The Effect of Combined Strength Training on Vertical Jump Performance in Young Basketball Players: A Systematic Review and Meta-analysis

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ABSTRACT

Combined strength training is performed with a combination of plyometric exercises and traditional strength exercises. This training method with different protocols (such as complex training or contrast training) is used to develop vertical jump performance in basketball. Combined strength training is based on the theory of PAP, and physiological changes in the nervous musculature allow for acute performance enhancement. Included and excluded studies were determined according to PICOS criteria. The search was performed on the electronic databases of Google Scholar, PubMed, and Scopus between September 1-7, 2022. The effect of combined strength training on vertical jump performance in basketball was compared with different training methods and as a result, a moderate effect was found in favor of combined strength training (ES=1.11, (95%CI 0.63-1.60), I^2= 82%). As a result of systematic review and meta-analysis, it has been found that combined strength training applied in different forms in basketball is superior to other training methods in improving vertical jump performance. On the other hand, there is no superiority between the combined strength training protocols. Athletic performance specialists may improve jump performance by combining plyometric and traditional strength exercises in the same training season.

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INTRODUCTION

Basketball is a team sport played at intervals of 4 quarters, in which high-intensity movement patterns and low-intensity actions are performed together (1,2). Specific actions based on anaerobic metabolism and power, such as running, sprinting, reverse dribbling, rebounding, and blocking, which take place at varying intensity and speed, are essential variables that determine success in basketball (3–5). One of the most critical variables required to score in basketball, constituting the basis for many specific movement patterns, is the ability to jump. Researchers report that a basketball player performs 50 explosive vertical jumps during a game on average, relatively higher statistics when compared with other team sports (2,6). Jumping ability, one of the components of athletic performance, is associated with the athletes' muscle

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power. Researchers argue that athletes with higher muscle power have a better jumping height (7–10).

In basketball, jumping ability can be improved through training methods, including the stretch-shortening cycle and traditional strength training (11,12). However, the requirement for a specific time interval for the development of different levels of strength, busy competition periods, and the limited time allocated for strength training during weekly microcycles pose obstacles to the development of qualified strength (13–15). Trainers and researchers resort to combined strength training methods, which include a combination of different strength training methods, to eliminate these limitations; in this way, both maximal strength development and performance level can increase in many movement patterns involving explosiveness, such as jumping (16,17). In the design of combined strength training, a low-intensity plyometric exercise is generally preferred after a high-intensity strength exercise. In contrast, the basis of the training methods is based on the theory called postactivation potentiation (PAP) (18).

In the 1960s, Verkhoshansky made a training design using a combination of plyometric and traditional strength exercises, and he claimed that this design positively affected athletes' performance (19). In the following years, researchers conducted studies with similar exercise combinations and started to perform exercises at different loading intervals in the same training season (14). This combined strength training has taken various names according to the order of the exercise pairs during the training and the differences in the number of repetitions and sets (such as complex training, contrast training, and French contrast method). Contrast training is 1 set of high-intensity strength training followed by 1 set of low-intensity strength exercises. Similarly, complex training consists of 2–3 sets of high-intensity strength exercises followed by 2–3 sets of low-intensity strength exercises. However, a series of high-intensity strength exercises are performed at the beginning of the combined training. Then the training is finished with low-intensity strength exercises. Different loads are performed within the same training unit based on the PAP theory in these training methods. PAP is a temporary performance increase in muscle strength after a high-intensity exercise (18). It refers to the rise in electrical stimuli resulting from biological activity at repetitive frequencies in the nervous system. The researchers claimed that an acute increase in strength and power occurs after a maximal or near-maximal voluntary muscle contraction with PAP (55). The defined training method terms can be used interchangeably (14–17,19). However, systematic reviews and meta-analyses have evaluated training methods based on PAP theory by separating them from each other (15,20,21). This case creates a limitation in determining the effect of combined strength training on performance. In addition, there is no systematic review and meta-analysis in the literature addressing the effect of combined strength training on young basketball players.

This systematic review and meta-analysis aimed to compare the effect of combined strength training applied with different protocols, such as contrast and complex training, on vertical jump performance in young basketball players versus different training methods. In addition, this study aimed to determine the moderator variables that may affect the jumping performance of young basketball players and the predictive variables of vertical jump performance.

METHODS

The literature review of this systematic review and meta-analysis was carried out according to the guidelines set by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (22). Detailed information about the PRISMA checklist is in Supplemental Digital Content 1, http://links.lww.com/SCJ/A346. The protocol of this study was registered in the prospective international register of systematic reviews (PROSPERO) (code: CRD42022306065). The following statements form the problem statement of this research: What is the effect of strength training combined with basketball on vertical jump performance? However, answers to the following questions sought to identify moderator variables: In which jump test is the combined strength training more effective? In which age groups are combined strength training more effective? How many weeks of combined strength training should apply for the most effective jump performance impact? Which combined strength training protocol is more effective for jump performance? (contrast, complex, or combined); What is the effect of the combined strength training against the experimental and control groups?

ELIGIBILITY CRITERIA

The eligibility levels of the studies were determined through the Population, Intervention, Comparison, Outcomes, and Study Design (PICOS) approach. As a result of the preliminary examination, there was no combined strength training study with basketball players over 25 years in the literature. Therefore, young basketball players under 25 years were included in the study. Besides the PICOS approach, methodological quality scores were evaluated as eligibility criteria. Poor-quality studies were excluded because research findings could adversely affect meta-analysis outcomes. In this context, the inclusion and exclusion criteria of the research are reported in Table 1.

INFORMATION SOURCES AND SEARCH STRATEGY

Rayyan, an automation tool, carried out the literature review. The first search was electronically searched in different databases (Google Scholar, PubMed, Scopus, and Science Direct) between December 8, 2021 and January 21, 2022. The literature search was updated with the exact keywords and databases between September 1 and 7, 2022. Two authors (F.M.C., H.N.) were also part of the process to compare the results and to discuss possible nonconformity of articles found. In case of disagreement, they discussed inclusion and exclusion. In addition to expert opinions, systematic reviews were used to identify the keywords for the literature search. Boolean terms and keyword combinations were used for the literature search: basketball OR basketball player AND complex training OR contrast training OR compound training OR combine training OR combined resistance training and plyometrics AND "jump." In addition, the reference lists and citations of the selected studies were manually reviewed via Google Scholar to identify potential studies. After the literature search, reviewers collected selection studies in Mendeley Desktop software and removed duplications. Reviewers evaluated studies in title, abstract, and full-text details.

DATA EXTRACTION

Data extraction was performed by two researchers (Z.A., H.S.U.), whereas the third researcher (H.N.) ensured the control of the extracted data. Although data extraction was being performed using Microsoft Excel 16 software (Microsoft Corporation, USA), the researchers independently filled out the data form, which included the pretest and posttest results of, consecutively, authors (1), jumping test (2), groups (3), experimental and control groups (4), and the detailed information about training methods (5). In case of disagreement among the researchers, a meeting was held. During the meeting, the studies through which numerical values could not be accessed and the ones urging disagreement were discussed. Consequently, the authors of the relevant studies were contacted over ResearchGate, and thus, the disagreements were resolved (23,24). The reliability of the data extracted by 2 reviewers was evaluated through the interclass correlation coefficient (ICC) test. Although 0.90–1 values in the ICC test indicate a high agreement (25), the agreement between the researchers was 0.92, and the extracted data were seen to have high reliability.

DATA ITEMS

During the literature search, 3 data items were searched in the publications. These are combined strength training, basketball, and jumping ability. Attention has been paid to studies combining high-intensity strength exercises with low-intensity exercises for combined strength training. Combined strength training studies that did not test vertical jump performance were not analyzed. The data of basketball players over 25 years were removed from the study. Data items only tested by 1 study, such as the Sargent jump, were not included in the analysis. Among the included studies, only 1 study was conducted with female basketball players. Therefore, an analysis of gender differences was not conducted. Code lines were scanned only with randomized and controlled articles. Only English data items were evaluated to avoid search bias.

METHODOLOGICAL QUALITY OF STUDIES

The methodological quality of the studies included in this systematic review and meta-analysis was determined by the Tool for the Assessment of Study Quality and Reporting in Exercise (TESTEX) scale (26). The TESTEX scale consists of 12 quality criteria, and the studies that meet all the criteria get 15 points (26). The included studies were graded within the range of 0–15 points by the quality criteria, and the following reference values expressed the quality level of a study: poor quality for points 4 and below, medium quality for 4–7, good quality for 8–11, and excellent quality for 11 and above (27). At the end of the evaluation, 2 studies were excluded from the research (28,29) because they were of inadequate quality. The details of quality evaluations are seen in Table 2. Two authors (O.D. and S.K.) independently scored the articles based on the criteria. The final scores were compared after the presence of a third author (F.M.C.), and any disagreement was discussed and solved in debate with the third author.

CERTAINTY ASSESSMENT

Two researchers (O.D., Z.A.) independently performed the Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) scale to determine the level of evidence from the meta-analysis results. Study outcomes were evaluated on the following 5 criteria: risk of bias, imprecision, inconsistency, indirectness, and publication bias. These criteria were scored according to the level of importance.

STATISTICAL ANALYSES

This research used R software (Version 4.1.0) for meta-analysis applications, whereas intercoder reliability analysis was performed using SPSS (Version 20). Although different package programs are required to analyze with R software, meta, metaphor, and dmetar packages were used to apply this meta-analysis (30–32).

Because many factors other than combined strength training affect jumping ability, the random effect model was preferred to estimate the overall effect size (33). The standardized mean difference (SMD) was used to combine the data to estimate the effect size; however, the SMD was weighted accordingly to the inverse variance method (34). The individual effect size of the included studies was estimated through Cohen's d formula (35), $d = \frac{M_1 - M_2}{SD_{pooled}}$. For the interpretation of the effect size, the reference values created by Hopkins et al. (36) were taken into consideration: trivial (<0.2), small (0.2–0.59), moderate (0.60–1.19), large (1.2–1.99), or very large (>2).

Interstudy heterogeneity was assessed by using the I^2 test, and the heterogeneity was reported with percentile

Table 1
Inclusion and exclusion criteria according to PICOS

Parameter	Inclusion criteria	Exclusion criteria
Population	Healthy, younger than 25 years, male and female competitive basketball players	Amateur or professional-level athletes performing in various sports branches other than basketball
Intervention	Combined strength workouts through high-intensity and low-intensity strength exercises (complex training, contrast training, compound training, combined training, etc.)	Training methods that include only plyometric workouts and traditional strength workouts, or the ones not including the exercise combinations of different intensities
Comparator	Combined strength training versus traditional strength training and basketball-only training	Studies carried out with a single experimental group
Outcome	Studies evaluating the jumping height through combined strength training with vertical jump test	Studies that do not evaluate jumping ability through combined strength training or only perform descriptive testing
Study design	Randomized and controlled trials	Dissertations, unpublished papers, and noncontrolled trials
Methodology quality of study	Studies with a score of 5 or more according to the TESTEX scale	Studies with a score of 4 or less according to the TESTEX scale

reference values: low magnitude (<25%), medium magnitude (25–75%), and high magnitude (>75%) (37). Egger's and Rosenthal's failsafe N tests were applied to check the publication bias of the included studies' funnel plot asymmetry (38,39).

Extreme values were determined by performing sensitivity analyses in this meta-analysis because the calculated overall effect size was proven not to depend on just a few studies, a possible cause of heterogeneity existed, and it impacted publication bias (40,41). In the dmetar package, influence.analysis" and find.outliers functions were used to control outliers. Overall effect size (ES) and publication bias analyses were performed with and without extreme values. Alternative approaches have been developed to reduce the effect of extreme values in the meta-analysis (42,43). One of these approaches, the restricted maximum likelihood estimation (REML) method, was used to reduce the effect of extreme values in estimating variance between studies (44).

Training duration, age, groups compared, and jumping tests were evaluated as moderators that could affect the main effect, so subgroup and meta-regression analyses were performed

Table 2
Quality score of the included studies according to the TESTEX scale

Study	Criteria												Total TESTEX score
	1	2	3	4	5	6	7	8	9	10	11	12	
Andrejic (45)	0	1	**0**	1	**0**	2	**0**	2	1	**0**	1	1	11
Bayram (28)	0	1	**0**	0	**0**	0	**0**	0	1	**0**	1	1	4
Freitas et al. (47)	0	1	**0**	1	**0**	2	**0**	1	1	**0**	1	1	8
Gonzalo Skok et al. (68)	0	1	**0**	1	**0**	3	**0**	2	1	**0**	1	0	9
Inovero & Pagaduan (29)	0	1	**0**	0	**0**	0	**0**	0	1	**0**	1	1	4
Kukric et al. (70)	0	0	**0**	1	**0**	1	**0**	2	1	**0**	0	0	5
Kukric et al. (69)	0	0	**0**	1	**0**	1	**0**	2	1	**0**	0	1	6
Latorre Roman et al. (46)	0	1	**0**	1	**0**	2	**0**	2	1	**0**	1	1	9
Rajaram (71)	0	1	**0**	0	**0**	0	**0**	2	1	**0**	0	1	5
Roden et al. (72)	0	1	**0**	1	**0**	1	**0**	2	1	**0**	1	0	7
Sánchez-Sixto et al. (23)	1	1	**0**	1	**0**	0	**0**	2	1	**0**	1	1	8
Santos & Janeıra (12)	0	1	**0**	1	**0**	1	**0**	2	1	**0**	1	1	8
Tsimahidis et al. (24)	1	1	**0**	1	**0**	1	**0**	2	0	**0**	1	1	8

Note: 4 point and below: Poor quality; 4-7 point: Medium quality; 8–11 point: Good quality; 11 and above: Excellent quality. TESTEX, Tool for the Assessment of Study Quality and Reporting in Exercise.

over these moderator variables. In all analyses, the confidence interval (CI) was accepted as 95%, and the assessment was fulfilled over the $p < 0.5$ value, the statistical significance level.

RESULTS

STUDY SELECTION

The literature review was carried out through different databases, resulting in 1,596 articles to be accessed, while 3 articles were additionally obtained through citation searches and reference lists. After excluding the duplication and the articles written in different languages, the titles and abstracts of 1,056 articles were examined for eligibility. As a result, 1,031 articles were excluded, and 25 articles were evaluated in full detail according to the inclusion and exclusion criteria through literature review and other screening processes. After the study selection process, although 11 articles (12,23,24,45–47,68–72) met the eligibility criteria (Figure 1) 2 articles (28,29) were excluded from this systematic review and meta-analysis because they did not meet the quality criteria. As a result, a meta-analysis was carried out with 11 studies.

CHARACTERISTICS OF INCLUDED STUDIES

This systematic review and meta-analysis included 12 combined strength training groups, 7 traditional strength training groups, and 6 control groups that only performed basketball training. The number of participants in the groups ranged from 8 to 30. These groups were compared over 28 test protocols. Eight hundred thirty-three participants were included in the study. The combined strength training sample size was 433, and the sample size of different training groups was 399. Combined strength training consisted of various protocols such as complex training, contrast training, and combined training. Different training methods contained traditional strength training and basketball training. Young male basketball players were 82% of the participants (12,24,45,47,68–72). Although one study was conducted with young female basketball players (23), the other study was performed with a mixed group of participants (46). Detailed information on the characteristics of the included studies is given in Table 3 and Table 4.

METHODOLOGICAL QUALITY OF INCLUDED STUDIES

When the mean TESTEX scale quality scores of the studies were calculated, the reviewed studies were included in this systematic review and meta-analysis, being of good quality with a score of 8.36. Two studies were considered inadequate and thus excluded from the research (28,29), whereas the study by Andrejic (45) scored the highest quality. In the quality evaluations, although the studies could not score for the criteria of “allocation concealment,” “assessor blinding in study reporting,” “intention-to-treat analysis,” and “activity monitoring in the controlled group,” the highest score was given to the “between-group statistical comparisons reported” criterion. Detailed information on methodological quality scores is given in Table 2.

OVERALL EVIDENCE LEVEL OF META-ANALYSIS OUTPUTS

Overall effect size and subgroup analyses were done, and the results showed high heterogeneity. However, the source of this heterogeneity was extreme values at specific rates. Heterogeneity was controlled to a certain level. Therefore, heterogeneity in study outputs was not considered necessary in inconsistency. Publication bias was checked with 3 different tests, and no bias was found in the results.

For this reason, the study outputs were evaluated as high quality concerning publication bias. Methodological quality was evaluated with TESTEX, and the average publication quality was 8.36. For this reason, it was thought that there was no danger in risk bias in the research outputs. Because of the presence of extreme values, there was a difference in the confidence intervals. It was considered important for the research outputs. Differences in the study population were understood to be an important factor in the impact of the results. As a result of the evaluations, it was determined that the research outputs had a moderate quality of evidence.

EVALUATION OF PUBLICATION BIAS

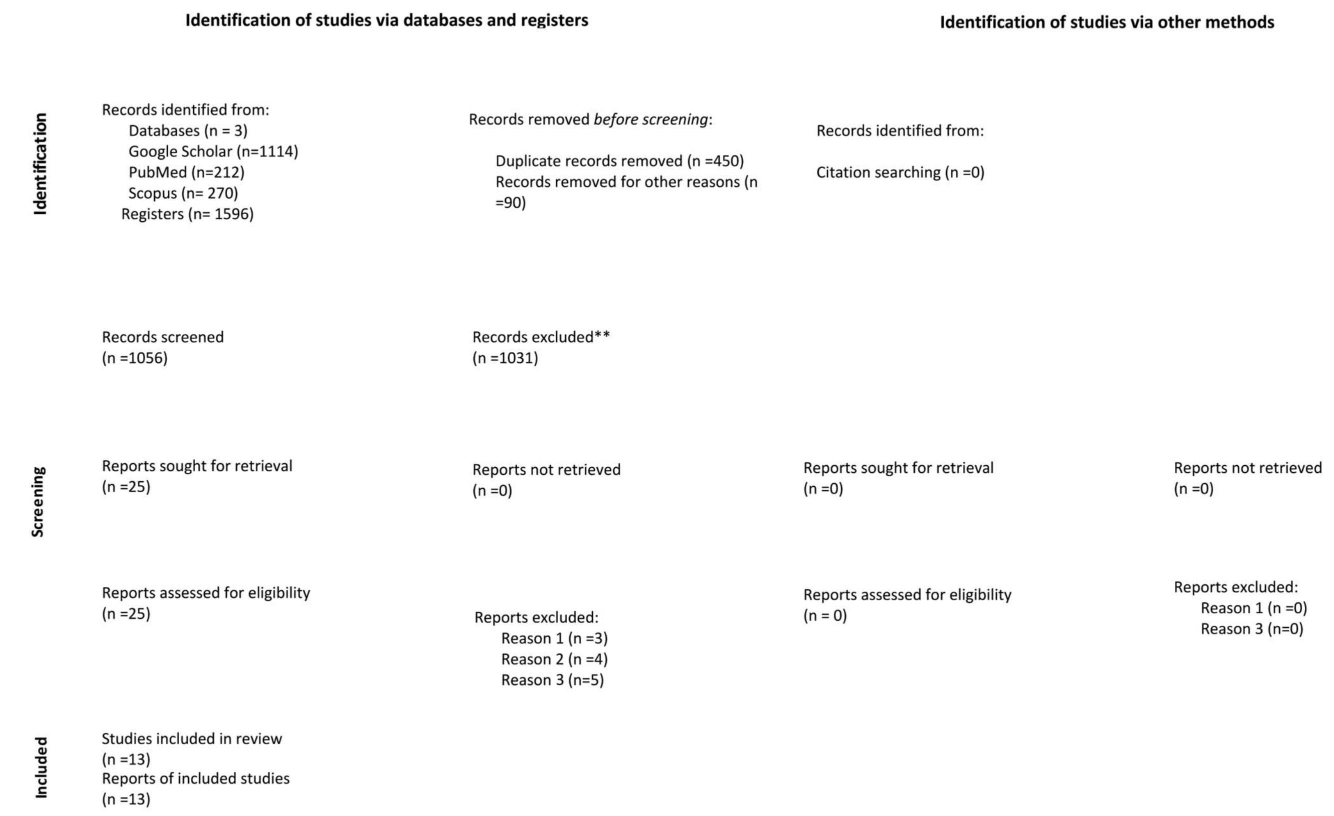
In the evaluation of publication bias, primarily, the funnel plot was used. Sensitivity analyses were performed to control for publication bias. As a result of sensitivity analyses, 6 test data, belonging to 2 studies, formed the extreme values of this research (24,46).

No publication bias was found in the funnel plot with the control of outliers (Figure 2). No publication bias was observed with Egger’s test in the analyses performed ($p = 0.05$). In addition, Rosenthal’s failsafe N test determined that 627 studies were needed to change these results in the opposite direction, and reliability regarding publication bias was ensured.

MAIN EFFECT

When the effect of combined strength training on jumping ability was evaluated against different training groups, a moderate effect size was found in favor of combined strength training (ES = 1.11, (95% CI 0.63–1.60), $z = 4.48$, $p < 0.01$). Although the weight of each study included in the meta-analysis ranged between 2.9 and 3.9% (except for a few studies), the results demonstrated a positive effect in favor of combined strength training (Figure 3).

Because of the high heterogeneity ($I^2 = 82\%$) identified in the overall effect size analysis, sensitivity analyses were performed to find the source of this heterogeneity and to test the strength of the result. In addition to the drop jump and long jump tests by Latorre Roman et al. (46), the tests by Tsimahidis et al. (24) were determined as extreme values, and the overall effect size was recalculated by excluding 6 tests from the meta-analysis. As a result of this analysis, the effect level remained moderate (ES = 0.82, (95% CI 0.58–1.06), $z = 6.73$, $p < 0.01$), and the heterogeneity decreased to



Reason 1= Vertical jump ability not measured; Reason 2= Consisted of mixed subject groups; Reason 3= Training content is not appropriate.

Figure 1. Flow diagram of the study selection process.

moderate levels (I^2 = 47%), whereas the extreme values were missing. The effect obtained in the general effect size analysis by removing the extreme values was proven to be strong and reliable; however, it was concluded that the existence of the extreme values was a source of heterogeneity.

SUBGROUP AND META-REGRESSION ANALYSIS

Subgroup analyses were applied to evaluate the moderator variables potentially affecting combined strength training (CST). Five variables (jumping type, groups compared, training duration, age, and combined training type), of which all studies could be included, were considered moderators of this study for the subgroup analyses. As a result of the moderator analysis of jumping type after CST, a statistically significant difference was found among the 5 subgroups (p = 0.01). CST had the greatest impact on squat jumping

Table 3
Evidence quality profile of meta-analysis outputs (GRADE scale)

Outputs	Number of study outputs	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Overall quality
Jump type	28	Not significant	Not significant	Significant	Significant	Not significant	Moderate
Groups compared	28	Not significant	Not significant	Significant	Significant	Not significant	Moderate
Training duration (wk)	28	Not significant	Not significant	Significant	Significant	Not significant	Moderate
Age	28	Not significant	Not significant	Significant	Significant	Not significant	Moderate
Combined training type	12	Not significant	Not significant	Significant	Significant	Not significant	Moderate

Table 4
Characteristics of combined strength training programs included in the systematic review

Authors	Groups compared	Characteristics of participants			Detail of combined training		
		Gender	Age (y)	Training experienced (y)	Duration/ frequency	Combine type	Programs of combine training
Andrejic (45)	CST vs ST	M	12.5 ± 0.5[a]	1.5 ± 0.5[a]	6/2	ST after PT	10–12 plyometric exercises 1 set/4–6 reps + 7 strength exercises with rubber cord 1 set/8–12 reps + 5 bodyweight exercises 1 set/12–25 reps
Bayram (28)	CST vs CG	M	18.2 ± 1.2[a]	N/A	6/2	PT after ST	10–12 strength exercises 2–3 sets/6–15 reps + 3 plyometric medicine ball exercises with 1–2 kg 3 sets/15 reps
Freitas et al. (47)	COCST vs OLT and CG	M	21.3 ± 4.3	>8	6/2	3 sets PE after 3 sets SE	3 strength exercises with 80% 1RM 3 sets/3 reps + 3 strength exercises with optimal load 3 sets/4–5 reps
Gonzalo Skok et al. (68)	CST vs OLT	M	16.7 ± 1.7[a]	<5	6/2	PT after ST	1 strength exercise with 80–100% 1 MP 3 sets/with the number of repetitions within the defined MP range + 2 plyometric exercises with (0.25–0.5 m) 4 sets/20 reps
Inovero & Pagaduan (29)	CST vs CG	M	17.6 ± 1.04[a]	N/A	6/2	PT after ST	10–12 strength exercises 2–3 sets/6–15 reps + 3 plyometric medicine ball exercises with 1–2 kg 3 sets/15 reps
Kukric et al. (70)	COCST vs UCT	M	16–17	N/A	10/2	SE after ST	3–5 strength exercises with 50–80% 1RM 4 sets/6–8 reps + 1 specific exercise without effort 4 sets/10 reps
Kukric et al. (69)	COCST vs CG and PT	N/A	16–17	7	10/2	3 sets PE after 3 sets SE	4 strength exercises with 80% 1RM 3 sets/3–5 reps + 4 plyometric exercises 3 sets/8 reps
Latorre Roman et al. (46)	CCST vs CG	M/F	8.72 ± 0.9	>2	10/2	2 sets PE after 1 set SE	2 strength exercises with external load and isometric load (40–70 s) 5–13 sets + 2 plyometric exercises 5–13 sets/50–130 reps
Rajaram (71)	COCST vs CCST and ST	M	19.4 ± 0.6[a]	3.2 ± 1.7[a]	8/3	3 sets PE after 3 sets SE 1 set PE after 1 set SE	5 strength exercises 3 sets/12 reps + 5 plyometric exercises 3 sets/10 reps
Roden et al. (72)	COCST vs HRCT	M	15.4 ± 1.2	N/A	6/2	3 sets PE after 3 sets SE	1 strength training with 60–85 1RM 3 sets/8–15 reps + 1 plyometric training 3 sets/10 reps
Sánchez-Sixto et al. (23)	CST vs PT and CG	F	18.17 ± 4.6[a]	>5	6/2	PT after ST	1 strength exercise/3–4 sets/3–6 reps + 1 plyometric exercise 5 sets/5 reps
Santos & Janeıra (12)	COCST vs CG	M	14.5 ± 0.4[a]	5.0 ± 2.1[a]	10/2	PT after ST	3 strength exercises 2–3 sets/10–12 reps + 3 plyometric exercises 2–4 sets/6–15 reps
Tsimahidis et al. (24)	CCST vs CG	M	18.0 ± 0.9[a]	5.6 ± 1.7[a]	10/2	1 set SW after 1 set SE	1 strength exercise 5 sets/5–8 reps + 30-m sprint 5 sets/5 reps

CST = combine strength training; ST = strength training; CG = control group; OLT = optimal load training; UCT = unilateral combine training; PT = plyometric training; COCST = complex combine strength training; CCST = contrast combine strength training; HRCT = high repeat combine training; SE = strength exercises; m = meter; SW = sprint workout; SpE = specific exercises.

[a]While calculating age and training history, combined arithmetic mean and SD values were used with the help of the formulas followed in studies that did not specify the combined mean and SD: For the studies with 2 groups = SQUAREROOT((N1-1)*SS1^2+(N2-1)*SS2^2)/(N1+N2-2), =(m1*n1+m2*n2/n1+n2); For the studies with 3 groups = SQUAREROOT((N1-1)*SS1^2+(N2-1)*SS2^2)+ (N3-1)*SS3^2)/(N1+N2+N3-3)), (m1*n1+m2*n2+m3*n3/n1+n2+n3).

among jumping types (ES = 2.00 (95% CI 0.56–3.43)). When the effect of combined strength training against different training methods was evaluated, it was detected that there was no statistically significant difference between the effect on the control groups and the effect on different strength training methods ($p >$ 0.05). However, the results indicated that the combined strength training had a greater effect on control groups (ES = 1.50 (95% CI 0.64–2.36)). During the subgroup analyses on training weeks, performing the CST for 8 weeks (or less) and 10 weeks were compared. It was noted that statistically significant and greater improvements in the vertical jumping ability of basketball players were ensured through the application of CST for 10 weeks (ES = 1.56, (95% CI 0.69–2.43)), $p = 0.03$). When the subgroups of the age moderator were compared, the basketball players aged 18 years and above were noted to improve their vertical jumping skills through CST more than those aged 18 years and below (ES = 2.01, (95% CI 0.79–3.23), $p = 0.02$). Finally, the difference between the combined training types was examined. It was observed that there was no significant difference between complex training, contrast training, and combined training on the development of jumping ability in basketball ($p = 0.12$).

In this research, in addition to subgroup analyses, meta-regression analyses were conducted, and these analyses were carried out with at least 10 studies per covariate. Jumping type, training duration, and age variables were determined to predict vertical jumping ability through CST. As a result of meta-regression analysis, it was understood that the effect sizes among the subgroups, including jumping type and training duration, were not large enough to predict the effect of CST on vertical jumping performance ($p > 0.05$). However, it has been reported that the age variable is an important variable in predicting the vertical jump performance of the CST ($p = 0.0078$, $R^2 = 22\%$).

RESULTS OF CERTAINTY ASSESSMENT

After the overall assessment, the level of evidence of the research outputs was determined and classified from high evidence to low evidence. Evidence of certainty in the study outputs was identified at a moderate level because of indirectness and imprecision in the included studies. Detailed information about the level of evidence is given in Table 3.

ADVERSE EFFECTS OF THE COMBINED STRENGTH TRAINING PROTOCOL

Among the 11 studies included, 2 reported injuries in 4 attendees (46,47). Freitas et al. (47) reported 3 attendees getting injured unrelated to the training protocol, whereas Latorre Roman et al. (46) reported an unspecified injury (Tables 5–7).

DISCUSSION

The first aim of this systematic review and meta-analysis was to evaluate the overall effect of combined strength training on jumping height in basketball. The study's results indicated that combined strength training to improve jump height in basketball is a more effective method for improving jumping ability. Result of the sensitivity analysis showed that the main reason for the heterogeneity among the studies was the extreme values, and the effect size obtained was not based on a few studies. Our research findings revealed similar results to meta-analyses performed on different populations (20,48). The advantage ensured by combined strength training for athletic performance components such as jumping ability is associated with different adaptation processes (49). Performing low-intensity exercises after high-intensity ones activate myosin regulatory light chain phosphorylation and increase the sensitivity to calcium (Ca^{2+}) ions in the muscle (50). Through this physiological process, stronger muscle contractions can occur (49,51). Another adaptation process is associated with neural excitability, known as the H-reflex. Researchers state that high-

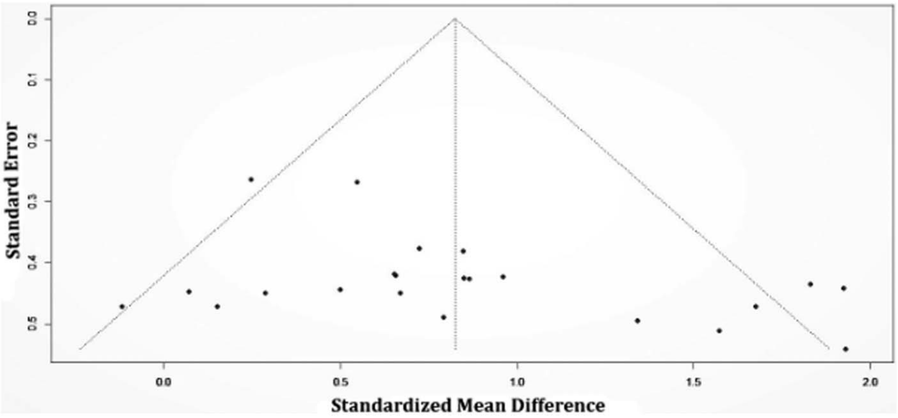


Figure 2. Funnel plot.

Study	Combined Strength Training Mean	SD	Total	Other Groups Mean	SD	Total	Weight (common)	Weight (random)	Std. Mean Difference IV, Fixed + Random, 95% CI
Andrejic (2012) SJT / CST−EG	44.40	8.40	11	40.80	5.60	10	2.9%	3.6%	0.50 [−0.37; 1.37]
Andrejic (2012) LJ / CST−EG	204.20	22.70	11	191.80	12.30	10	2.8%	3.6%	0.67 [−0.21; 1.55]
Freitas et, al, (2018) CMJ / CST−EG	37.20	3.60	9	37.90	7.50	9	2.6%	3.6%	−0.12 [−1.04; 0.81]
Freitas et, al, (2018) LJ / CST−EG	2.46	0.24	9	2.27	0.24	9	2.3%	3.5%	0.79 [−0.17; 1.76]
Gonzalo Skok et, al, (2016) CMJ / CST−EG	40.60	5.50	9	39.80	5.10	9	2.5%	3.6%	0.15 [−0.77; 1.08]
Kukric et, al, (2009) CMJ / CST−CG	37.40	2.79	10	33.40	2.27	10	2.1%	3.5%	1.57 [0.55; 2.59]
Kukric et, al, (2009) SJ / CST−CG	36.00	2.25	10	31.10	2.80	10	1.9%	3.4%	1.93 [0.85; 3.01]
Kukric et, al, (2012) CMJ / CST−CG	42.20	3.36	10	37.40	3.79	10	2.3%	3.5%	1.34 [0.36; 2.32]
Kukric et, al, (2012) CMJ / CST−EG	42.20	3.36	10	41.20	3.64	10	2.8%	3.6%	0.29 [−0.60; 1.17]
Latorre Roman et, al, (2017) CMJ / CST−CG	20.36	2.34	30	18.51	4.24	28	7.9%	3.9%	0.55 [0.02; 1.07]
Latorre Roman et, al, (2017) DropJ20 / CST−CG	17.78	4.02	30	17.48	4.06	28	8.2%	3.9%	0.07 [−0.44; 0.59]
Latorre Roman et, al, (2017) DropJ40 / CST−CG	16.99	3.95	30	17.36	4.29	28	8.2%	3.9%	−0.09 [−0.61; 0.43]
Latorre Roman et, al, (2017) LJ / CST−CG	135.80	19.20	30	135.86	19.95	28	8.2%	3.9%	−0.00 [−0.52; 0.51]
Latorre Roman et, al, (2017) SJ / CST−CG	19.48	4.82	30	18.39	3.98	28	8.2%	3.9%	0.25 [−0.27; 0.76]
Rajaram (2020) CMJ / CST1−EG	33.15	6.20	15	28.60	4.40	15	3.9%	3.7%	0.85 [0.10; 1.60]
Rajaram (2020) CMJ / CST2−EG	32.44	6.10	15	28.60	4.40	15	4.0%	3.8%	0.72 [−0.02; 1.46]
Rajaram (2020) SJ / CST1− EG	26.20	4.40	15	18.20	3.90	15	2.8%	3.6%	1.92 [1.05; 2.80]
Rajaram (2020) SJ / CST2− EG	26.20	4.80	15	18.20	3.90	15	2.9%	3.6%	1.83 [0.97; 2.69]
Roden et, al, (2014) CMJ / CST− EG	56.20	6.90	10	55.70	7.40	10	2.8%	3.6%	0.07 [−0.81; 0.95]
Sanchez−Sixto et, al, (2021) CMJ / CST−CG	37.69	5.17	13	34.00	3.00	12	3.2%	3.7%	0.86 [0.04; 1.69]
Sanchez−Sixto et, al, (2021) CMJ / CST−EG	37.69	5.17	13	35.17	3.92	11	3.3%	3.7%	0.54 [−0.28; 1.36]
Santos & Janeira (2008) AT / CST−CG	38.43	7.10	15	34.32	4.80	10	3.2%	3.7%	0.65 [−0.17; 1.47]
Santos & Janeira (2008) CMJ / CST−CG	33.02	6.20	15	28.40	4.00	10	3.1%	3.7%	0.85 [0.01; 1.69]
Santos & Janeira (2008) DepthJ / CST−CG	36.64	8.10	15	30.75	4.10	10	3.1%	3.7%	0.86 [0.03; 1.70]
Santos & Janeira (2008) SJ / CST−CG	28.01	4.60	15	20.74	3.90	10	2.5%	3.6%	1.68 [0.74; 2.61]
Tsimihadis et, al, (2010) CMJ / CST−CG	38.03	0.72	13	32.32	0.84	13	0.4%	2.2%	7.30 [5.08; 9.51]
Tsimihadis et, al, (2010) DJ / CST−CG	35.40	0.87	13	32.01	0.68	13	1.0%	3.0%	4.34 [2.89; 5.80]
Tsimihadis et, al, (2010) SJ / CST−CG	36.99	0.79	13	33.10	0.69	13	0.8%	2.8%	5.24 [3.57; 6.92]
			434			399			
Total (random effects, 95% CI)							--	100.0%	1.11 [0.63; 1.60]

Heterogeneity: $Tau^2 = 1.5043$; $Chi^2 = 147.20$, df = 27 ($P < 0.01$); $I^2 = 82\%$
Test for overall effect (random effects): $Z = 4.48$ ($P < 0.01$)

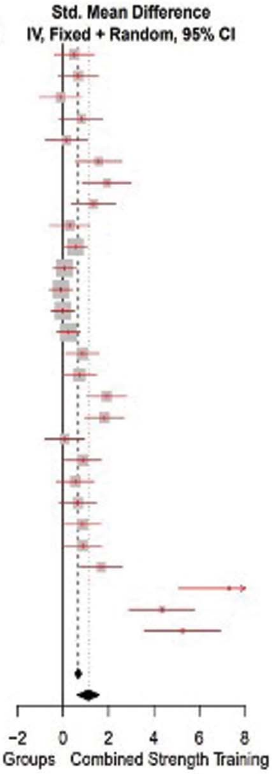


Figure 3. Forest plot summarizing the effects of combined strength training on jump height versus different training methods. CST = combined strength training; EG = experimental group; CG = control group; SJT = Sargent jump test; LJ = long jump; CMJ = countermovement jump; SJ = squat jump; DropJ20 = drop jump 20 cm; DropJ40 = drop jump 40 cm; CST1 = first combined strength training group; CST2 = second combined strength training group; AT = Abalakov test; DepthJ = depth jump; DJ = drop jump.

intensity exercises enhance neural impulses to the muscles through maximal strength. However, this mechanism is controversial because of opposing views (52–54). The involvement of pennation angles and titin protein during muscle contraction also points out different mechanisms described by increased performance through combined strength training (55,56). These mechanisms, expressed as postactivation potentiation theory, can contribute to developing jumping performance in basketball through various adaptation processes. Indeed, the relevant researchers note that jumping ability can be improved through postactivation potentiation (57–59). Although the PAP theory of exercise pairs usually explains the gain from combined strength training, this gain can also be based on strength exercises that involve opposite loadings. Indeed, high-intensity strength exercises can heighten the level of anabolic hormones in athletes while reducing the level of catabolic hormones, increasing maximal strength and anaerobic power (60,61). However, muscle tension, reactive force index, and Achilles tendon thickness can be enhanced through exercises involving the stretch-shortening cycle (62,63). All the mechanisms can increase the harmony of the neuromuscular system, enabling it to improve jumping performance.

That combined strength training impacts vertical jumping ability through various mechanisms in basketball necessitated the analysis for the alternative aims of this research. Subgroup and meta-regression analyses were performed over covariates (jump type, training duration, age, and groups compared) to identify moderators, which were the alternative aims of the study. Although all types of jumping were determined to improve vertical jumping ability, the most significant improvement was seen to occur in squat jumping ability. This finding of our research revealed a result discordant with the current literature. Because of both the vertical jumping kinetics of basketball and the kinetics applied during the test, the researchers have the opinion that the test results obtained with the countermovement jump (CMJ) are more effective than the squat jump (SJ) (64,65). Therefore, the source of our findings contradicting the literature may be the extreme values. The in-group I^2 value of the SJ test was determined as 89.6%. When the impact of CST on vertical jumping performance was compared with the control groups and the experimental groups involving different strength training, it was determined that it had a more significant impact on the control groups. Still, this impact did not

Table 5
Pretest-posttest results of the research groups included in the meta-analysis

Authors	Groups compared	Test parameters	Combined strength training groups			Other groups			Measurement device
			Sample size	Pre (cm)	Post (cm)	Sample size	Pre (cm)	Post (cm)	
Andrejic (45)	CST vs ST	Vertical jump	11	41.2 ± 7.6	44.4 ± 8.4	10	40.2 ± 6.4	40.8 ± 5.6	N/A
		Long jump		193.9 ± 19.6	204.2 ± 22.7		189.6 ± 10.1	191.8 ± 12.3	
Bayram (28)	CST vs CG	Sargent jump	8	51.1 ± 6.4	56.7 ± 3.6	8	56.1 ± 4.9	60.9 ± 6.6	—
Freitas et al. (47)	COCST vs OLT	Countermovement jump	9	36.4 ± 4.2	37.2 ± 3.6	9	36.5 ± 7.2	37.9 ± 7.5	Force Platform
		Long jump		2.39 ± 0.23	2.46 ± 0.24		2.27 ± 0.22	2.27 ± 0.24	
Gonzalo Skok et al. (68)	CST vs UCT	Countermovement jump	9	38.9 ± 5.3	40.6 ± 5.5	9	37.4 ± 4.2	39.8 ± 5.1	Optojump System
Inovero & Pagaduan (29)	CST vs CG	Sargent jump	8	50.5 ± 6.7	55.7 ± 3.8	8	55.8 ± 5.1	61.1 ± 6.3	—
Kukric et al. (70)	COCST vs CG	Countermovement jump	10	32.7 ± 2.58	37.4 ± 2.79	10	33.0 ± 2.40	33.4 ± 2.27	Force Platform
		Squat jump		31.2 ± 1.81	36.0 ± 2.25		30.7 ± 2.98	31.1 ± 2.80	
Kukric et al. (69)	COCST cs CG	Countermovement jump	10	37.10 ± 3.34	42.20 ± 3.36	10	37.20 ± 3.03	37.40 ± 3.79	Force Platform
Kukric et al. (69)	COCST vs PT	Countermovement jump				10	37.30 ± 3.33	41.20 ± 3.64	
Latorre Roman et al. (46)	CCST vs CG	Countermovement jump	30	17.85 ± 4.08	20.36 ± 4.34	30	17.47 ± 4.27	18.51 ± 4.24	OptoGaint System
		Drop jump 20 cm		15.76 ± 4.11	17.78 ± 4.02		16.41 ± 3.68	17.48 ± 4.06	
		Drop jump 40 cm		14.96 ± 4.42	16.99 ± 3.95		16.25 ± 3.93	17.36 ± 4.29	
		Long jump		131.03 ± 16.86	135.80 ± 19.20		132.00 ± 19.11	135.86 ± 19.95	
		Squat jump		17.53 ± 4.39	19.48 ± 4.82		17.15 ± 3.75	18.39 ± 3.98	
Rajaram (71)	COCST vs CCST	Countermovement jump	15	28.64 ± 5.4	32.44 ± 6.1	15	29.25 ± 5.6	33.15 ± 6.2	N/A
		Squat jump		22.70 ± 4.0	26.20 ± 4.8		22.02 ± 4.4	26.20 ± 4.4	
	COCST vs ST	Countermovement jump		28.64 ± 5.4	32.44 ± 6.1	15	30.42 ± 4.8	28.60 ± 4.4	
		Squat jump		22.70 ± 4.0	26.20 ± 4.8		20.04 ± 4.3	18.20 ± 3.9	
Roden et al. (72)	COCST vs HRCT	CMJ	10	52.2 ± 6.3	56.2 ± 6.9	10	53.1 ± 7.4	55.7 ± 7.4	Just Jump System
Sánchez-Sixto et al. (23)	CST vs CG	Countermovement jump	13	0.34 ± 0.03	0.38 ± 0.05	12	0.33 ± 0.03	0.34 ± 0.03	Force Platform
	CST vs PT	Countermovement jump				11	0.33 ± 0.04	0.35 ± 0.04	
Santos & Janeıra (12)	COCST vs CG	Abalakov test	15	34.77 ± 6.3	38.43 ± 7.1	10	36.12 ± 4.8	34.32 ± 4.8	Globus Ergo Tester
		Countermovement jump		29.88 ± 5.9	33.02 ± 6.2		30.76 ± 5.1	28.40 ± 4.0	
		Depth jump		34.71 ± 7.4	36.64 ± 8.1		31.11 ± 4.8	30.75 ± 4.1	
		Squat jump		24.79 ± 4.2	28.01 ± 4.6		22.70 ± 4.3	20.74 ± 3.9	
Tsimahidis et al. (24)	CCST vs CG	Countermovement jump	13	33.11 ± 1.33	38.03 ± 0.72	13	31.90 ± 0.90	32.32 ± 0.84	ErgoJump
		Drop jump		31.02 ± 0.83	35.4 ± 0.87		31.38 ± 0.89	32.01 ± 0.68	
		Squat jump		32.75 ± 1.29	36.99 ± 0.79		32.54 ± 0.81	33.1 ± 0.69	

CST = combine strength training; ST = strength training; CG = control group; OLT = optimal load training; UCT = unilateral combine training; PT = plyometric training; COCST = complex combine strength training; CCST = contrast combine strength training; HRCT = high repeat combine training.

Subgroups	Outputs in studies (*n*)	ES	95% CI	ES comment	Within-group *p*	Within-group I^2 (%)	Between-group difference *p*
Jump type							**0.01**
SJT	3	0.68	−0.09 to 1.44	Moderate	0.13	50.1%	
LJ	3	0.11	−0.29 to 0.51	Trivial	0.59	0.0%	
CMJ	13	0.98	0.47 to 1.48	Moderate	0.01	70.4%	
DJ	4	1.17	−0.69 to 3.02	Moderate	0.22	90.6%	
SJ	5	2.00	0.56 to 3.43	Large	<0.01	89.6%	
Groups compared							0.08
CST vs CG	16	1.50	0.64 to 2.36	Large	<0.01	87.1%	
CST vs EG	12	0.68	0.34 to 1.02	Moderate	<0.01	46.4%	
Training duration (wk)							**0.03**
≤8	12	0.54	0.30 to 0.78	Trivial	<0.01	6.5%	
>10	16	1.56	0.69 to 2.43	Large	<0.01	87.8%	
Age (y)							**0.02**
≤18	17	0.54	0.28 to 0.80	Trivial	<0.01	50.6%	
>18	11	2.01	0.79 to 3.23	Large	<0.01	87.6%	
Combined training type							0.12
CT	5	0.96	0.64 to 1.27	Moderate	<0.01	48%	
CONT	2	2.00	0.11 to 3.89	Large	<0.01	82%	
COMT	2	0.54	0.15; 0.93	Moderate	<0.05	0%	

Table 6
Subgroup analyses of the potential moderators of combined strength training

Bold entries mean that the significance value of the $p < 0.05$.

SJT = squat long jump; LJ = long jump; CMJ = counter movement jump; DJ = drop jump; SJ = squat jump; CG = control group; CST = combined strength training; EG = experimental group; CT = complex training; CONT = contrast training; COMT = combine training.

Table 7
Results of the meta-regression analysis to predict the effect of CST on vertical jumping performance in basketball

	Coefficient	SE	95% CI	z	p
Jump type	0.8942	0.7322	−0.5408 to 2.3292	1.2213	0.4361
Training duration	0.9201	0.4979	−0.0558 to 1.8960	1.8478	0.0646
Age	1.2658	0.4761	0.3326 to 2.1990	2.6586	**0.0078**

Bold entries mean that the significance value of the $p < 0.05$.

cause a statistically significant difference ($p > 0.05$). That CST is less effective in different strength training can be explained by the fact that different pieces of strength training trigger similar adaptation processes with CST. However, the combined strength training applied for 10 weeks had a more significant effect on vertical jumping ability than the one for ≤8 weeks. Associated with the subgroup analyses of the study's age moderator, this can be explained by the chronic effect of postactivation potentiation (66). Indeed, in the subgroup analyses, basketball players over 18 years recorded a greater improvement in their vertical jumping performance through the combined strength training than the basketball players aged 18 years and younger. Similar findings were found in a meta-analysis of combined strength training on different populations; the subjects older than 20 years improved vertical jumping performance more than the ones aged 20 years and younger (48). This is explained by the fact that adults have more type II muscle fibers, and it is stated that individuals with type II muscle fibers benefit more effectively from postactivation potentiation (18,51,56,67). As a matter of fact, in the meta-regression analyses, only the age moderator was determined to be an important predictor of the overall effect size obtained. This finding indicated that the increase in basketball players' age in combined strength training might be accordant with the enhancement in vertical jumping performance.

Three different forms of combined strength training were included in this research: (1) low-intensity plyometric training after high-intensity strength training, (2) low-intensity plyometric exercise sets after high-intensity strength training sets, and (3) specific low-intensity drills after high-intensity strength exercises. Three different combined strength training forms (contrast training, complex training, and combined training) were included in this study. However, except for a few variables included in the meta-analysis, all pieces of combined strength training provide an advantage over the group it is compared against. This case showed that different CST forms to be applied might be sufficient to improve jumping ability in basketball.

OVERVIEW OF STUDY'S LIMITATIONS AND FUTURE RESEARCH

This study includes various limitations from the search stage to the findings stage. The first of these limitations is the search databases. To control the number of duplicate data, only 3 databases were included in the study (Google Scholar, PubMed, and Scopus). The second limitation is the language of the article's writing. Only articles written in English were evaluated in the databases. However, automation tools such as RobotReviewer were not used for systematic search and risk of bias.

Another limitation of this systematic review and meta-analysis concerns the studies included. The present systematic review and meta-analysis results have created some restrictions arising from the included studies. The TESTEX scale recommended in sports science research was used to assess methodological quality and risk of bias. However, the included studies were determined to be of moderate or good quality. The level of quality may have decreased due to the inclusion of controlled experimental studies in this study. Therefore, there is a need for randomized controlled experimental studies to conduct systematic reviews and meta-analyses with higher quality studies.

Another limitation of the studies was participant characteristics. Only 1 of the 11 studies included in this study was conducted with young female basketball players. Studies with the female population are needed to address the effect of combined strength training on gender. As a result of the examinations, no CST studies were found in the literature with basketball players over age 25 years. More research is needed to examine the effect of CST in different age groups comprehensively.

Finally, this study's number of short-term studies was understood to be very small. Conducting short-term (≤4) studies with combined strength training in basketball may allow the subject to be better evaluated in time effect.

CONCLUSIONS

There was no publication bias in the data of this study, heterogeneity was controlled, and a moderate level of evidence was obtained. As a result, CST was more effective in improving the vertical jump performance of young basketball players compared with different training methods. There is no significant difference between CST protocols (contrast, complex, and combined) in improving vertical jump performance. CST showed the most critical effect in the squat jump test protocol. The study's findings pointed out that training for 10 weeks or more should optimally improve vertical jump performance with CST. This study determined that CST can improve the jumping performance of basketball players between 9 and 18 years old at a higher level.

PRACTICAL APPLICATIONS

According to the findings of the studies included in this systematic review and meta-analysis, basketball coaches may prefer to integrate CST into their basketball training to improve the jumping performance of the athletes. CST can be used 2 days a week for 10 weeks to provide the most effective performance on basketball players' jumping performance. Because the effect of PAP on performance depends on many factors, the characteristics of the included studies for the determination of rest periods can be examined. Considering the features of the studies included in the systematic review, the number of sets for CST can be determined depending on the number of exercises. One set per exercise can be applied during the training protocol consisting of 12 exercise pairs. However, the same function can be performed in 4 sets with 3 combined strength exercises. Specifically, applying CST at age 18 years and above may improve jumping performance more effectively. The results of this systematic review and meta-analysis may benefit athletic performance specialists and coaches to improve the jumping performance of young basketball players.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on website: https://osf.io/ud42b/ with Identifier: DOI 10.17605/OSF.IO/UD42B.

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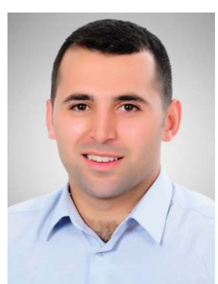

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