diverse intensities ST: 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; rest periods not reported	CPX and PW: 4–8 × 5 reps of CMJs	3	7	CPX (40.0 ± 8.9/43.4 ± 8.2)
			ST (39)[b]					PW (37.5 ± 5.5/40.7 ± 5.8)
			PW (12)					ST (37.4 ± 6.7/41.1 ± 7.1)[b]
Faude et al. (2013)	16 M (22.5 ± 2.5)	Third Swiss league soccer players	CT (8)	CT: 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; rest periods of 4 min between sets on day 1, and of 1–2 min between sets on day 2	CPX: 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	CT (40.2 ± 4.8/41.4 ± 3.5)
			CTRL (8)					CTRL (43.0 ± 2.1/39.8 ± 2.4)

▶ **Table 1** Continued.

Author and year	Population		Training program					
	Sample size (n), sex and age (years) [mean ± SD]	Subjects	Set structure (number of subjects per set structure)	Strength training	Power training	Frequency (times/week)	Training duration (weeks)	Results CMJ height (cm) pre-/postintervention [mean ± SD]
Hammami et al. (2019a)	28 F (16.6 ± 0.3)	Handball players (elite-level) with some experience in resistance training	CT (14)	CT: 4 × 6–8 reps of half squats, leg-press, isometric half squats, calf raises at 75–90 % of 1-RM; rest periods of 1–2 min between sets	CT: 6 reps of hurdle jumps + 10 m sprint, 6 horizontal jumps + 10 m sprint, 3 single leg hops + 10 m sprint, 6 hurdle jumps with legs extended + 10 m sprint	2	10	CT (28.1 ± 1.6/33.8 ± 1.6)
			CTRL (14)					CTRL (27.0 ± 3.5/28.1 ± 3.4)
Hammami et al. (2019b)	40 M (15.8 ± 0.4)	Soccer player (elite-level)	CT (14)	CT: 3–5 × 3–8 reps of half squats at 70–90 % of 1-RM (ascending and descending sets); rest periods not reported	CT: 3–5 × 3 reps of CMJs (week 1–4), 3–5 × 1 rep of CMJ + 15 m sprint (week 5–8) PW 5–10 × 7–10 reps of hurdle jumps (week 1–4), 4 × 7–10 reps of DJs (week 5–8)	2	8	CT (38.2 ± 2.1/47.0 ± 5.9)
			PW (14)					PW (36.9 ± 3.9/42.1 ± 6.0)
			CTRL (12)					CTRL (37.9 ± 5.4/37.2 ± 4.5)
Herrero et al. (2010)	29 M (20,9 ± 2,1)[a]	Physical education students	CP (8)	CP: 8 × 10 reps of knee extension at 70 % of 1-RM ST/PW 8 × 10 reps of knee extension with EMS; rest periods of 3 min between sets	CP and ST/PW: 90 total reps of DJs and horizontal jumps (week 1–2), 105 total reps of DJs and horizontal jumps (week 3–4)	4	4	CP (37.6 ± 1.7/38.9 ± 3.2)
			ST/PW (11)					ST/PW (42.5 ± 7.0/42.8 ± 7.3)
			CTRL (10)					CTRL (34.7 ± 5.8/33.4 ± 5.0)
Juarez et al. (2009)	16 M (19.7 ± 1.7)[a]	Active undergraduate students with no specific strength training experience	CT (8)	CT: 2 × 4 reps of squats at 70–85 % of 1-RM ST/PW 4–5 × 4–8 reps of squats at 70–85 % of 1-RM (week 1–4); rest periods of 3–5 min between sets	CT: 2 × 5 reps of CMJs, hurdle jumps, or DJs combined with 2 × 20 m sprints ST/PW: 4–5 × 5 reps of CMJs, DJs, or box jumps combined with 4–5 × 2 reps of 20 m sprints (week 5–8)	2	8	CT (45.9 ± 5.8/51.3 ± 6.6)
			ST/PW (8)					ST/PW (46.1 ± 5.6/48.6 ± 6.2)

▶ **Table 1** Continued.

Author and year	Population		Training program					
	Sample size (n), sex and age (years) [mean ± SD]	Subjects	Set structure (number of subjects per set structure)	Strength training	Power training	Frequency (times/week)	Training duration (weeks)	Results CMJ height (cm) pre-/postintervention [mean ± SD]
Kijowski et al. (2015)	18 M (21.2 ± 1.2)	Male subjects with a minimum experience of 24 months in recreational strength and power training	TT (9)	TT: 3 × 3 reps of squats at 90 % of 1-RM; rest periods of 2 min between drop jump sets, and 5 min between squat sets	TT: 5 × 6 reps of DJs	2	4	TT (46 ± 8.0/49 ± 6.0)
			CTRL (10)					CTRL (47 ± 6.0/44 ± 5.0)
Kobal et al. (2016)	27 M (18.9 ± 0.6)	Soccer players (first Brazilian division) without experience in resistance or plyometric training	CPX (9)	CPX, CT and TT: 3–5 × 6–10 reps of squats at 60–80 % of 1-RM; rest periods of 3 min between sets and exercises	CPX, CT and TT: 3–5 × 10–12 reps of DJs	2	8	CPX (37.8 ± 4.5/42.9 ± 4.7)
			CT (9)					CT (37.3 ± 4.1/42.8 ± 3.3)
			TT (9)					TT (37.2 ± 4.7/42.5 ± 4.9)
Krishna et al. (2019)	42 M (20,8 ± 2,9)[a]	State and top division-level cricket fast bowlers	TT (21)	TT: 3 × 8–10 reps of squats, lunges, trap bar deadlifts, single-leg hip thrusts, hamstring curl, planks (week 1–3), front squats, step-ups, trap bar deadlifts, single leg Romanian deadlifts, hamstring curls, planks (week 4–6), squats, step-ups, kettlebell swings, single leg Romanian deadlifts, hamstring curls (week 7–9), squats, lateral lunges, trap bar deadlifts, single leg Romanian deadlifts, hamstring curls, back extension (week 10–12) at 75 % of 1-RM; rest periods of 1 min between sets	TT: 3 × 8 reps of SJs, hurdle jumps, hurdle hops (week 1–3), broad jumps, hurdle jumps, hurdle hops (week 4–6), single-leg box jump, lateral bounds, hurdle hops (week 7–9), box jumps, bounding, hurdle hops, rotational vertical hops (week 10–12)	3	12	TT (3.7 ± 3.6)[c]
			CTRL (21)					CTRL (0.6 ± 1.1)[c]

▸ **Table 1** Continued.

Author and year	Population		Training program					
	Sample size (n), sex and age (years) [mean ± SD]	**Subjects**	**Set structure (number of subjects per set structure)**	**Strength training**	**Power training**	**Frequency (times/week)**	**Training duration (weeks)**	**Results CMJ height (cm) pre-/postintervention [mean ± SD]**
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	CPX (11)	CPX: 1–3 × 6–10RM of bench press and squats; rest periods not reported	CPX: 1–2 × 4 reps of medicine ball throws and DJs PW 2–6 × 8 reps explosive bench press and SJs at 30 % of 1-RM	2	8	CPX (52.8 ± 11.5/58.4 ± 9.3)
			PW (11)					PW (50.8 ± 9.0/54.6 ± 8.5)
			CTRL (11)					CTRL (49.2 ± 3.5/49.2 ± 5.7)
Perez-Gomez et al. (2008)	37 M (23.9 ± 0,3)[a]	Physical education students with no strength training for at least six months	TT (16)	TT: 1–3 × 2–12 reps of leg-press, leg-extensions, half squats and leg-curls at 50–90 % of 1-RM; rest periods not reported	TT 4–9 × 5 reps of DJs and hurdle jumps	3	6	TT (36 ± 4.0/39 ± 4.0)
			CTRL (21)					CTRL (34 ± 4.5/34 ± 4.5)
Robineau et al. (2017)	30 M (26,3 ± 0,5)[a]	Amateur rugby sevens players with a minimum of two-year resistance training experience	CP (19)[b]	CP and ST: 3 × 3–10 reps of half squats, leg-extension, deadlifts, bench press, and bench row at 70–90 % of 1-RM; rest periods of 2–3 min between sets	CP: 4 x 30 s sprints or 2 x 8 min 30/30 s sprints (week 1–3), 6 x 30 s sprints or 2 x 10 min 30/30 s sprints (week 4–6), 8 × 30 sprints or 2 x 12 min 30/30 s sprints (week 7–9)	4	8	CP (32.6 ± 3.8/33.9 ± 4.2)[b]
			ST (11)					ST (31.3 ± 4.7/34.2 ± 4.9)
Ronnestad et al. (2008)	21 M (22.7 ± 2.0)[a]	Norwegian premier league soccer players with experience in strength training	CPX (8)	CPX and ST: 3–5 × 4–6RM of squats and hip flexion exercises; rest periods of 1 min between sets (only reported for jumps during CPX), not reported for ST and general strength exercises	CPX: 2–4 × 10 reps of alternate leg bounds, 2 × 5 reps of double-leg hurdle jumps and single-leg forward hops	2	7	CPX (36.0 ± 5.6/36.7 ± 5.3)
			ST (6)					ST (32.9 ± 1.9/33.9 ± 1.4)
			CTRL (7)					CTRL (36.0 ± 2.3/35.7 ± 3.7)
Santos et al.(2008)	25 M (14,5 ± 0.1)[a]	Basketball players without experience in resistance or plyometric training	CPX (15)	CPX: 2–3 × 10–12RM of leg-extensions, pullovers, leg-curls, decline press, leg-press and latissimus pulldowns; rest periods of 1–3 min between sets, 15–60 s between exercises	CPX: 2–3 × 5–15 reps of different plyometric drills	2	10	CPX (29.8 ± 5.9/33.0 ± 6.2)
			CTRL (10)					CTRL (30.7 ± 5.1/28.4 ± 4.0)

▶ **Table 1** Continued.

Author and year	Population		Training program					
	Sample size (n), sex and age (years) [mean ± SD]	**Subjects**	**Set structure (number of subjects per set structure)**	**Strength training**	**Power training**	**Frequency (times/week)**	**Training duration (weeks)**	**Results CMJ height (cm) pre-/postintervention [mean ± SD]**
Smith et al. (2014)	28 MW (20–29)	Recreational athletes with regularly moderate-to-vigorous physical activity for at least 3 months	CT (19)[b]	CT: 3 × 4–6RM of squats or kettlebell swings; rest periods of 3 min between sets	CT: 3 × 5 reps of CMJs	3	6	CT (52.5 ± 12.4/57.6 ± 12.9)[b]
			CTRL (9)					CTRL (53.1 ± 8.4/55.4 ± 11.4)
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	CPX (9)	CPX and TT: 3–4 × 3–8RM of half squats; rest periods of 4 min between squat sets, and 3 min between jump sets	CPX and TT: 3–4 × 4 reps of SJs	2	9	CPX (43.1 ± 3.9/46.6 ± 5.0)
			TT (11)					TT (41.9 ± 5.2/45.9 ± 4.3)
Trecroci et al. (2020)	18 M (14.2 ± 0.2)[a]	Sub-elite soccer players without experience in structured and advanced strength and plyometric training	CP (9)	CP: 3 × 15 reps (4–6 RIR) of front squats, hip thrusts and alternating side lunges at 60 % of 1-RM + 30 s of plank, standing superman and side plank; unclear reporting of rest periods (work to rest ratio 1:2 plus 2 min additional rest between sets)	CP: 4–6 × 5 reps of double-leg hurdle jumps + 5 m sprint and diagonal bounds + 5 m sprint	2	5	CP (47.11 ± 3.5/49.22 ± 3.5)
			CTRL (9)					CTRL (46.59 ± 4.6/46.79 ± 4.1)
Tricoli et al. (2005)	32 M (22 ± 1.5)	Physical education students with experience in strength training	TT (12)	TT: 4 x 6RM of half squats ST: 3–4 × 4–6RM of high pulls, power cleans, clean and jerks and half squats; rest periods not reported	TT: 4–10 × 4 reps of double-leg hurdle hops, alternated single-leg hurdle hops, single-leg hurdle hops and DJs	3	8	TT (40.2 ± 3.9/ ± 42.5 ± 3.0)
			ST (12)					ST (42.2 ± 2.1/45.0 ± 2.6)
			CTRL (12)					CTRL (42.2 ± 4.9/42.6 ± 5.2)

▶ **Table 1** Continued.

Author and year	Population		Training program					
	Sample size (n), sex and age (years) [mean ± SD]	**Subjects**	**Set structure (number of subjects per set structure)**	**Strength training**	**Power training**	**Frequency (times/week)**	**Training duration (weeks)**	**Results CMJ height (cm) pre-/postintervention [mean ± SD]**
Zsis (2013)	21 M (17.1 ± 1.1)	Amateur soccer players with a minimum experience of twelve months in conditioning programs	CP (7)	CP and ST: 3 × 10 reps of leg-press, knee-extensions, squat at 80 % of 1-RM; rest periods of 3 min between sets, and 1 min between exercises	CP and PW 2–3 × 10 reps of DJs, split squat jumps, elastic jumps, vertical and horizontal jumps	2	8	CP (39.8 ± 3.3/42.4 ± 7.1)
			ST (7)					ST (36.6 ± 4.5/39.1 ± 6.6)
			PW (7)					PW (37.3 ± 4.3/38.6 ± 2.3)

1-RM, one repetition maximum; cm, centimeter; CMJ, countermovement jump; COD, change of direction; CPX, complex training; CTRL, control group; DJ, drop jump/depth jump; EMS, electromyostimulation; kg, kilogram; m, meter; min, minute(s); M, male only; MW, male and female together; PW, power training; reps, repetition; RIR, repetitions in reserve; RM, repetition maximum; s, seconds; SD, standard deviation; SJ, squat jump; ST, strength training; TT, traditional training; W, female only 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) × sd1^2 + (n2 − 1) × sd2^2 + n1 × (m1 − m)^2 + n2 × (m2 − m)^2)/(n1 + n2 − 1)]. b: Data from groups carrying out the same set structure were combined c: Only changes from baseline were reported

leading to an already defined probability that the research hypothesis is valid within the available data. Therefore, the choice of acceptance or rejection of the research hypothesis is solely made based on the p-value or the CI [69].

Results

Selection process

The flow of the systematic review is presented in ▶ **Fig. 1**. The electronic database search lead to 3281 records after duplicates (n = 3447) were removed. Following the screening of titles and abstracts, 78 full-text records were assessed for eligibility. Fifty-four studies were excluded with reasons. Among the 24 studies included [46–50, 58–65, 70–80], ten incorporated CPX training [46–49, 59, 61, 70, 71, 76, 78], and seven included CT training [46, 49, 58, 63, 64, 73, 77], with five studies applying CP training [47, 62, 65, 75, 80] and eight TT training [46, 49, 50, 60, 72, 74, 78, 79]. Of these 24 studies, 13 [46, 47, 70–80] were considered suitable for the network, analyzing the influence of different exercise intervention trials on CMJ height in subjects with training experience in ST and/or PW. Six studies [49, 58–62] were used for the narrative analysis, examining the influence of different exercise intervention trials on CMJ height in subjects without training experience in ST and/or PW.

Characteristics of the included studies

A detailed summary of each individual study is presented in ▶ **Table 1**. The sample size in all exercise intervention RCTs ranged from n = 16 to n = 65 subjects. The ages of the subjects ranged from 14.2 to 26.3 years. Study duration ranged from four to twelve weeks and training sessions completed in the studies ranged from eight to 36. Most of the subjects in the included studies were men (84 %). The largest number of the subjects were involved in a total of ten exercise intervention RCTs evaluating CPX training compared to CTRL or another intervention defined previously. Overall, 694 individuals were included from which 346 were strength and/or power trained participants **(▶ Table 1)**.

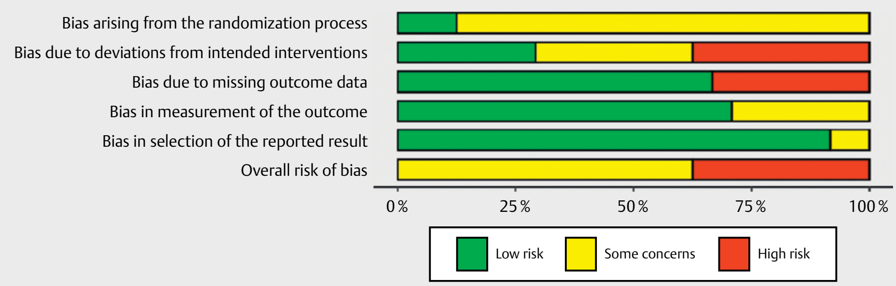
Risk of bias and certainty of the evidence

Most studies were at some concerns (62.5 %), with a high risk of bias in 37.5 % (▶ **Fig. 2** and **3**). Deviations from the intended intervention (37.5 %) and missing outcome data (33.3 %) were the most common bias sources. The certainty of the evidence for rating the quality of treatment effect estimates was low to very low for all comparisons. The downgrading of the comparison's evidence was done due to the risk of bias ("serious" to "very serious") and imprecision for all comparisons (100 %) (▶ **Table 2**). For the narrative analysis of studies that included only non-strength and/or power trained subjects, the level of evidence was downgraded due to the serious risk of bias limitations. Moreover, downgrading was executed for imprecision as the overall sample size was small. In conclusion, there is very low-quality evidence for different exercise interventions on CMJ height in subjects without training experience.

▶ **Fig. 2** Risk of bias judgement for each study examining the effects of different training set structures on countermovement jump height in healthy subjects with low risk of bias, some concerns, and high risk of bias for each domain of the Cochrane Risk of Bias 2 tool.

Comparative effects on CMJ height

Across all subjects, the analysis showed that all interventions were superior to control: CPX (MD = 2.87, 95 % CI: 1.99 to 3.74), CT (MD = 3.37, 95 % CI: 2.36 to 4.39), CP (MD = 3.38, 95 % CI: 2.07 to 4.68), TT (MD = 3.43, 95 % CI: 2.61 to 4.26) (▶ **Table 2**). Although the P-score indicated that ST (0.8892), TT (0.6998), CP (0.6937), and CT (0.6923) were the best interventions for improving CMJ height in all subjects (▶ **Table 3a**), only CPX was inferior to TT and to ST (MD = 0.56, 95 % CI: 0.18 to 0.95, and, MD = 0.75 95 % CI: 0.34 to 1.16, respectively) while TT was inferior to ST (MD = 0.18, 95 % CI: 0.03 to 0.33). No further specific intervention was superior to another (▶ **Table 4a**). In strength and/or power trained subjects, all interventions were effective in increasing CMJ height compared with control: CPX (MD = 3.08, 95 % CI: 1.58 to 4.58), CT (MD = 3.86,



▶ **Fig. 3** Percentage (%) of studies examining the effects of different training set structures on countermovement jump height in healthy subjects with low risk of bias, some concerns, and high risk of bias for each domain of the Cochrane Risk of Bias 2 tool.

95 % CI: 2.36 to 5.36), CP (MD = 3.81, 95 % CI: 1.81 to 5.80), TT (MD = 3.79, 95 % CI: 2.36 to 5.22) (▶ **Table 2**). The P-score indicated that the best treatments for improving CMJ height in subjects with training experience were CT (0.7443), TT (0.7394), CP (0.7124), and ST (0.6297) (▶ **Table 3b**). The NMA revealed that no specific intervention was superior to another intervention except for CPX, which was inferior to ST (MD = 0.51, 95 % CI: 0.65 to 1.68) (▶ **Table 4b**). The network-graph is presented in ▶ **Fig. 4**.

Overall, both the four different approaches, CPX, CT, CP, and TT, as well as the solely strength or power training interventions, achieved similar changes from baseline in comparison to control conditions across all analyses (▶ **Fig. 5**). There was no evidence of inconsistency between direct and indirect comparisons in both networks, where data from direct and indirect evidence were available. "Small study bias" could not be assessed due to the low number of trials.

Six studies [49, 58–62] investigated the effectiveness of different interventions on CMJ height in subjects without training experience. Three of them compared either TT, CPX, or CP with CTRL [60–62]. All of them supported the use of one of these interventions to increase CMJ height when compared to CTRL [TT (mean ± SD): 3.0 ± 3.6 cm; CTRL: 0.0 ± 4.0 cm; CPX: 3.2 ± 6.4 cm; CTRL: -2.3 ± 6.4 cm; CP: 2.1 ± 3.1 cm; CTRL: 0.2 ± 3.9 cm]. One study [49] compared CPX with CT and TT. Results suggested that each intervention was effective to increase CMJ height, but no intervention was superior (TT: 5.3 ± 4.3 am; CPX: 5.1 ± 4.1 cm; CT: 5.5 ± 3.4 cm). One study [59] compared CPX with PW and CTRL. CPX and PW were equally effective when compared to CTRL, but no intervention was superior (CPX: 5.6 ± 9.5 cm; PW: 3.8 ± 7.8 cm; CTRL: 0.0 ± 4.6 cm). One study [58] compared CT with solely ST or PW and showed that both interventions increased CMJ height, but CT was superior (CT: 5.4 ± 5.6 cm; ST or PW: 2.5 ± 5.3 cm).

Discussion

The purpose of this network meta-analysis was to determine the effects of CPX, CT, CP, and TT in comparison to each other, ST and/or PW alone, and control conditions, on CMJ performance. The results of 24 RCTs, including 694 healthy subjects, were incorporated. The analyses indicated that individuals performing either CPX, CT, CP, or TT significantly increased CMJ height compared to those of the controlled conditions (no training). However, compared to ST and/or PW alone or to each other, all interventions yielded similar improvements in both sets of NMAs.

To the best of the authors' knowledge, the present study is the first formal evaluation of the comparative effects of different exercise interventions on CMJ height. Previous systematic reviews and meta-analyses have examined the CMJ height effects of CPX, CT or their combination [17, 23, 24, 81, 82]. Similar to these reviews, the different training set structures in the present analysis varied broadly based on the number of exercises, volume, intensity, and duration. In a recent review and meta-analysis, Marshall et al. [28] suggested, that CT, CPX and TT are all useful to particularly target athletic properties. To increase force, the exercise should be carried out with an augmented level of fatigue leading to training close to failure. This can be induced by completing multiple sets of a comparable lighter exercise prior to the heavy exercise sets, which is defined as TT. Enhancing velocity of the lighter exercise can be achieved, e. g. by combining it with a heavier exercise in a contrast pair to generate a PAPE effect.

The present findings were in accordance with the meta-analyses by Pagaduan et al. [23], Pagaduan et al. [24], and Freitas et al. [81], revealing that both CPX and CT administer an appropriate training stimulus to improve CMJ height when compared to control conditions. A recent meta-analysis by Bauer et al. [17] with a large number of trials strengthens the present findings that no differences between CPX or CT and TT or CP, and alternative training methods such as ST or PW exist to improve CMJ performance. It should be noted that authors investigated combined CPX and CT compared to a combination of TT, CP, ST, and PW.

As mentioned before, ST alone was ranked as one of the best interventions while PW achieved similar effects for improving the CMJ height compared to other interventions both in the complete analysis and the exclusive analysis of subjects with training experience. These results are not surprising since both ST and PW alone can lead to an increase in muscular power and therefore to an improvement of vertical jump performance [83–85]. A growing body of evidence suggests muscular strength as the fundamental component to increase the athlete's performance, especially in terms of power production, velocity, and rate of force development, which is defined as the ability to produce large forces in a short time [86–89]. While these power gains become less distinct when higher muscular strength is achieved, some evidence suggests that squatting at least two times of a subject's bodyweight might be a

▶ **Table 2** Certainty of the evidence using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach.

All subjects	**Direct evidence**		**Indirect evidence**		**Network meta-analysis**	
	Mean difference (95 % CI)	**Quality of evidence**	**Mean difference (95 % CI)**	**Quality of evidence**	**Mean difference (95 % CI)**	**Quality of evidence**
Complex vs. Contrast	−0.40 (−1.41 to 0.61)	Low	−0.70 (−2.10 to 0.68)	Moderate	−0.50 (−1.32 to 0.31)	Low
Complex vs. Compound	2.40 (−1.31 to 6.11)	Moderate	0.26 (−1.05 to 1.58)	Moderate	0.50 (−0.73 to 1.75)	Low
Complex vs. Traditional	−0.64 (−1.04 to −0.25)	Moderate	0.64 (−0.88 to 2.17)	Moderate	−0.56 (−0.95 to −0.18)	Low
Complex vs. Strength	−0.02 (−1.87 to 1.81)	Moderate	0.79 (0.37 to 1.21)	Low	0.75 (0.34 to 1.16)	Low
Complex vs. Power	−0.10 (−2.60 to 2.38)	Moderate	−0.43 (−1.90 to 1.02)	Moderate	−0.35 (−1.61 to 0.91)	Low
Complex vs. Strength/Power	NA	NA	−1.31 (−4.65 to 2.01)	Low	−1.31 (−4.65 to 2.01)	Very Low
Complex vs. Control	3.34 (1.15 to 5.52)	Moderate	2.78 (to 1.82 to 3.74)	Low	2.87 (1.99 to 3.74)	Low
Contrast vs. Compound	NA	NA	0.00 (−1.38 to 1.38)	Moderate	0.00 (−1.38 to 1.38)	Low
Contrast vs. Traditional	−0.91 (−1.88 to 0.06)	Low	1.67 (0.27 to 3.06)	Moderate	−0.06 (−0.86 to 0.73)	Low
Contrast vs. Strength	NA	NA	0.24 (−0.56 to 1.05)	Low	0.24 (−0.56 to 1.05)	Very Low
Contrast vs. Power	−3.60 (−7.20 to 0)	Moderate	−0.37 (−1.89 to 1.14)	Low	−0.85 (−2.25 to 0.54)	Low
Contrast vs. Strength/Power	−2.90 (−8.24 to 2.44)	Moderate	−1.14 (−5.39 to 3.11)	Moderate	−1.82 (−5.15 to 1.50)	Low
Contrast vs. Control	5.25 (3.54 to 6.96)	Moderate	2.36 (1.10 to 3.62)	Low	3.37 (2.36 to 4.39)	Low
Compound vs. Traditional	NA	NA	−0.05 (−1.26 to 1.14)	Moderate	−0.05 (−1.26 to 1.14)	Low
Compound vs. Strength	0.02 (−1.48 to 1.52)	Moderate	0.63 (−1.34 to 2.61)	Moderate	0.24 (−0.95 to 1.44)	Low
Compound vs. Power	−1.45 (−2.94 to 0.04)	Moderate	1.02 (−1.64 to 3.70)	Moderate	−0.85 (−2.16 to 0.44)	Low
Compound vs. Strength/Power	−1.00 (−5.18 to 3.18)	Moderate	−3.22 (−8.66 to 2.21)	Moderate	−1.82 (−5.14 to 1.48)	Low
Compound vs. Control	2.22 (−0.16 to 4.61)	Moderate	3.87 (2.31 to 5.42)	Moderate	3.38 (2.07 to 4.68)	Low
Traditional vs. Strength	0.20 (0.05 to 0.34)	Low	−1.08 (−2.42 to 0.25)	Moderate	0.18 (0.03 to 0.33)	Low
Traditional vs. Power	NA	NA	−0.91 (−2.14 to 0.30)	Moderate	−0.91 (−2.14 to 0.30)	Low
Traditional vs. Strength/Power	NA	NA	−1.88 (−5.20 to 1.43)	Low	−1.88 (−5.20 to 1.43)	Very Low
Traditional vs. Control	3.04 (1.84 to 4.25)	Moderate	3.78 (2.65 to 4.90)	Moderate	3.43 (2.61 to 4.26)	Low
Strength and/or power trained						
subjects						
Complex vs. Contrast	−0.40 (−2.02 to 1.22)	Low	−1.51 (−3.78 to 0.74)	Low	−0.78 (−2.10 to 0.54)	Very Low
Complex vs. Compound	2.40 (−1.51 to 6.31)	Moderate	0.25 (−1.83 to 2.33)	Moderate	0.72 (−1.11 to 2.56)	Low
Complex vs. Traditional	−0.87 (−1.88 to 0.13)	Moderate	0.05 (−2.15 to 2.25)	Low	−0.71 (−1.62 to 0.20)	Low
Complex vs. Strength	−0.09 (−2.23 to 2.05)	Moderate	0.77 (−0.62 to 2.16)	Low	0.51 (−0.65 to 1.68)	Low

▶ **Table 2** Continued.

All subjects	**Direct evidence**		**Indirect evidence**		**Network meta-analysis**	
	Mean difference (95 % CI)	**Quality of evidence**	**Mean difference (95 % CI)**	**Quality of evidence**	**Mean difference (95 % CI)**	**Quality of evidence**
Complex vs. Power	0.20 (−3.00 to 3.42)	Moderate	−0.62 (−2.69 to 1.45)	Moderate	−0.37 (−2.12 to 1.37)	Low
Complex vs. Control	2.38 (−0.33 to 5.11)	Moderate	3.38 (1.58 to 5.18)	Moderate	3.08 (1.58 to 4.58)	Low
Contrast vs. Compound	NA	NA	−0.05 (−2.07 to 1.96)	Low	−0.05 (−2.07 to 1.96)	Very Low
Contrast vs. Traditional	−1.00 (−2.60 to 0.60)	Low	2.02 (−0.14 to 4.18)	Moderate	0.07 (−1.21 to 1.35)	Low
Contrast vs. Strength	NA	NA	−0.26 (−1.71 to 1.18)	Low	−0.26 (−1.71 to 1.18)	Very Low
Contrast vs. Power	−3.60 (−7.41 to 0.21)	Moderate	−0.36 (−2.53 to 1.80)	Low	−1.15 (−3.04 to 0.72)	Low
Contrast vs. Control	5.47 (3.44 to 7.51)	Moderate	1.94 (−0.27 to 4.16)	Low	3.86 (2.36 to 5.36)	Low
Compound vs. Traditional	NA	NA	0.01 (−1.75 to 1.78)	Low	0.01 (−1.75 to 1.78)	Very Low
Compound vs. Strength	0.00 (−1.70 to 1.71)	Low	−1.55 (−5.78 to 2.68)	Moderate	−0.21 (−1.79 to 1.37)	Low
Compound vs. Power	−1.48 (−3.25 to 0.29)	Moderate	1.11 (−3.19 to 5.41)	Moderate	−1.10 (−2.74 to 0.54)	Low
Compound vs. Control	NA	NA	3.81 (1.81 to 5.80)	Moderate	3.81 (1.81 to 5.80)	Low
Traditional vs. Strength	0.26 (−0.85 to 1.37)	Low	−1.54 (−3.46 to 0.37)	Moderate	−0.19 (−1.16 to 0.77)	Low
Traditional vs. Power	NA	NA	−1.08 (−2.78 to 0.60)	Moderate	−1.08 (-2.78 to 0.60)	Low
Traditional vs. Control	3.04 (0.19 to 5.89)	Moderate	4.04 (2.39 to 5.69	Moderate	3.79 (2.36 to 5.22)	Low
Non-strength and/or power trained						
subjects						
GRADE	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Quality
Rating	Serious	No	No	Yes	NA	Very Low

95 % CI, 95 % confidence interval; NA, not applicable.

good indicator of an optimal lower body strength standard, which may lead to more benefits of power exercises like plyometrics [3, 90–92]. Therefore, youth athletes and subjects without training experience might prioritize ST to build a solid base before focusing on PW or incorporating power exercises in their training plans, respectively [92, 93]. Taking these considerations into account, stronger and more strength and/or power trained subjects might benefit more from CPX, CT, CP, and TT than their weaker counterparts. This could not be shown in the present study's exclusive analysis of strength and/or power trained subjects, where the combined set structures were not superior to ST or PW alone.

Implications for research

The current research suggests several factors influencing the level of the PAPE effect in training practice. These factors include ideal parameters of conditioning activity, such as the optimal type of exercise, optimal intensity and volume, and rest periods [94]. Thereby, intensities range from plyometric body-weight to supramaximal loads. Moreover, individual characteristics of the subjects, involving training experience, the type of muscle fibers, muscle strength, and fatigue resistance are crucial. There is inconsistent evidence when strength training load and volume, as well as recovery periods are being discussed. PAPE effects occur over a wide range of intensities, with loads around 80 to 90 % 1-RM being the most investigated [94]. In the included studies of the present analysis, loads over 80 % 1-RM were primarily used in strength and/or power trained subjects (▶ **Table 1**). Studies with non-strength and/or power trained subjects usually used loads ≤ 80 % 1-RM. Evidence revealed that stronger and more strength and/or power trained athletes show considerably larger potentiation effects than their weaker and less trained counterparts [33, 40], suggesting that differences in strength and training experience contribute to PAPE effects. If non-strength and/or power trained subjects would show smaller PAPE effects, their CMJ height may be smaller compared to strength and/or power trained subjects, regardless of the type of training intervention. However, due to the low number of studies with non-strength and/or power trained subjects and the lack of sufficient study population characteristics based on the training

▶ **Table 3** P-score for CMJ height, a) when comparing all subjects, and b) when comparing strength and/or power trained subjects.

a) all subjects	
Intervention	**P-score**
Strength	0.8892
Traditional	0.6998
Compound	0.6937
Contrast	0.6923
Complex	0.4022
Power	0.3321
Strength/power	0.2647
Control	0.0259
b) strength and/or power trained subjects	
Intervention	**P-score**
Contrast	0.7443
Traditional	0.7394
Compound	0.7124
Strength	0.6297
Complex	0.3776
Power	0.2962
Control	0.0004

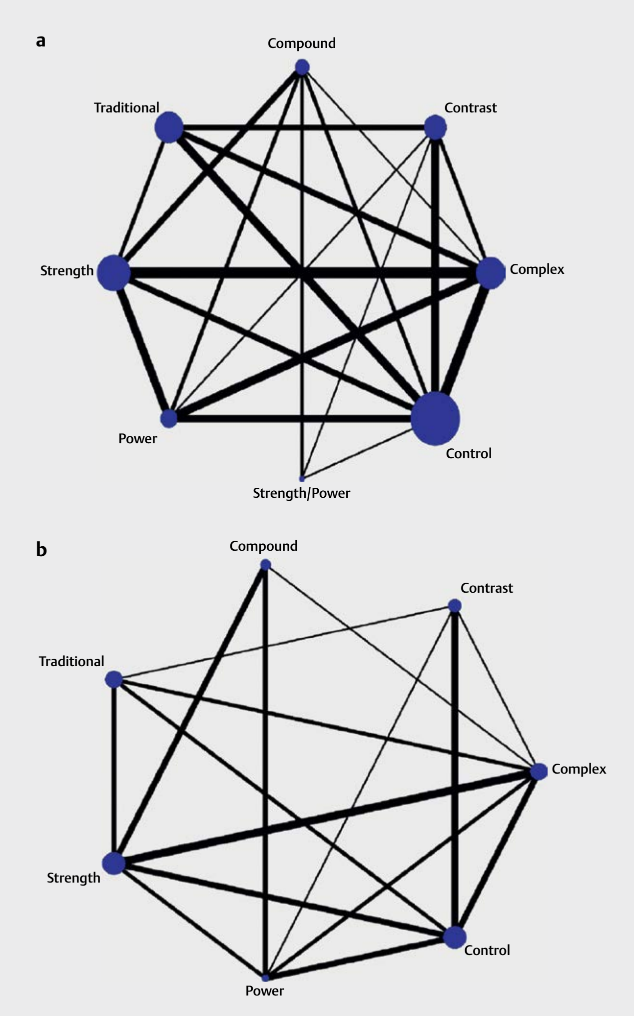
experience, analysis of non-strength and/or power trained subjects could only be carried out narratively. The present analysis of strength and/or power trained subjects showed no different effects on CMJ heights between the compared training interventions, concluding that all the analyzed regimes could be recommended to increase CMJ height, which is similar to findings reported recently [28]. A growing body of evidence indicates that training experience influences the outcomes achieved by ST and PW [95, 96]. While non-strength and/or power trained subjects may getting stronger and more athletic primarily through the neural adaptations, the influence of muscular strength on an athlete's performance may diminish when strength and/or power trained subjects already maintain high strength levels [92]. Future research should provide precise study population characteristics to distinguish between the effects the combination of ST and PW has on non-strength and/or power trained subjects and strength and/or power trained subjects.

The training volume is considered the number of performed repetitions, which may vary depending on movement speed, in a set or a complete session in addition to the time under tension [97, 98]. The number of repetitions and sets of the interventions varied between studies in the present analysis, leading to the assumption that strength and power training volume may not be the

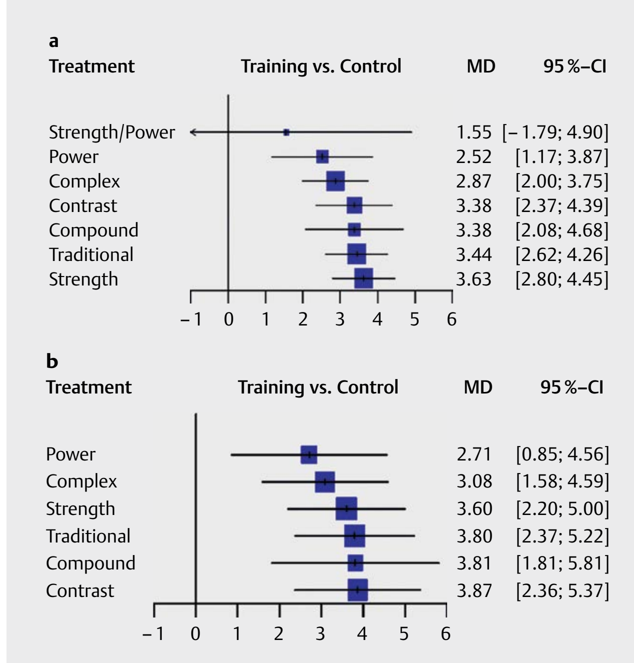
▶ **Table 4** Treatment effects for CMJ height. Change from baseline when comparing a) all subjects, and b) when comparing strength and/or power trained subjects.

a) all subjects							
Control							
2.87 (1.99 to 3.74)	**Complex**						
3.37 (2.36 to 4.39)	0.50 (−0.31 to 1.32)	**Contrast**					
3.38 (2.07 to 4.68)	0.50 (−0.73 to 1.75)	0.00 (−1.38 to 1.38)	**Compound**				
3.43 (2.61 to 4.26)	**0.56 (0.18 to 0.95)**	0.06 (−0.73 to 0.86)	0.05 (−1.14 to 1.26)	**Traditional**			
3.62 (2.79 to 4.45)	**0.75 (0.34 to 1.16)**	0.24 (−0.56 to 1.05)	0.24 (−0.95 to 1.44)	**0.18 (0.03 to 0.33)**	**Strength**		
2.52 (1.17 to 3.86)	−0.35 (−1.61 to 0.91)	−0.85 (−2.25 to 0.54)	−0.85 (−2.16 to 0.44)	−0.91 (−2.14 to 0.30)	−1.10 (−2.33 to 0.12)	**Power**	
1.55 (2.79 to 4.45)	−1.31 (−4.65 to 2.01)	−1.82 (−5.15 to 1.50)	−1.82 (−5.14 to 1.48)	−1.88 (−5.20 to 1.43)	−2.07 (−5.39 to 1.24)	−0.96 (−4.40 to 2.47)	**Strength/Power**
b) strength and/or power trained subjects							
Control							
3.08 (1.58 to 4.58)	**Complex**						
3.86 (2.36 to 5.36)	0.78 (−0.54 to 2.10)	**Contrast**					
3.81 (1.81 to 5.80)	0.72 (−1.11 to 2.56)	−0.05 (−2.07 to 1.96)	**Compound**				
3.79 (2.36 to 5.22)	0.71 (−0.20 to 1.62)	−0.07 (−1.35 to 1.21)	−0.01 (−1.78 to 1.75)	**Traditional**			
3.60 (2.20 to 4.99)	**0.51 (0.65 to 1.68)**	−0.26 (−1.71 to 1.18)	−0.21 (−1.79 to 1.37)	−0.19 (−1.16 to 0.77)	**Strength**		
2.70 (0.85 to 4.56)	−0.37 (−2.21 to 1.37)	−1.15 (−3.04 to 0.72)	−1.10 (−2.74 to 0.54)	−1.08 (−2.78 to 0.60)	−0.89 (−2.44 to 0.66)	**Power**	

Note: Mean differences (MD) with their 95 % confidence intervals from the network meta-analysis are shown; A negative MD value favors the upper-left treatment for any cell, and a positive MD value favors the lower-right treatment. Relative treatment effect differences are shown in bold type.



▶ **Fig. 4** Network meta-analysis demonstrating available evidence comparing (**a**) the influence of different interventions on countermovement jump (CMJ) height and (**b**) the influence of different interventions on CMJ height in strength and/or power trained subjects. The nodes represent different interventions and the lines connecting the nodes represent direct head-to-head randomized controlled trials comparing the interventions. The thickness of the lines and the size of the dots are proportional to the number of trial comparisons and the number of participants in the treatment arms, respectively.



▶ **Fig. 5** Findings of network meta-analyses. Change from baseline countermovement jump (CMJ) height (cm) and 95 % confidence interval (CI) achieved with training interventions as compared with control (no training). (**a**) influence of different interventions on CMJ height and (**b**) influence of different interventions on CMJ height in strength and/or power trained subjects.

main factor for improving CMJ height. The effects of PAPE on resistance training volume remain unclear, because they have only been investigated for the upper body [99], demonstrating the need for studies of the lower extremity.

The recovery periods of the CPX and CT interventions in the present study differed from current research recommendations on potentiation. It was reported, that it should last at least five minutes [33, 40]. Formerly, a recovery duration of eight to twelve minutes after the conditioning activity was reported to generate the greatest PAPE effect [100]. The included studies on CPX and CT interventions used average rest periods of about two minutes, ranging from 30 seconds to five minutes [46–49, 58, 59, 61, 63, 64, 70, 71, 73, 77, 78]. Therefore, athletes potentially elicited lower PAPE levels, which in turn could have been limiting their potential to adapt to CPX and CT interventions. However, in a recent study it was found that a PAPE recovery time course of one minute after squat sets within different contrast resistance training schemes revealed no adverse effect on subsequent drop jump performance when compared to a four minute recovery duration [101].

Limitations

This study has limitations that needed to be mentioned. First, the studies' quality was low with the possible risk of bias, which leads to limitations in terms of the informative value of the present findings. With high-quality studies, the certainty that the effect estimates from the analyses are the true effects is supposed to be higher. Then, altering the estimate would be less probable if more studies would be added. Unfortunately, large high-quality studies are rare in the field of sports science. This limitation was attempted to be overcome by using the GRADE approach. Since the quality of the evidence was low to very low in the present study, future modifications of the treatment rankings and the effect sizes should be considered.

Second, although the different interventions were well defined, the frequency, intensity, as well as exercises, total number of exercises, and training loads differed. This may have led to different adaptations of resistance training, as it is load specific, with higher loads leading to greater strength gains [18]. The optimal range is between 80 and 95 % of 1-RM [39]. However, ST has been defined as exercises involving the lower extremity with an average load > 60 % of 1-RM, as maximal strength gains are mainly achieved with training loads > 60 % of 1-RM [21]. Some interventions incorporated weightlifting exercises into strength training programs. Since power output is one of the primary goals of weightlifting, loads are selected with this goal in mind. Power is a product of force and velocity, and there is an inverse relationship between the two. In fact, it has generally been found that power output during weightlifting exercises is greatest at loads of 70 to 85 % of 1-RM for snatch or clean exercises [18, 22]. Although typical loads of 70 to 85 % of 1-RM are on the low end of the optimal range for strength gains (80 to 95 % of 1-RM), several studies suggest that when compared, both traditional strength training and weightlifting can lead to similar improvements in strength, power, and overall fitness [22, 102].

Studies in the present analysis reporting intensities on the lower spectrum (average training load of 60 %) are those with non-strength and/or power trained subjects. This is in accordance with Rhea et al. [96], who reported that subjects with no experience in resistance training make the most of their strength gains with mean intensities of 60 % of 1-RM. However, the influence of training frequency remains unclear. It seems that, especially in non-strength and/or power trained individuals, higher frequencies in terms of training volume are likely to result in greater muscle strength gains [103].

Conclusion

The present network meta-analysis confirms that CPX, CT, TT, and CP have a beneficial effect on CMJ performance compared to control condition (no intervention). However, none of these interventions seem to be superior compared to each other, or to strength or power training alone, or to strength and power training combined, in non-strength and/or power trained subjects as well as strength and/or power trained subjects. These conclusions can only be drawn from low to very low-quality evidence and should therefore be interpreted cautiously. Nonetheless, the present findings are mainly important for practitioners because the choice of how ST and PW exercises could be incorporated in one training regime might be decided on individual preference. Furthermore, coaches and athletes can potentially switch the approaches and bring greater variety to their training programs. More high-quality research on combined ST and PT should be conducted to confirm and possibly extend this systematic review results. Future studies should focus on longer intervention durations with clear distinction of non-strength and/or power trained participants and strength and/or power trained subjects. Further work is also needed to understand how PAPE can be maximized in terms of optimal load and volume, and recovery periods. In summary, the present findings support the combination of ST and PW to improve CMJ height in healthy subjects.

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Conflicts of Interest

The authors declare that they have no conflicts of interest relevant to the content of this review.

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