The chronic effects of change of direction during repeated-sprint training on jumping, sprinting, and change-of-direction abilities in players: a systematic review and meta-analysis

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ABSTRACT

Objectives. This systematic review and meta-analysis aimed to compare the effects of repeated sprint training with one change of direction (RS-OCOD) and multidirectional changes of direction (RS-MCOD) on players' jumping, sprinting, and change-of-direction (COD) ability.

Methods. Following PRISMA guidelines, 15 randomized controlled trials involving 223 players were analyzed. Standardized mean differences (SMD) and 95% confidence intervals (CI) were calculated using fixed- or random-effects models. Heterogeneity (I^2 statistic), publication bias (funnel plots and Egger's test), and sensitivity analyses were conducted. Subgroup analyses differentiated RS-OCOD and RS-MCOD outcomes.

Results. RS-COD training significantly improved countermovement jump (CMJ) (SMD = −0.68, 95% CI [−1.04 to −0.34]), 20–40 m sprinting ability (SMD = 0.70 [0.39, 1.01]), and COD ability (SMD = 0.77 [0.39, 1.16]). RS-MCOD demonstrated superior effects on 20–40 m sprinting ability (large effect: SMD = 0.97) and COD ability (large effect: SMD = 0.97), while RS-OCOD showed greater benefits for CMJ (large effect: SMD = −0.92). High heterogeneity ($I^2 > 70\%$) was observed in 5 m/10 m sprint analyses, attributed to methodological diversity and age variability. Prediction intervals indicated potential overestimation of RS-MCOD effects.

Conclusion. RS-OCOD can significantly enhance a player's CMJ ability, while RS-MCOD can notably improve sprinting and COD abilities. These findings advocate for the incorporation of RS-COD into training programs to boost competitive performance. However, the effectiveness of RS-COD may vary based on the number and complexity of directional changes incorporated into the training regimen. Among them, RS-MCOD is prioritized for sports requiring frequent directional changes, whereas RS-OCOD enhances vertical jump performance in explosive sports.

Subjects Kinesiology, Public Health
Keywords Multidirectional sprint protocols, Explosive movement measures, Neuromuscular adaptation

INTRODUCTION

Repeated-sprint training (RST) can be utilized to prepare players for the intermittent, high-intensity demands of competition, which involve frequent accelerations, decelerations, and changes of direction (*Taylor et al., 2017*). RST has garnered increasing attention in recent scientific literature (*Hoffmann Jr et al., 2014*; *Fernandez-Fernandez et al., 2012*; *Bishop, Girard & Mendez-Villanueva, 2011*). It is operationally defined as a training modality involving ≥ 3 maximal-effort sprints (≤ 10 s duration) interspersed with brief (≤ 60 s) passive recovery period (*Thurlow et al., 2023*). Existing evidence indicates that RST acutely enhances the activity of key enzymes in both anaerobic and aerobic energy pathways (*Burgomaster, Heigenhauser & Gibala, 2006*; *Gibala et al., 2006*). Therefore, RST is a mixed training method that targets both neuromuscular and metabolic systems simultaneously (*Thurlow et al., 2025*), resulting in substantial improvements across a range of physical qualities that are important to sports performance, including speed, aerobic capacity, intermittent running performance, repeated-sprint ability, change of direction (COD) ability, and jump height (*Thurlow et al., 2024*).

In various ball sports (*e.g.*, basketball, football, tennis, *etc.*), RST with COD (RS-COD) is essential due to the frequent accelerations and decelerations that involve COD (*Taylor et al., 2015*). It has been reported in the literature that elite soccer players change direction at angles less than 90° up to 300 times per game per side, and change direction at angles between 90° and 180° 45 to 49 times per game (*Taylor et al., 2017*). The acute demand of RS-COD depends on the number of direction changes, angles, distance between each direction change, and the duration of the sequence (*Zagatto et al., 2017*; *Padulo et al., 2015*; *Attene et al., 2016*). These factors affect the absolute speed gained and muscle work during sprinting, propelling, and braking. In addition, RS-COD involves the accumulation of acceleration and deceleration, which can increase neuromuscular demands (*Buchheit, Haydar & Ahmaidi, 2012*).

Thurlow et al. (2025) classified RST into three forms: straight line sprints, shuttle sprints and multidirectional sprints. And they suggested that shuttle sprints, by emphasizing changes of direction to limit absolute running speed, may improve COD ability to a greater extent than straight-line sprints, despite uncertain effects shown by the width of the confidence interval. Additionally, multidirectional sprint protocols can similarly enhance COD ability, acceleration, and deceleration, but the repeated distances should be limited to maintain the intensity of each effort (*Thurlow et al., 2024*).

Previous studies mainly compared RST with a control group to assess its training effects, or compared straight line sprints with RS-COD to explore the differences between RST with and without COD. Few have directly examined the impact of the number of direction changes in RST on physical qualities. Thus, this study aims to systematically review and meta-analyze the effects of RS-COD on jumping, sprinting, and COD abilities, and to compare the differences between one-direction (RS-OCOD) and multi-direction changes (RS-MCOD).

INFORMATION AND RESEARCH METHODS

Study selection

This meta-analysis followed the Cochrane Collaboration (*Cumpston et al., 2019*) and adhered to the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (*Moher et al., 2010*). The PICOS (Population, Intervention, Control, Outcome, Study Design) principles were used to define the inclusion and exclusion criteria, as shown in Table 1. The present systematic review and meta-analysis followed the PRISMA guidelines, and the protocol has been registered in PROSPERO (ID: CRD42024620508).

Search strategy

The systematic review and meta-analysis conducted searches in databases such as PubMed (Algorithm: Title/Abstract; Filters applied: Randomized Controlled Trail, English, Humans), Web of Science (Algorithm: Topic; Filters applied: Article or Dissertation Thesis, English, Sports Sciences), Scopus (Algorithm: TITLE-ABS-KEY, Filters applied: English, Chinese), ScienceDirect (Algorithm: Title/abstract/author-specified keywords; Filters applied: Research articles, English), and China National Knowledge Infrastructure (CNKI) (Algorithm: Topic, Filters applied: English, Chinese), SPORTDiscus (Algorithm: SU; Filters applied: English). The search time frame extended from the inception of records in each database to March 7, 2025, languages were limited to Chinese and English.

An example of the database search process was presented in Table 2. To ensure the accuracy of the search, two researchers cross-checked the search keywords. If there were any disagreements on keyword selection between the two researchers, a third researcher made the final decision. If necessary, manual searches were conducted to supplement the literature.

Data extraction

Two researchers (R.K. and L.C.) searched each database using the same search formula and independently translated and reviewed the titles and abstracts for preliminary screening with Google Translate. After screening the literature in each database, the results were imported into EndNote X9 software for organization. Additionally, the researchers used Google Translate to review the full texts and determined which studies met the inclusion and exclusion criteria. The literature screening process was conducted by two investigators independently, and any disputes were subject to final decision by the third investigator (D.L.) based on the inclusion and exclusion criteria.

After confirming the final inclusion of all literature in the analysis, two researchers (R.K. and L.C.) extracted the data into a Microsoft Excel spreadsheet. The extracted data included the article title, year of publication, author(s) name, subject characteristics (*e.g.*, age, number and type of participants, training protocol, period, outcome, results), training regimen (intervention period, training frequency, intervention), and pre- and post-testing data for outcome indicators (jumping ability, sprinting speed, and COD ability). The pre- and post-testing data were as mean ± standard deviation (mean ± SD). If the data were presented in pictures in the study, Getdata was used for data extraction. In instances where the data extracted by the two researchers (R.K. and L.C.) showed bias, a third researcher

Table 1 Inclusion and exclusion criteria.

Project	Inclusion criteria	Exclusion criteria
P	The pool of eligible participants included both male and female players who reported no existing injuries or illnesses and possessed a minimum competitive level corresponding to Tier 2 of the Participants Classification Framework (trained/developmental level)[1], regardless of age.	We excluded players who were disabled, injured, or in an unhealthy state from consideration. Furthermore, participants classified in tiers 0 or 1 of the Participants Classification Framework were also excluded.
I	RST were interventions performed as standalone interventions, alongside normal training practice. The intervention period was more than 2 weeks.	RST with no changes of direction was excluded. Other interventions were included in the RST (*e.g.*, RST + plyometric training). The repetitive sprint training intervention consisted of both straight sprints and changes of direction sprints.
C	The control group had no restrictions.	—
O	The primary outcomes involve adaptations (medium to long term adaptations), concentrating on assessments of physiological or physical fitness levels at a minimum of two time points (baseline and post-intervention). These adaptations include different aspects, including explosive power, sprint speed, aerobic capacity, anaerobic capacity, and the ability to change direction.	The results of acute adaptation, physiological indicators, and anatomical indicators were excluded
S	Randomized parallel controlled trial	Self-controlled trial, correlation study

Notes.
[1] *McKay et al. (2022)*.

Table 2 Web of Science literature selection strategy.

Program	Retrieval formula
#1	TS = ("Repeated sprint training" OR "Straight Line Sprinting" OR "Straight Line" OR "repeated sprint" OR "Repeated sprint running" OR "repeated sprint" OR "intensive repeated sprint" OR "Change-of-Direction Sprinting" OR "Change-of-Direction" OR "Multi-Directional Sprint Training" OR "Multiple-sprint" OR "Multiple-sprint work" OR "Multiple-sprint running" OR "Repeated change of direction" OR "Shuttle-based sprints" OR "Repeated Shuttle Sprints" OR "shuttle run" OR "intermittent sprint" OR "Shuttle Sprints")
#2	TS = (player OR athletes OR "sportsman")
#3	TS = ("jump ability" OR "jump performance" OR "jump" OR "COD" OR "change-of-direction" OR "agility" OR "sprint" OR "sprint speed")
#4	#1 AND #2 AND #3

(D.L.) was assigned to review and finalize the data. When full-text articles or study data were unavailable, efforts were made to obtain the necessary content by contacting the authors *via* email.

Assessment of risk of bias

Two independent researchers (R.K. and L.C.) employed the Cochrane Risk of Bias Tool within Review Manager software version 5.4 to assess the methodological rigor of each eligible randomized controlled trial (RCT). The risk of bias across the included studies was

evaluated based on seven criteria: (1) generation of random sequences, (2) concealment of allocation, (3) blinding of participants and staff, (4) blinding of outcome assessment, (5) incomplete outcome data, (6) selective reporting, and (7) any other sources of bias. The quality of the literature was determined by the number of studies classified as "low risk of bias" (with scores of ≥ 4 considered low risk, 2–3 as moderate risk, and 0–1 as high risk). These findings were crucial in establishing the overall quality assessment of the literature.

Statistical analysis

Data analysis was conducted using Review Manager software version 5.4, Stata 15.0 and R 4.4.3. We employed the standardized mean difference (SMD) along with 95% confidence intervals (CI) as the metric for aggregating effects on continuous outcome variables. The study conducted by *Sanchez-Sanchez et al. (2019)* included two RS-MCOD groups, which were combined in accordance with the recommendations outlined in the Cochrane Handbook (detailed formulas refer to Table 6.5.a of the Cochrane Handbook) (*Chandler et al., 2019*). Heterogeneity across studies was assessed using the I^2 statistic, categorized as low (0% to 25%), moderate (25% to 75%), or high (75% to 100%) (*Higgins et al., 2003*). The fixed-effects model was applied for outcome indicators when I^2 was less than 25%; otherwise, a random effects model was utilized. Statistical significance was set at $p < 0.05$. Effect sizes (ES) were classified based on Hedge' g index into small (0.2 to 0.5), moderate (0.5 to 0.8), or large (above 0.8). Prediction intervals (PI) were computed alongside the estimates to convey the likely range of the true change in similar future studies. The Cochrane Risk of Bias Tool was employed to evaluate the methodological quality of the included studies, ensuring their internal and external validity. Between-study subgroup analysis to clarify the impact of RS-OCOD and RS-MCOD on final outcomes. Publication bias was assessed using funnel plots and Egger's test. In cases where publication bias was detected, the trim-and-fill procedure by Duval and Tweedie was applied to adjust the funnel plot, with the bias reassessed after adjustment. A sensitivity analysis was performed to evaluate the stability and reliability of the pooled results from the meta-analysis.

RESULTS

Literature search

A total of 2,983 studies were retrieved (Fig. 1). After exclusion and initial screening, 134 articles were left for further screening, and finally 27 possible articles were read in full. After full-text screening, four studies were correlation study (*Padulo et al., 2015*; *Brini, Delextrat & Bouassida, 2021*; *Padulo et al., 2016*; *Dal Pupo et al., 2013*) and three studies were self-control study (*Born et al., 2016*; *Taylor et al., 2016*; *Ozgunen et al., 2021*), therefore excluded. Two studies were excluded because the subjects were Tier 1 participants (*Chen, 2019*; *Shi, 2021*). Five studies were excluded because they did not meet the inclusion criteria for the intervention protocol. One study involved the RST without a COD (*Tian, 2020*), while the other four studies involved the RST in conjunction with other interventions (*Brini et al., 2022*; *Brini et al., 2023*; *Morais et al., 2025*; *Kilit et al., 2025*). The details of the excluded literature are provided in the Annex 1. Finally, 15 studies (*Attene et al., 2016*; *Sanchez-Sanchez et al., 2019*; *Arede et al., 2021*; *Attene et al., 2015*; *Beato et al., 2019a*; *Beato*

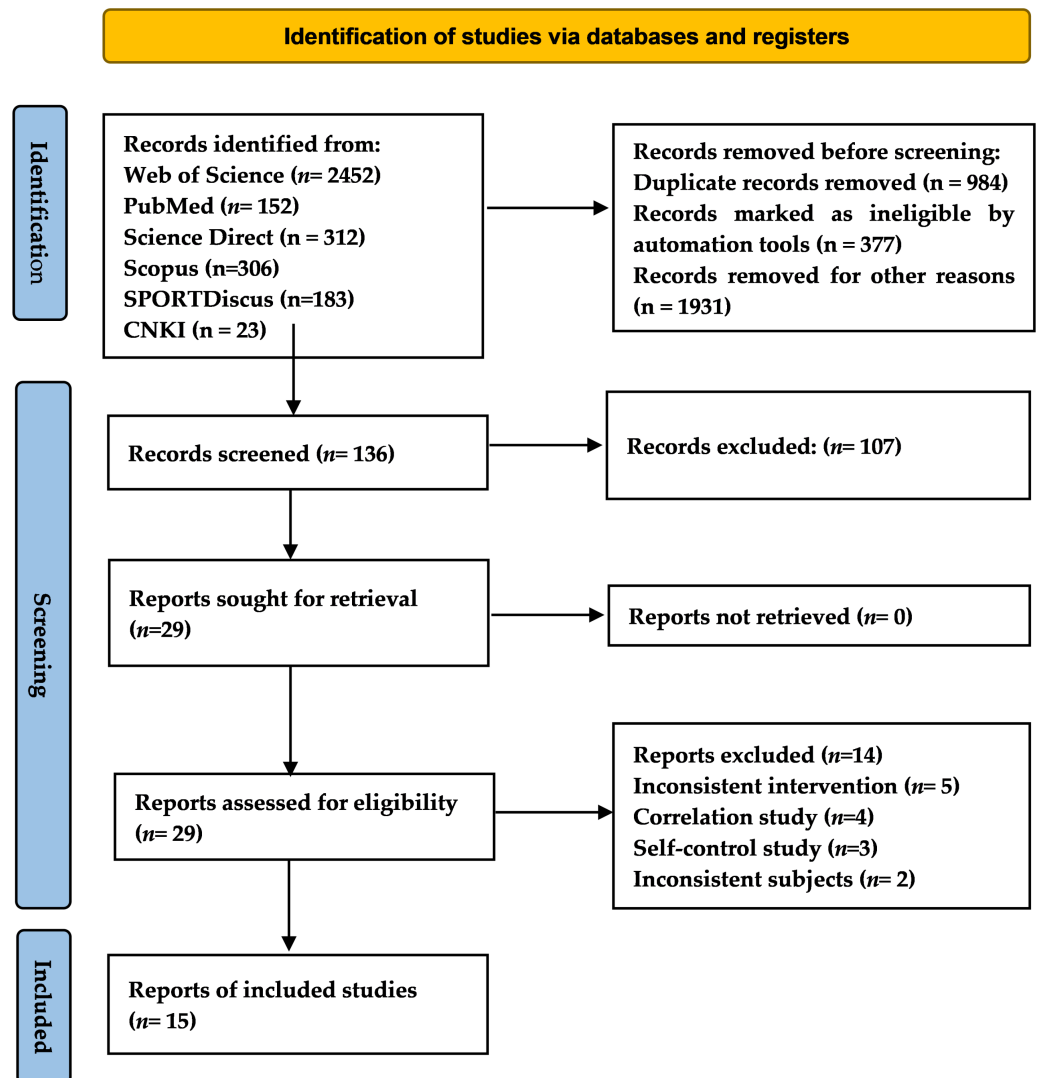**Identification of studies via databases and registers**

Identification

Records identified from:
Web of Science (*n*= 2452)
PubMed (*n*= 152)
Science Direct (n = 312)
Scopus (n=306)
SPORTDiscus (n=183)
CNKI (n = 23)

Records removed before screening:
Duplicate records removed (n = 984)
Records marked as ineligible by automation tools (n = 377)
Records removed for other reasons (n = 1931)

Screening

Records screened (*n*= 136)

Records excluded: (*n*= 107)

Reports sought for retrieval (*n*=29)

Reports not retrieved (*n*= 0)

Reports assessed for eligibility (*n*= 29)

Reports excluded (*n*=14)
Inconsistent intervention (*n*= 5)
Correlation study (*n*=4)
Self-control study (*n*=3)
Inconsistent subjects (*n*= 2)

Included

Reports of included studies (*n*= 15)

Figure 1 PRISMA flow chart for inclusion and exclusion of studies.
Full-size ☑ DOI: 10.7717/peerj.19416/fig-1

et al., 2019b; *Brini et al., 2020*; *Negra et al., 2022*; *Pavillon et al., 2021*; *Sagelv et al., 2019*; *Stanković et al., 2024*; *Zhou et al., 2024*; *Chtara et al., 2017*; *Young et al., 2013*; *Zhao, 2022*), meeting the eligibility criteria, were included for further analysis.

Study characteristics

A total of 15 studies involving 223 players were ultimately included in this article, as they met the inclusion criteria for the analysis. The detailed inclusion and exclusion process is illustrated in Fig. 1 below. The RS-OCOD group ($N = 124$) received repeat sprint training with one change of direction, while the RS-MCOD group ($N = 99$) received repeat sprint training with multiple change of direction (Table 3). Furthermore, all included studies were randomized parallel controlled trials. Soccer was the most frequently studied sport, comprising 10 studies (66.7%), followed by basketball with four studies (26.7%) and tennis

with 1 study (6.7%). Nine studies (60%) focused on trained or developmental players, while three studies (20%) involved highly trained or national-level players, and another three studies (20%) included elite or international-level players. Five studies (33.3%) examined adult players, whereas 10 studies (66.7%) focused on adolescent players. Only three studies (20%) included female players.

Risk of bias in the included articles

The Cochrane Risk of Bias assessment tool was utilized to evaluate the quality of the literature included in this meta-analysis. All studies considered in this analysis were randomized controlled trials that clearly described their methods for allocation concealment. Among these studies, only one reported the use of blinding for both researchers and participants. Regarding attrition bias, seven studies were found to be free of such bias, while one study demonstrated a high level of attrition bias. Within the scope of this meta-analysis, the body of included studies consisted of nine studies identified as having a low risk of bias and five studies with a moderate risk of bias, as illustrated in Fig. 2.

Meta-analysis results

The impact of RS-COD training on players' jumping ability

A cumulative total of eight studies, comprising 15 experimental groups and involving 250 participants, were included in this meta-analysis to evaluate the impact of RS-COD on players' jumping ability, as illustrated in Fig. 3. The aggregated effect sizes indicated that RS-COD had a moderate effect on countermovement jump (CMJ) (SMD = −0.69, 95% CI [−1.04 to −0.34]; $I^2 = 51.7\%$, $p = 0.01$). RS-OCOD demonstrated a large effect on CMJ (SMD = −0.92, 95% CI [−1.52 to −0.32]; $I^2 = 61.5\%$, $p = 0.02$), while RS-MCOD exhibited a moderate effect on CMJ (SMD = −0.53, 95% CI [−0.95 to −0.10]; $I^2 = 44.9\%$, $p = 0.08$). The aggregated effect sizes indicated that RS-COD had a small effect on SJ (SMD = −0.27, 95% CI [−0.56–0.02]; $I^2 = 0\%$, $p = 0.51$). Both RS-OCOD (SMD = −0.22, 95% CI [−065–0.21]; $I^2 = 0\%$, $p = 0.98$) and RS-MCOD (SMD = −0.29, 95% CI [−0.81–0.24]; $I^2 = 41.8\%$, $p = 0.16$) demonstrated a small effect on SJ. The prediction interval results were consistent with those of the meta-analysis, suggesting that the effect sizes of future studies on CMJ and SJ may not be statistically significant. Additionally, the prediction intervals for the subgroups indicated a consistent outcome.

The impact of RS-COD training on players' sprinting ability

A total of eleven studies, which included 28 experimental groups and 347 participants, were evaluated to determine the impact of RS-COD on players' sprinting ability, as illustrated in Fig. 4. The aggregated effect sizes indicated that RS-COD had a moderate effect on 5 m sprint speed (SMD = 0.69, 95% CI [−0.50–2.75]; $I^2 = 84.8\%$, $p = 0.00$). RS-OCOD demonstrated had a small effect on 5 m sprint speed (SMD = −0.31, 95% CI [−2.21–1.59]; $I^2 = 87.6\%$, $p = 0.00$), while RS-MCOD exhibited a large effect (SMD = 1.62, 95% CI [0.50–2.75]; $I^2 = 71.6\%$, $p = 0.01$). The aggregated effect sizes indicated that RS-COD had a small effect on 10 m sprint speed (SMD = 0.34, 95% CI [−0.11–0.78]; $I^2 = 67.8\%$, $p = 0.00$). Both RS-OCOD (SMD = 0.29, 95% CI [−0.24–0.82]; $I^2 = 65.1\%$, $p = 0.00$) and

Table 3 Summary of reviewed studies including study design, level of evidence, period, outcome and result.

Study	Participants	Age (yrs)	Intervention protocol		Week/ fre	Outcomes	Test equipment
			RS-OCOD	RS-MCOD			
Arede et al. (2021)	Amateur senior female basketball players	<19	Two sets of 10*10+10 m (one COD of 180°) with 30 s and 3 min recovery between sprints and sets	——	4/3	**Jumping ability:** CMJ (cm) **Sprint speed:** T10 (s), T25 (s) **Agility:** COD180R (s), COD180L (s)	Infrared optical system (OptoJump Next-Microgate, Bolzano, Italy) Photoelectric cells (Witty, Microgate, Bolzano, Italy)
Attene et al. (2015)	Young male basketball players	16 ± 1	Three sets of 6-8*15+15 m (one COD) with 20 s and 4 min recovery between sprints and sets	Three sets of 6-8*10+10+10 m with 30 s of passive recovery	4/2	**Jumping ability:** CMJ (cm), SJ (cm)	Accelerometer Myotest™ (Myotest SA, Sion, Switzerland)
Attene et al. (2016)	Young male (*n* = 14) and female (*n* = 22) basketball players	16.1 ± 0.9	Three sets of 6-8*15+15 m (one COD) with 20 s and 4 min recovery between sprints and sets	Three sets of 6-8*30 m (6*5m) with 30 s of passive recovery	4/2	**Jumping ability:** CMJ (cm), SJ (cm)	Accelerometer Myotest™ (Myotest SA, Sion, Switzerland)
Beato et al. (2019a)	Elite level young soccer players	18–21	Three sets of 7*20+20 m (one COD of 180°) with 20 s and 4 min recovery between sprints and sets	——	8/1	**Sprint speed:** T10 (s), T30 (s), T40 (s) **Agility:** 505COD (s)	Infrared timing gates (Microgate, Bolzano, Italy)
Beato et al. (2019b)	Amateur soccer players	21 ± 2.4	Three sets of 7*20+20 m (one COD of 180°) with 20 s and 4 min recovery between sprints and sets	——	2/2	**Sprint speed:** T10 (s), T20 (s) **Agility:** 505COD (s)	Infrared timing gates (Microgate, Bolzano, Italy)
Brini et al. (2020)	Professional male basketball players	22.06 ± 2.8	——	Three sets of 8*30 m (five COD of 90°) with 20 s and 4 min recovery between sprints and sets	12/2	**Jumping ability:** CMJ (cm), SJ (cm) **Agility:** *T*-test (s)	Optoelectric system (OptoJump Microgate, Italy) Electronic timing system (Brower Timing Systems, Salt Lake City, UT, USA)
Sanchez-Sanchez et al. (2019)	Youth soccer players	14.7 ± 0.5 14.4 ± 0.5	——	Three sets of 10*18 m (two COD of 90°) with 18 m low-intensity recovery running and 4 min passive recovery between sprints and sets	8/2	**Agility:** COD test (s)	Timing gates (Sport Test software, version 3.2.1; DSD Laser System)
Negra et al. (2022)	Youth male soccer players	15.6 ± 0.3	Two sets of 10*10+10 m with 5 s and 25 s recovery between sprints and sets	——	9/2	**Sprint speed:** T10 (s), T20 (s) **Agility** 505COD	Electronic timing system (Microgate srl, Bolzano, Italy)
Pavillon et al. (2021)	Elite young male soccer players	One: 15.5 ± 2.7 Multi: 15.9 ± 1.7	Two sets of 10*10+10 m with 5 s and 25 s recovery between sprints and sets	Four sets of 10*20 m (with 3 directions) with 5 s and 25 s recovery between sprints and sets	30/6	**Jumping ability:** CMJ (cm) **Sprint speed:** T5 (s), T10 (s) **Agility:** SPS (s)	Smart jump portable force platform (Fusion Smart Speed Jump Fusion Sport, Australia) Photoelectric cells (Smart Speed, Fusion Sport, Australia)
Sagelv et al. (2019)	High-level male junior football players	17.4 ± 0.7	——	Four sets of 10*20 m (with 3 directions) with 5 s and 25 s recovery between sprints and sets	22/2	**Sprint speed:** T10 (s), T20 (s)	Photocells (TC-Timer, Bower Timing System, Draper, UT, USA)

Table 3 (*continued*)

Study	Participants	Age (yrs)	Intervention protocol		Week/ fre	Outcomes	Test equipment
			RS-OCOD	**RS-MCOD**			
Stanković et al. (2024)	Highest level female soccer players	19.2 ± 4.2	——	Three sets of 4*5+5+20 m with 30 s and 5 s recovery between sprints and sets	6/2	**Jumping ability:** CMJ (cm), SJ (cm)	Two photoelectric cells (Optojump, Microgate, Bol''-zano, Italy)
						Sprint speed: T10 (s), T20 (s), T30 (s) **Agility:** Pro-agility test (s), Zig-zag test (s), 9-6-3-6-9 sprint (s)	Photocell infrared timing gates (Microgate, Polifemo Radio Light, Bolzano, Italy)
Zhou et al. (2024)	Collegiate tennis players	21.9 ± 1.66	——	15, 20 or 25 s linear running with three COD of 180° turn during each interval running	3/3	**Sprint speed:** T5 (s) **Agility:** T-drill test (s), Spider run test (s), Termed reactive agility (s)	Smart Speeds
Chtara et al. (2017)	Male elite-level field soccer players	13.6 ± 0.3	Two to four sets of 5-6*20-30 m (180° turns) sprints interspersed with 20s of passive recovery	——	6/2	**Sprint speed:** T10 (s), T30 (s)	Photocell gates (Brower Timing Systems, Salt Lake City, Utah, USA
						Agility: Zig-zag test (s)	Electronic timing gates (Brower Timing System, Salt Lake City, UT)
Zhao (2022)	Young football players	U17	Three sets of 5-7*30-40 m (180° turns) sprints interspersed with 20-25s of passive recovery and 4 min recovery between sprints and sets		8/2	**Jumping ability:** CMJ (cm), SJ (cm)	Smart jump portable force platform (Fusion Smart Speed Jump Fusion Sport, Australia)
						Sprint speed: T5 (s), T10 (s), T30 (s)	Electronic timing gates (Brower Timing System, Salt Lake City, UT)
Young et al. (2013)	Well-trained soccer player	21.2 ± 2.6		Two sets of 4-8*40 m (with 4 directions) with 2 min and 10 min recovery between sprints and sets	8/1	**Jumping ability:** CMJ (cm)	AMTI force platform; model OR6-5-1 (Watertown, USA)
						Sprint speed: T20 (s)	Infrared photocells

Notes.

CMJ, countermovement jump; SPS, Slalom sprint test; R, right; L, left.

T5/T10/T20/T25/T30/T40, 5-/10-/20-/25-/30-/40-meter sprint.

RS-MCOD (SMD = 0.42, 95% CI [−0.48–1.32]; I^2 = 76.5%, p = 0.00) demonstrated a small effect on 10 m sprint speed. The aggregated effect sizes indicated that RS-COD had a moderate effect on 20–40 m sprint speed (SMD = 0.70, 95% CI [0.39–1.01]; I^2 = 26.5%, p = 0.19). RS-OCOD demonstrated a moderate effect on 20–40 m sprint speed (SMD = 0.53, 95% CI [0.21–0.86]; I^2 = 0%, p = 0.52), while RS-MCOD exhibited a large effect (SMD = 0.97, 95% CI [0.37–1.58]; I^2 = 46.2%, p = 0.13). The prediction interval results were consistent with the meta-analysis results, which suggests that the effect size of future studies may not be statistically significant. The prediction interval results were consistent with those of the meta-analysis, suggesting that the effect sizes of future studies on 5 m, 10 m, and 20–40 m sprints may not be statistically significant. Additionally, the results of the
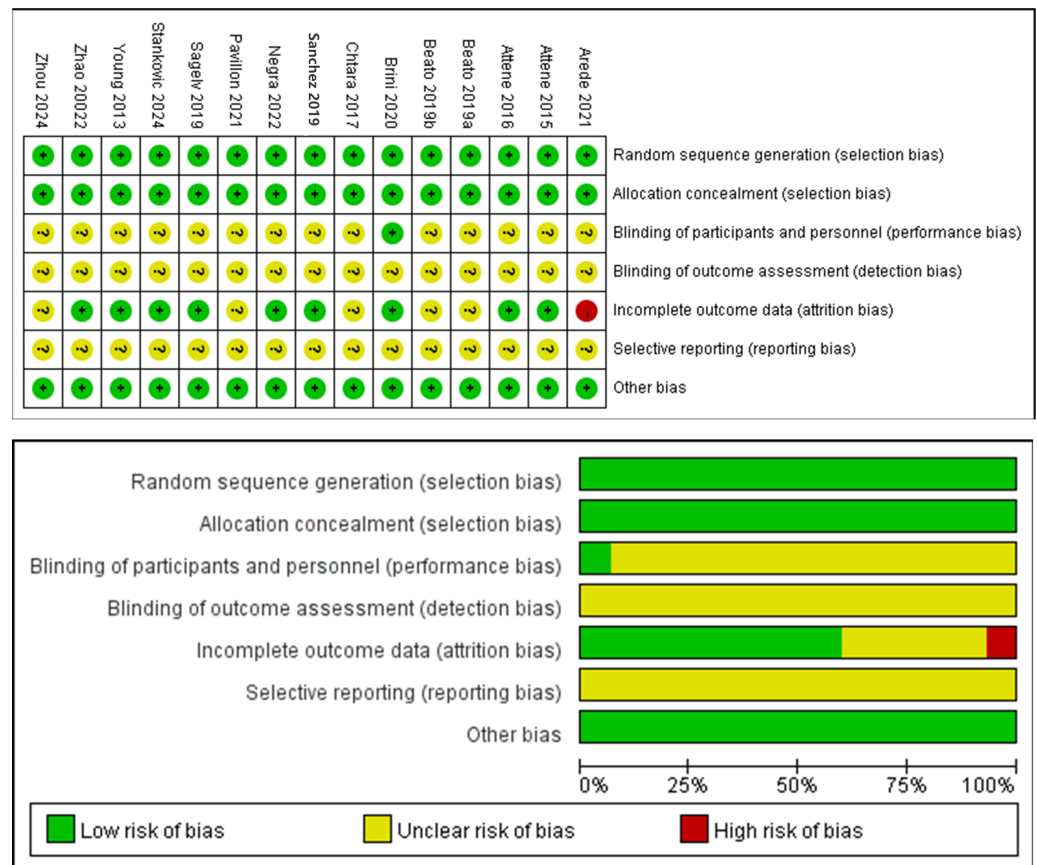
Figure 2 Risk of bias assessment chart. Note: *Arede et al. (2021)*; *Attene et al. (2015)*; *Attene et al. (2016)*; *Beato et al. (2019a)*; *Beato et al. (2019b)*; *Brini et al. (2020)*; *Chtara et al. (2017)*; *Sanchez-Sanchez et al. (2019)*; *Negra et al. (2022)*; *Pavillon et al. (2021)*; *Sagelv et al. (2019)*; *Stanković et al. (2024)*; *Young et al. (2013)*; *Zhao (2022)*; *Zhou et al. (2024)*.
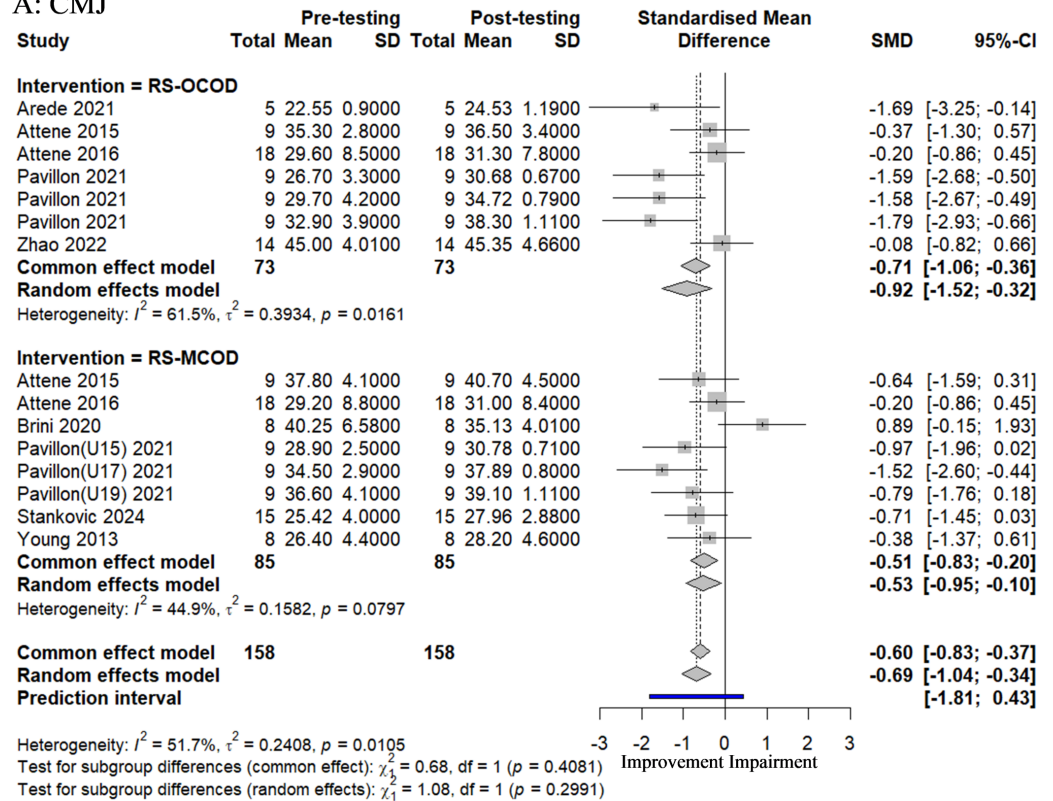
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20–40 m prediction interval yielded varying outcomes, and the prediction interval for the RS-OCOD subgroup confirmed its significantly enhanced effect (Supplementary file S2).

The impact of RS-COD training on COD ability

A total of ten studies, comprising 19 experimental groups and involving 259 participants. It was conducted to evaluate the impact of RS-COD on players' COD ability, as illustrated in Fig. 5. The aggregated effect sizes indicated that RS-COD had a moderate effect on COD ability (SMD = 0.77, 95% CI [0.39–1.16]; $I^2 = 71.7\%$, $p = 0.00$). RS-OCOD demonstrated a small effect on agility (SMD = 0.54, 95% CI [−0.15–1.22]; $I^2 = 77.5\%$, $p = 0.00$), while RS-MCOD exhibited a large effect (SMD = 0.97, 95% CI [0.56–1.38]; $I^2 = 60.2\%$, $p = 0.00$). The prediction interval results were consistent with the meta-analysis results, which suggests that the effect size of future studies may not be statistically significant. The prediction interval results were consistent with those of the meta-analysis, suggesting that the effect sizes of future studies may not be statistically significant. Additionally, the prediction intervals for the subgroups indicated a consistent outcome.
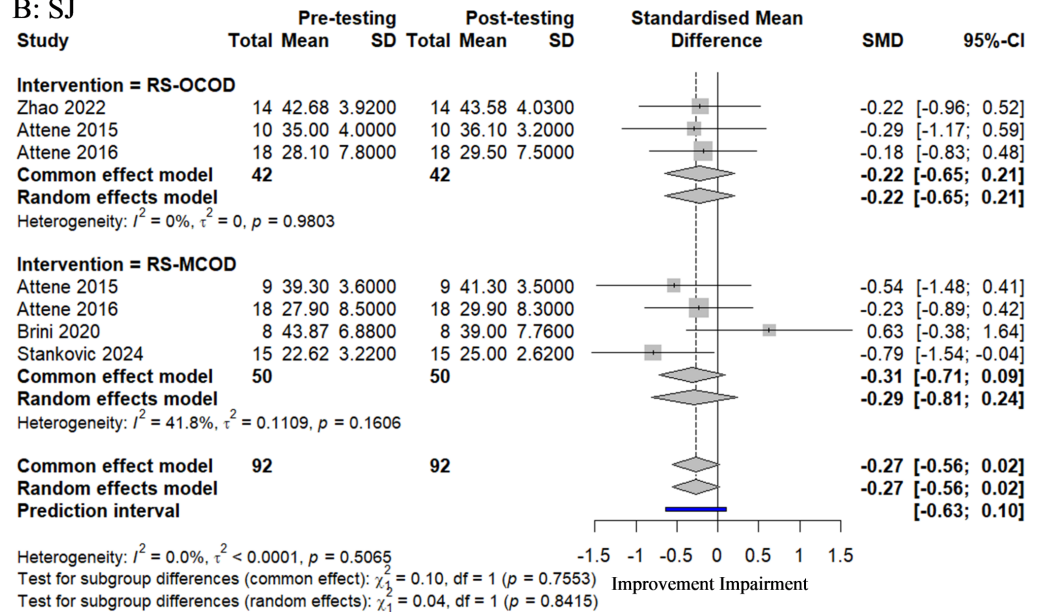
A: CMJ

		Pre-testing			Post-testing		Standardised Mean		
Study	Total	Mean	SD	Total	Mean	SD	Difference	SMD	95%-CI

Intervention = RS-OCOD

Study	Total	Mean	SD	Total	Mean	SD	SMD	95%-CI
Arede 2021	5	22.55	0.9000	5	24.53	1.1900	-1.69	[-3.25; -0.14]
Attene 2015	9	35.30	2.8000	9	36.50	3.4000	-0.37	[-1.30; 0.57]
Attene 2016	18	29.60	8.5000	18	31.30	7.8000	-0.20	[-0.86; 0.45]
Pavillon 2021	9	26.70	3.3000	9	30.68	0.6700	-1.59	[-2.68; -0.50]
Pavillon 2021	9	29.70	4.2000	9	34.72	0.7900	-1.58	[-2.67; -0.49]
Pavillon 2021	9	32.90	3.9000	9	38.30	1.1100	-1.79	[-2.93; -0.66]
Zhao 2022	14	45.00	4.0100	14	45.35	4.6600	-0.08	[-0.82; 0.66]
Common effect model	73			73			**-0.71**	**[-1.06; -0.36]**
Random effects model							**-0.92**	**[-1.52; -0.32]**

Heterogeneity: $I^2 = 61.5\%$, $\tau^2 = 0.3934$, $p = 0.0161$

Intervention = RS-MCOD

Study	Total	Mean	SD	Total	Mean	SD	SMD	95%-CI
Attene 2015	9	37.80	4.1000	9	40.70	4.5000	-0.64	[-1.59; 0.31]
Attene 2016	18	29.20	8.8000	18	31.00	8.4000	-0.20	[-0.86; 0.45]
Brini 2020	8	40.25	6.5800	8	35.13	4.0100	0.89	[-0.15; 1.93]
Pavillon(U15) 2021	9	28.90	2.5000	9	30.78	0.7100	-0.97	[-1.96; 0.02]
Pavillon(U17) 2021	9	34.50	2.9000	9	37.89	0.8000	-1.52	[-2.60; -0.44]
Pavillon(U19) 2021	9	36.60	4.1000	9	39.10	1.1100	-0.79	[-1.76; 0.18]
Stankovic 2024	15	25.42	4.0000	15	27.96	2.8800	-0.71	[-1.45; 0.03]
Young 2013	8	26.40	4.4000	8	28.20	4.6000	-0.38	[-1.37; 0.61]
Common effect model	85			85			**-0.51**	**[-0.83; -0.20]**
Random effects model							**-0.53**	**[-0.95; -0.10]**

Heterogeneity: $I^2 = 44.9\%$, $\tau^2 = 0.1582$, $p = 0.0797$

Common effect model	158			158				**-0.60**	**[-0.83; -0.37]**
Random effects model								**-0.69**	**[-1.04; -0.34]**
Prediction interval									**[-1.81; 0.43]**

Heterogeneity: $I^2 = 51.7\%$, $\tau^2 = 0.2408$, $p = 0.0105$
Test for subgroup differences (common effect): $\chi^2_1 = 0.68$, df = 1 ($p = 0.4081$)
Test for subgroup differences (random effects): $\chi^2_1 = 1.08$, df = 1 ($p = 0.2991$)

-3 -2 -1 0 1 2 3
Improvement Impairment

B: SJ

		Pre-testing			Post-testing		Standardised Mean		
Study	Total	Mean	SD	Total	Mean	SD	Difference	SMD	95%-CI

Intervention = RS-OCOD

Study	Total	Mean	SD	Total	Mean	SD	SMD	95%-CI
Zhao 2022	14	42.68	3.9200	14	43.58	4.0300	-0.22	[-0.96; 0.52]
Attene 2015	10	35.00	4.0000	10	36.10	3.2000	-0.29	[-1.17; 0.59]
Attene 2016	18	28.10	7.8000	18	29.50	7.5000	-0.18	[-0.83; 0.48]
Common effect model	42			42			**-0.22**	**[-0.65; 0.21]**
Random effects model							**-0.22**	**[-0.65; 0.21]**

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.9803$

Intervention = RS-MCOD

Study	Total	Mean	SD	Total	Mean	SD	SMD	95%-CI
Attene 2015	9	39.30	3.6000	9	41.30	3.5000	-0.54	[-1.48; 0.41]
Attene 2016	18	27.90	8.5000	18	29.90	8.3000	-0.23	[-0.89; 0.42]
Brini 2020	8	43.87	6.8800	8	39.00	7.7600	0.63	[-0.38; 1.64]
Stankovic 2024	15	22.62	3.2200	15	25.00	2.6200	-0.79	[-1.54; -0.04]
Common effect model	50			50			**-0.31**	**[-0.71; 0.09]**
Random effects model							**-0.29**	**[-0.81; 0.24]**

Heterogeneity: $I^2 = 41.8\%$, $\tau^2 = 0.1109$, $p = 0.1606$

Common effect model	92			92				**-0.27**	**[-0.56; 0.02]**
Random effects model								**-0.27**	**[-0.56; 0.02]**
Prediction interval									**[-0.63; 0.10]**

Heterogeneity: $I^2 = 0.0\%$, $\tau^2 < 0.0001$, $p = 0.5065$
Test for subgroup differences (common effect): $\chi^2_1 = 0.10$, df = 1 ($p = 0.7553$)
Test for subgroup differences (random effects): $\chi^2_1 = 0.04$, df = 1 ($p = 0.8415$)

-1.5 -1 -0.5 0 0.5 1 1.5
Improvement Impairment

Figure 3 **Forest plot of the effect of RS-COD on players' jumping ability.** Note: *Arede et al. (2021)*; *Attene et al. (2015)*; *Attene et al. (2016)*; *Brini et al. (2020)*; *Chtara et al. (2017)*; *Sanchez-Sanchez et al. (2019)*; *Pavillon et al. (2021)*; *Stanković et al. (2024)*; *Young et al. (2013)*; *Zhao (2022)*.
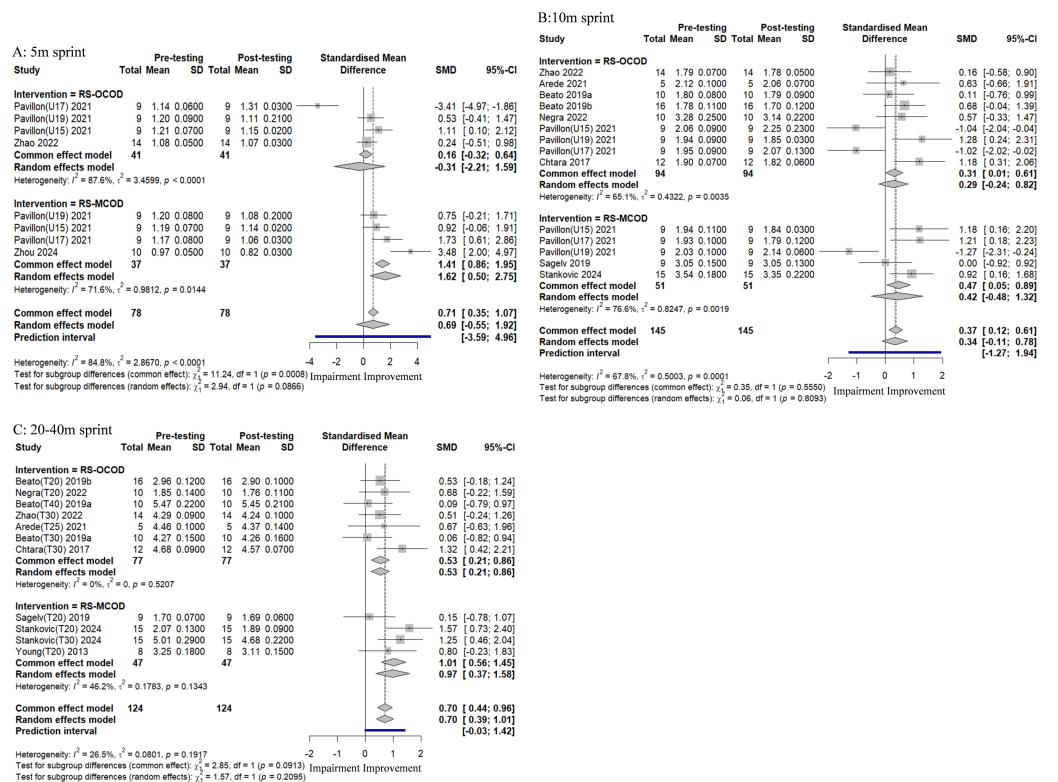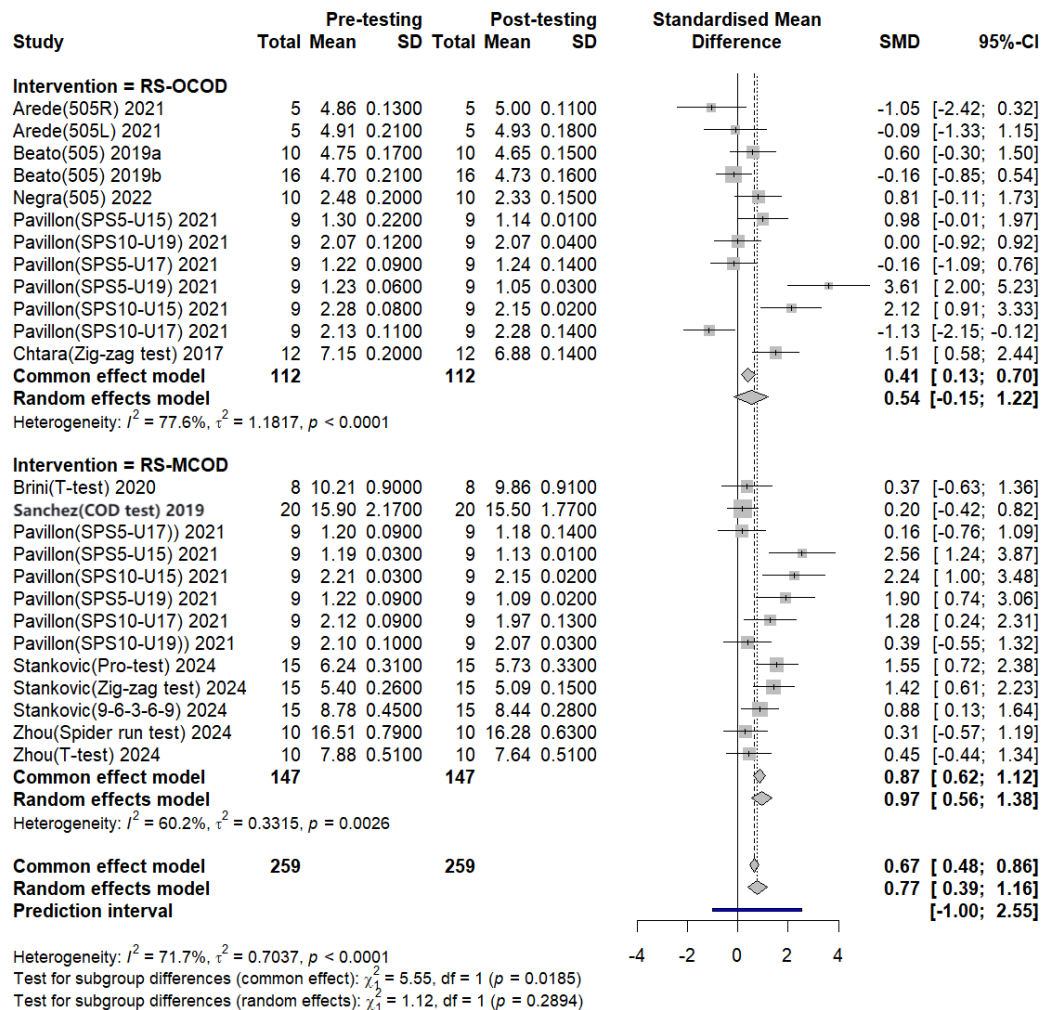
Full-size 🖼 DOI: 10.7717/peerj.19416/fig-3

Figure 4 Forest plot of the effect of RS-COD on players' sprinting ability. Note: *Arede et al. (2021)*; *Attene et al. (2015)*; *Attene et al. (2016)*; *Beato et al. (2019a)*; *Beato et al. (2019b)*; *Brini et al. (2020)*; *Chtara et al. (2017)*; *Sanchez-Sanchez et al. (2019)*; *Negra et al. (2022)*; *Pavillon et al. (2021)*; *Sagelv et al. (2019)*; *Stanković et al. (2024)*; *Young et al. (2013)*; *Zhao (2022)*; *Zhou et al. (2024)*.

Full-size 🖼 DOI: 10.7717/peerj.19416/fig-4

Reporting bias

Upon visual inspection of the funnel plot (Fig. 6), indications of publication bias were observed. The distribution of effect sizes for explosive force was asymmetrical, with the majority of effect sizes skewed to the left side of the funnel, resulting in an irregular shape of the funnel plot. Egger's test confirmed these visual observations, yielding significant results for jumping ability ($p = 0.04$). In contrast, no significant publication bias was detected for sprinting ability ($p = 0.46$) or COD ability ($p = 0.06$). The presence of publication bias, particularly concerning jumping ability, was further supported by the funnel plot analysis. Notably, after four iterations using the linear method, the software estimated that there were no missing studies, resulting in a count of zero. Following the pruning and filling procedure, no adjustments were made to the funnel plot, and the combined results remained unchanged. This suggests that the aggregated outcomes of the meta-analysis are robust and reliable.

Sensitivity analysis

A sensitivity analysis was conducted using Stata 15.0 to assess the impact of each individual study on the outcomes of the meta-analysis, as illustrated in Fig. 7. The analysis revealed that

Figure 5 **Forest plot of the effect of RS-COD on players' COD ability.** Note: *Arede et al. (2021)*; *Attene et al. (2015)*; *Attene et al. (2016)*; *Beato et al. (2019a)*; *Beato et al. (2019b)*; *Brini et al. (2020)*; *Chtara et al. (2017)*; *Sanchez-Sanchez et al. (2019)*; *Negra et al. (2022)*; *Pavillon et al. (2021)*; *Sagelv et al. (2019)*; *Stanković et al. (2024)*; *Young et al. (2013)*; *Zhao (2022)*; *Zhou et al. (2024)*.

Full-size 🖼 DOI: 10.7717/peerj.19416/fig-5

the sensitivity of RS-COD in relation to players' jumping ability is approximately -0.49, indicating a stable relationship within the study. Similarly, the sensitivity of RS-COD concerning players' sprinting ability was found to be around 0.58, while the sensitivity for COD ability was approximately 0.77. These sensitivity values highlight the relative stability and reliability of the data included in this meta-analysis. The results of this sensitivity analysis strengthen confidence in the robustness of the aggregated findings presented.

DISCUSSION

This systematic review and meta-analysis is the first to compare the effects of RS-OCOD and RS-MCOD on players' jumping, sprinting, and COD abilities. The analysis included 15 studies involving 223 players. The overall effect estimates indicated that RS-COD

A: Jumping ability

B: Sprinting ability
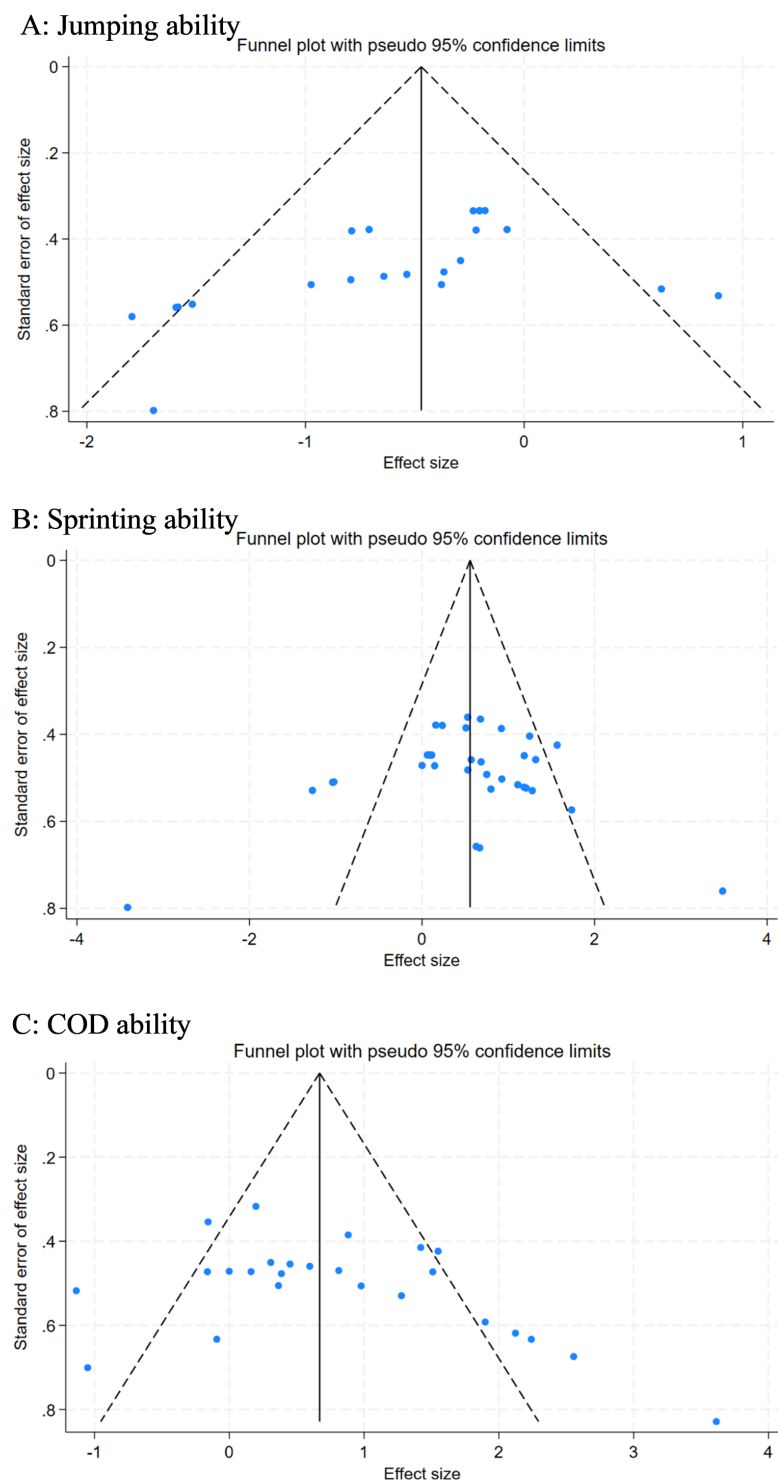
C: COD ability

Figure 6 Funnel plot of the effect of RS-COD on players' (A) jumping, (B) sprinting, and (C) COD abilities.

Full-size 🖼 DOI: 10.7717/peerj.19416/fig-6
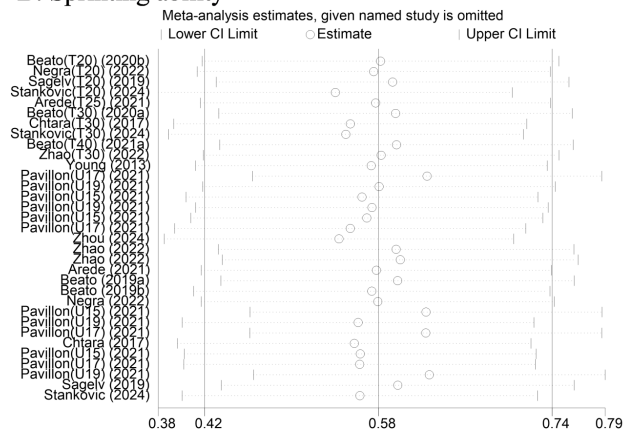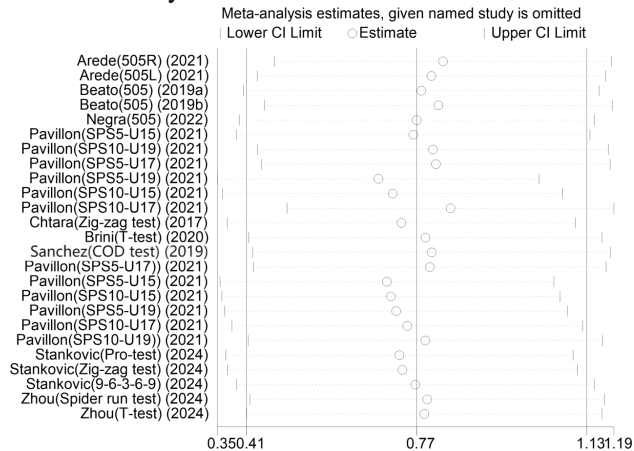
Figure 7   Sensitivity analysis of the effect of RS-COD on players' (A) jumping, (B) sprinting, and (C) COD abilities. Note: *Arede et al. (2021)*; *Attene et al. (2015)*; *Attene et al. (2016)*; *Beato et al. (2019a)*; *Beato et al. (2019b)*; *Brini et al. (2020)*; *Chtara et al. (2017)*; *Sanchez-Sanchez et al. (2019)*; *Negra et al. (2022)*; *Pavillon et al. (2021)*; *Sagelv et al. (2019)*; *Stanković et al. (2024)*; *Young et al. (2013)*; *Zhao (2022)*; *Zhou et al. (2024)*.

Full-size ⬚ DOI: 10.7717/peerj.19416/fig-7

effectively improved CMJ, 20–40 m sprinting ability, and COD ability. However, since none of these results were confirmed by prediction intervals, the interpretation of these meta-analysis findings should be approached with caution and an objective perspective. This also underscores the necessity for further research to better estimate the differential effects of RS-OCOD and RS-MCOD. The subgroup analyses in this study were pre-planned to prevent data-driven exploration and minimize Type I errors. Our results indicated that both RS-OCOD and RS-MCOD significantly improved CMJ, 20–40 m sprinting, and COD abilities, with RS-MCOD also showing a notable enhancement in 5 m sprinting ability. The prediction interval for RS-OCOD in 20–40 m sprinting ability suggests that its effects may persist in future studies. A comparison of effect sizes revealed that RS-OCOD was more effective than RS-MCOD in enhancing CMJ, while the reverse was true for 20–40 m sprinting ability and COD ability. Based on these findings, we recommend prioritizing RS-OCOD for sports that require explosive jumping, such as basketball and volleyball. Conversely, for sports that involve frequent directional changes, such as football and basketball, RS-MCOD is the preferred training method.

Jumping ability

This meta-analysis evaluated the effects of RS-COD on players' jumping ability. The results demonstrated that both RS-OCOD and RS-MCOD improved CMJ height, with RS-OCOD exhibiting a superior enhancement compared to RS-MCOD. The analysis revealed potential publication bias in the jumping ability data, which was adjusted using the trim-and-fill method. No additional studies were imputed during this adjustment, and sensitivity analysis confirmed the robustness of the findings, indicating relatively stable outcomes for meta-analysis of jumping ability. We conducted a self-assessment to identify potential causes of publication bias. First, the inclusion of both CMJ and SJ metrics in the jumping ability analysis may have contributed to heterogeneity. Second, duplicate inclusion of three studies was identified: two studies (*Attene et al., 2016*; *Attene et al., 2015*) were repeatedly incorporated due to reporting dual jump metrics, and one study (*Pavillon et al., 2021*) was redundantly included for analyzing three distinct population subgroups. These factors likely explain the observed publication bias in the jumping ability outcomes.

Previous studies suggest that most players benefit from increased exposure to varied movement combinations and repetitive high-intensity neuromuscular activation, which leads to short-term improvements in jumping ability (*Arede et al., 2021*). Specifically, enhancements in neural drive are associated with greater recruitment of agonist muscles, elevated neuronal firing rates, and improved synchronization of neural firing timing (*Haff, Triplett & NSCA, 2016*). Similarly, central adaptations induced by heightened neural activation can increase motor unit activation, resulting in enhanced muscle contraction intensity and stiffness (*Haff, Triplett & NSCA, 2016*). *Attene et al. (2015)* directly compared RS-OCOD and RS-MCOD (involving two 180° turns) and found that both significantly improved players' CMJ, while only RS-MCOD enhanced SJ height. Furthermore, RS-MCOD demonstrated a notable advantage over RS-OCOD in CMJ improvement. In a follow-up study with increased directional complexity (six directions), the researchers observed comparable effects of RS-OCOD and RS-MCOD on jumping ability (*Attene*

et al., 2016). *Pavillon et al. (2021)* reported similar conclusions in their investigation of RS-COD with three directional changes.

In the present study, the effect size comparison indicated that RS-OCOD may outperform RS-MCOD in CMJ improvement, although this difference was not confirmed by prediction intervals. CMJ is inherently a single explosive action requiring precise coordination between the braking (deceleration) and concentric (acceleration) phases. RS-OCOD may maximize the utilization of the stretch-shortening cycle, enabling muscles to generate higher power output within shorter timeframes, which plausibly explains its superior efficacy in CMJ enhancement observed in this analysis.

Sprinting ability

This meta-analysis evaluated the effects of RS-COD on players' sprinting ability. The results demonstrated that both RS-OCOD and RS-MCOD improved 20–40 m sprint speed in players, with effect size magnitudes indicating superior efficacy of RS-MCOD over RS-OCOD. Furthermore, RS-MCOD exhibited additional benefits in 5 m sprint speed.

The observed improvements in ≥20 m sprint speed across both protocols may be attributed to cumulative adaptations from RST. Previous studies have established that repeated sprint efforts induce increases in muscle metabolites (*e.g.*, phosphocreatine and glycogen* 32%) and enzymatic activity (*Rodas et al., 2000*). The total single-session sprint distances (20–40 m) employed in the included RS-COD interventions align closely with the outcome measures demonstrating significant effects, which may explain the primary training-induced enhancements in 20–40 m sprints. The superior effect sizes observed in RS-MCOD compared to RS-OCOD could be associated with the higher frequency of COD components in RS-MCOD protocols. Compared to mechanical straight-line repetitions (*Henz & Schöllhorn, 2016*) multidirectional movement patterns (*e.g.*, direction-altered sprints) elicit greater neuromuscular (*Horst et al., 2016*) and neurophysiological adaptations through enhanced storage of elastic energy during eccentric phases, thereby facilitating greater kinetic energy release during concentric phases. However, prediction intervals suggest potential overestimation of RS-MCOD effects while confirming RS-OCOD efficacy. These mechanisms may also account for the additional 5 m sprint speed improvements observed with RS-MCOD. Notably, the high methodological repetitiveness among studies investigating 5 m sprint speed in this meta-analysis (as reflected in prediction intervals indicating potential null effects in future studies) limits definitive conclusions, suggesting that RS-MCOD may only potentially induce positive effects on 5 m sprint speed. Therefore, further experimental investigations are warranted to clarify RS-COD's impacts on 5 m sprint speed.

Substantial heterogeneity was observed in meta-analyses of 5 m and 10 m sprint speeds. This may partially stem from our a priori decision to stratify interventions as subgroups, which inherently introduces methodological heterogeneity and justified our selection of random-effects models. Additionally, while we specifically selected player populations, the broad age range of included participants (13–22 years in 10 m sprint studies) likely contributed to the observed heterogeneity.

Change of direction ability

This meta-analysis evaluated the effects of RS-COD on players' COD ability. The results demonstrated that RS-COD effectively enhances players' COD ability, with RS-MCOD emerging as the primary influential modality for COD improvement. COD ability constitutes a critical physical competency component in numerous sports (*Brughelli et al., 2008*). RS-COD can be incorporated into RST programs to emphasize directional changes, limit absolute running velocity, and induce physiological demands comparable to RS-SS (*Thurlow et al., 2023*). Post-RST enhancements in explosive physical capacities may originate from neuromuscular and morphological adaptations. Neural adaptations may involve increased motor unit recruitment, firing frequency, and synchronization (*Schmidt, 2004*), while morphological changes could include shifts toward type IIa muscle fibers and increased muscle cross-sectional area (*Ross & Leveritt, 2001*). These mechanisms may explain RS-COD's superior efficacy in improving players' COD capabilities. Notably, the acute demands of RS-COD execution depend on the number and angles of directional changes, inter-change distances, and sequence duration (*Padulo et al., 2015*; *Attene et al., 2016*; *Buchheit et al., 2010*), all of which influence absolute velocities and muscular work during acceleration, propulsion, and deceleration phases. The integration of COD into RST accumulates acceleration-deceleration cycles, potentially amplifying neuromuscular demands (*Buchheit, Haydar & Ahmaidi, 2012*).

The effect size magnitudes indicated RS-MCOD as an effective approach for enhancing players' COD ability, whereas RS-OCOD demonstrated limited efficacy. During training interventions, both the frequency of COD maneuvers and turning angles serve as deterministic factors for muscular adaptation (*Stanković et al., 2022*). RS-MCOD's requirement for frequent directional changes promotes superior reactive strength development, optimizes pre-activation mechanisms, and enhances joint stiffness (*Arede et al., 2021*). Furthermore, RS-MCOD protocols involving multiple directional alterations (*e.g.*, 3–5 consecutive turns of 90°–180°) better replicate real-game scenarios, comprehensively stimulating players' deceleration-acceleration capacity, center-of-mass control, and dynamic balance, thereby significantly improving COD ability. However, substantial heterogeneity observed in forest plot interpretations introduced potential analytical errors. We attribute this heterogeneity primarily to methodological variations in COD assessment tools (Table 2). The included studies utilized diverse COD evaluation metrics: COD test, *T*-test, spider run test, zig-zag test, pro-test, 9-6-3-9 test, and slalom sprint test. While these measurement discrepancies likely contributed to heterogeneity, the established reliability and validity of all incorporated assessment methods partially mitigated methodological influences on outcome interpretation.

LIMITATIONS

When interpreting the findings of this study regarding the impact of RS-COD on player ability, several limitations must be acknowledged. Firstly, there is a scarcity of direct comparative studies between RS-OCOD and RS-MCOD, which may introduce bias when synthesizing data from various investigations. Secondly, the exclusion of five studies due

to non-compliance with established intervention definitions suggests inconsistencies and a lack of standardization in intervention protocols across studies (see Supplementary file S1). Variations in intervention schemes may also contribute to the heterogeneity of results (Table 2). Additionally, although we examined and cataloged the measurement devices used in the included studies and found that the methods employed were generally consistent, we cannot dismiss the possibility that minor variations in these methods may have influenced the results. Lastly, the presence of publication bias, as indicated by the asymmetry in the funnel plot and confirmed by Egger's test, suggests that unpublished studies may affect the comprehensiveness of our conclusions. While sensitivity analysis provided some assurance regarding the stability of the data, any analysis relying on a finite dataset is subject to the constraints of sample selection and data integrity. These limitations should be considered when assessing the effectiveness of RS-COD in enhancing player ability. Future research should aim to address these gaps to provide a more robust evidence base for the incorporation of RS-COD into training regimens.

CONCLUSION

This systematic review and meta-analysis comprehensively assessed the impact of RS-COD training on players' jumping, sprinting, and COD abilities. The results indicated that RS-COD significantly enhanced these key sports performance indicators, with RS-OCOD can significantly enhance a player's CMJ ability, while RS-MCOD can notably improve sprinting and COD abilities. These findings support the application of RS-COD as a specialized form of RST in player training to improve competitive performance. Among them, RS-MCOD is prioritized for sports requiring frequent directional changes, whereas RS-OCOD enhances vertical jump performance in explosive sports.

PRACTICAL APPLICATION

Based on the findings of this study, we recommend implementing sport-specific training protocols to optimize performance adaptations. For sports requiring explosive vertical jumps such as basketball and volleyball, RS-OCOD protocols incorporating 180° directional changes followed by vertical jumps should be prioritized, with a training frequency of 2–3 sessions per week, each comprising 6-8 sprints interspersed with 30-second recovery intervals to enhance lower limb explosive power. Sports involving frequent directional changes like soccer and basketball would benefit from RS-MCOD protocols consisting of 3–4 weekly sessions with 6-8 sprints per session (incorporating 3–5 directional changes at 90°–180° angles), implemented with 4–5 min of inter-set recovery and 20–40 s of inter-repetition rest, supplemented by cone drills or agility ladder exercises to simulate game-specific scenarios and improve rapid deceleration-acceleration capabilities. For racquet sports including tennis and badminton, modified RS-MCOD protocols focusing on smaller-range lateral movements are recommended to enhance sidestepping performance. Standardized movement execution should be strictly enforced during training to minimize injury risk, complemented by dynamic recovery activities (*e.g.*, light jogging/stretching) between sets and post-session cryotherapy to facilitate recovery. The training program

should integrate eccentric lower limb exercises (*e.g.*, Nordic hamstring curls) with neuromuscular activation drills (*e.g.*, light signal reaction training), while adopting periodized loading strategies—emphasizing RS-MCOD during preseason (12-week program) and transitioning to maintenance training during competitive seasons (1–2 sessions per week, *e.g.*, 2 sets × 4 sprints). Scientific optimization of training parameters (including directional complexity and recovery duration) combined with standardized monitoring protocols can maximize performance gains, while future research should explore potential synergistic effects with cognitive training interventions.

ADDITIONAL INFORMATION AND DECLARATIONS

REFERENCES

Arede J, Poureghbali S, Freitas T, Fernandes J, Schoellhorn WI, Leite N. 2021. The effect of differential repeated sprint training on physical performance in female basketball players: a pilot study. *International Journal of Environmental Research and Public Health* **18(23):**12616 DOI 10.3390/ijerph182312616.

Attene G, Laffaye G, Chaouachi A, Pizzolato F, Migliaccio GM, Padulo J. 2015. Repeated sprint ability in young basketball players: one *vs.* two changes of direction (Part 2). *Journal of Sports Sciences* **33(15)**:1553–1563 DOI 10.1080/02640414.2014.996182.

Attene G, Nikolaidis PT, Bragazzi NL, Dello Iacono A, Pizzolato F, Zagatto AM, Dal Pupo J, Oggianu M, Migliaccio GM, Pacini EM, Padulo J. 2016. Repeated sprint ability in young basketball players (Part 2): the chronic effects of multidirection and of one change of direction are comparable in terms of physiological and performance responses. *Frontiers in Physiology* **7** DOI 10.3389/fphys.2016.00262.

Beato M, Bianchi M, Coratella G, Merlini M, Drust B. 2019a. A single session of straight line and change-of-direction sprinting per week does not lead to different fitness improvements in elite young soccer players. *Journal of Strength and Conditioning Research* **36(2)**:518–524 DOI 10.1519/JSC.0000000000003369.

Beato M, Coratella G, Bianchi M, Costa E, Merlini M. 2019b. Short-term repeated-sprint training (straight sprint *vs.* changes of direction) in soccer players. *Journal of Human Kinetics* **70(1)**:183–190.

Bishop D, Girard O, Mendez-Villanueva A. 2011. Repeated-sprint ability—part II. *Sports Medicine* **41(9)**:741–756 DOI 10.2165/11590560-000000000-00000.

Born D-P, Zinner C, Dueking P, Sperlich B. 2016. Multi-directional sprint training improves change-of-direction speed and reactive agility in young highly trained soccer players. *Journal of Sports Science and Medicine* **15(2)**:314–319.

Brini S, Ben Abderrahman A, Boullosa D, Hackney AC, Zagatto AM, Castagna C, Bouassida A, Granacher U, Zouhal H. 2020. Effects of a 12-week change-of-direction sprints training program on selected physical and physiological parameters in professional basketball male players. *International Journal of Environmental Research and Public Health* **17(21)**.

Brini S, Boullosa D, Calleja-González J, Van den Hoek DJ, Nobari H, Clemente FM. 2022. Impact of combined versus single-mode training programs based on drop jump and specific multidirectional repeated sprint on bio-motor ability adaptations: a parallel study design in professional basketball players. *BMC Sports Science, Medicine & Rehabilitation* **14(1)**:160 DOI 10.1186/s13102-022-00551-w.

Brini S, Boullosa D, Calleja-González J, Ramirez-Campillo R, Nobari H, Castagna C, Clemente FM, Ardigò LP. 2023. Neuromuscular and balance adaptations following basketball-specific training programs based on combined drop jump and multidirectional repeated sprint versus multidirectional plyometric training. *PLOS ONE* **18(3)**:e0283026 DOI 10.1371/journal.pone.0283026.

Brini S, Delextrat A, Bouassida A. 2021. Variation in lower limb power and three point shot performance following repeated sprints: one *vs.* five changes of direction in male basketball players. *Journal of Human Kinetics* **77(1)**:169–179 DOI 10.2478/hukin-2021-0019.

Brughelli M, Cronin J, Levin G, Chaouachi A. 2008. Understanding change of direction ability in sport: a review of resistance training studies. *Sports Medicine* **38(12)**:1045–1063 DOI 10.2165/00007256-200838120-00007.

Buchheit M, Bishop D, Haydar B, Nakamura FY, Ahmaidi S. 2010. Physiological responses to shuttle repeated-sprint running. *International Journal of Sports Medicine* **31(6)**:402–409 DOI 10.1055/s-0030-1249620.

Buchheit M, Haydar B, Ahmaidi S. 2012. Repeated sprints with directional changes: do angles matter? *Journal of Sports Sciences* **30(6)**:555–562 DOI 10.1080/02640414.2012.658079.

Burgomaster KA, Heigenhauser GJ, Gibala MJ. 2006. Effect of short-term sprint interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance. *Journal of Applied Physiology* **100(6)**:2041–2047 DOI 10.1152/japplphysiol.01220.2005.

Chandler J, Cumpston M, Li T, Page MJ, Welch V. 2019. *Cochrane handbook for systematic reviews of interventions*. Vol. 4. Hoboken: Wiley.

Chen TT. 2019. Study on the effect of multi-direction repeated sprint running training on YOYO test scores and cognitive ability of children. Master's degree thesis, Shandong Normal University, Shandong.

Chtara M, Rouissi M, Haddad M, Chtara H, Chaalali A, Owen A, Chamari K. 2017. Specific physical trainability in elite young soccer players: efficiency over 6 weeks' in-season training. *Biology of Sport* **34(2)**:137–148 DOI 10.5114/biolsport.2017.64587.

Cumpston M, Li T, Page MJ, Chandler J, Welch VA, Higgins JP, Thomas J. 2019. Updated guidance for trusted systematic reviews: a new edition of the cochrane handbook for systematic reviews of interventions. *The Cochrane Database of Systematic Reviews* **10** DOI 10.1002/14651858.ED000142.

Dal Pupo J, Detanico D, Carminatti LJ, Santos SG. 2013. Physiological and neuro-muscular responses in the shuttle and straight line-repeated sprint running. *Apunts Medicina de L'Esport* **48(178)**:43–48 DOI 10.1016/j.apunts.2012.11.001.

Fernandez-Fernandez J, Zimek R, Wiewelhove T, Ferrauti A. 2012. High-intensity interval training *vs.* repeated-sprint training in tennis. *Journal of Strength and Conditioning Research* **26(1)**:53–62 DOI 10.1519/JSC.0b013e318220b4ff.

Gibala MJ, Little JP, Van Essen M, Wilkin GP, Burgomaster KA, Safdar A, Raha S, Tarnopolsky MA. 2006. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise perfor-mance. *Journal de Physiologie* **575(Pt 3)**:901–911 DOI 10.1113/jphysiol.2006.112094.

Haff GG, Triplett NT, NSCA—National Strength & Conditioning Association (ed). 2016. *Essentials of strength training and conditioning*. 4th Edition. Vol. 48(10). Human Kinetics, 2073.

Henz D, Schöllhorn WI. 2016. Differential training facilitates early consolidation in mo-tor learning. *Frontiers in Behavioral Neuroscience* **10** DOI 10.3389/fnbeh.2016.00199.

Higgins JP, Thompson SG, Deeks JJ, Altman DG. 2003. Measuring inconsistency in meta-analyses. *BMJ* **327(7414)**:557–560 DOI 10.1136/bmj.327.7414.557.

Hoffmann Jr J, Reed J, Leiting K, Chiang CY, Stone M. 2014. Repeated sprints, high-intensity interval training, small-sided games: theory and application to field sports. *International Journal of Sports Physiology & Performance* **9(2)**:352–357 DOI 10.1123/ijspp.2013-0189.

Horst F, Rupprecht C, Schmitt M, Hegen P, Schllhorn WI. 2016. Muscular activity in conventional and differential back squat exercise. In: *Proceedings of the 21st annual congress of the European College of Sport Science, F.*

Kilit B, Chmura P, Arslan E, Soylu Y, Radziminski L. 2025. Effects of 2 combined training protocols on the aerobic and anaerobic fitness, technical skills, and psychophysiological responses in young soccer players. *Journal of Strength and Conditioning Research* **39(1)**:86–93 DOI 10.1519/jsc.0000000000004955.

McKay AKA, Stellingwerff T, Smith ES, Martin DT, Mujika I, Goosey-Tolfrey VL, Sheppard J, Burke LM. 2022. Defining training and performance caliber: a participant classification framework. *International Journal of Sports Physiology and Performance* **17(2)**:317–331 DOI 10.1123/ijspp.2021-0451.

Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. 2010. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *International Journal of Surgery* **8(5)**:336–341 DOI 10.1016/j.ijsu.2010.02.007.

Morais JE, Kilit B, Arslan E, Bragada JA, Soylu Y, Marinho DA. 2025. Effects of on-court tennis training combined with HIIT versus RST on aerobic capacity, speed, agility, jumping ability, and internal loads in young tennis players. *Journal of Human Kinetics* **95**:173–185 DOI 10.5114/jhk/189691.

Negra Y, Sammoud S, Ramirez-Campillo R, Bouguezzi R, Moran J, Chaabene H. 2022. The effects of repeated sprint training with versus without change of direction on measures of physical fitness in youth male soccer players. *The Journal of Sports Medicine and Physical Fitness* **63(1)**:8–15 DOI 10.23736/S0022-4707.22.13521-8.

Ozgunen K, Ozdemir C, Adas U, Kilci A, Boyraz C, Eryilmaz SK, Gunasti O, Askeri N, Kurdak S. 2021. Effect of repeated sprint training on isokinetic strength parameters in youth soccer players. *Isokinetics and Exercise Science* **29(3)**:343–351 DOI 10.3233/IES-202231.

Padulo J, Bragazzi NL, Nikolaidis PT, Dello Iacono A, Attene G, Pizzolato F, Dal Pupo J, Zagatto AM, Oggianu M, Migliaccio GM. 2016. Repeated sprint ability in young basketball players: multi-direction *vs.* one-change of direction (Part 1). *Frontiers in Physiology* **7** DOI 10.3389/fphys.2016.00133.

Padulo J, Laffaye G, Haddad M, Chaouachi A, Attene G, Migliaccio GM, Chamari K, Pizzolato F. 2015. Repeated sprint ability in young basketball players: one *vs.* two changes of direction (Part 1). *Journal of Sports Sciences* **33(14)**:1480–1492 DOI 10.1080/02640414.2014.992936.

Pavillon T, Tourny C, Ben Aabderrahman A, Salhi I, Zouita S, Rouissi M, Hackney AC, Granacher U, Zouhal H. 2021. Sprint and jump performances in highly trained young soccer players of different chronological age: effects of linear *VS.* change-of-direction sprint training. *Journal of Exercise Science & Fitness* **19(2)**:81–90 DOI 10.1016/j.jesf.2020.10.003.

Rodas G, Ventura JL, Cadefau JA, Roser C, Parra J. 2000. A short training programme for the rapid improvement of both aerobic and anaerobic metabolism. *European Journal of Applied Physiology* **82(5–6)**:480–486 DOI 10.1007/s004210000223.

Ross A, Leveritt M. 2001. Long-term metabolic and skeletal muscle adaptations to short-sprint training: implications for sprint training and tapering. *Sports Medicine (Auckland, NZ)* **31(15)**:1063–1082 DOI 10.2165/00007256-200131150-00003.

Sagelv EH, Selnæs I, Pedersen S, Pettersen SA, Randers MB, Welde B. 2019. Effects of linear versus changes of direction repeated sprints on intermittent high intensity running performance in high-level junior football players over an entire season: a randomized trial. *Sports (Basel)* **7(8)** DOI 10.3390/sports7080189.

Sanchez-Sanchez J, Ramirez-Campillo R, Petisco C, Gonzalo-Skok O, Rodriguez-Fernandez A, Miñano J, Nakamura FY. 2019. Effects of repeated sprints with changes of direction on youth soccer player's performance: impact of initial fitness level. *Journal of Strength and Conditioning Research* **33(10)**:2753–2759 DOI 10.1519/JSC.0000000000002232.

Schmidt H. 2004. Neural, metabolic, and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. *International Journal of Sports Medicine* **25(02)**:92–98 DOI 10.1055/s-2004-819945.

Shi XL. 2021. Experimental study on the effect of multi-direction repeated sprinting and running training on the physical fitness of senior pupils. Master's degree thesis, Beijing Sport University, Beijing.

Stanković M, Đorđević D, Aleksić A, Lazić A, Lilić A, Čaprić I, Trajković N. 2022. The relationship between jump performance, speed and cod speed in elite female soccer players. *Facta Universitatis, Series: Physical Education and Sport* **20(1)**:047–059 DOI 10.22190/FUPES220216005S.

Stanković M, Trajković N, Mačak D, Đorđević D, Lazić A, Milanović Z. 2024. Effects of linear and change of direction high-intensity interval training on physical performance of elite female soccer players. *Biology of Sport* **41(4)**:31–39 DOI 10.5114/biolsport.2024.134761.

Taylor JM, Macpherson TW, McLaren SJ, Spears I, Weston M. 2016. Two weeks of repeated-sprint training in soccer: to turn or not to turn? *International Journal of Sports Physiology and Performance* **11(8)**:998–1004 DOI 10.1123/ijspp.2015-0608.

Taylor J, Macpherson T, Spears I, Weston M. 2015. The effects of repeated-sprint training on field-based fitness measures: a meta-analysis of controlled and non-controlled trials. *Sports Medicine* **45(6)**:881–891 DOI 10.1007/s40279-015-0324-9.

Taylor JB, Wright AA, Dischiavi SL, Townsend MA, Marmon AR. 2017. Activity demands during multi-directional team sports: a systematic review. *Sports Medicine* **47(12)**:2533–2551 DOI 10.1007/s40279-017-0772-5.

Thurlow F, Huynh M, Townshend A, McLaren SJ, James LP, Taylor JM, Weston M, Weakley J. 2024. The effects of repeated-sprint training on physical fitness and physiological adaptation in athletes: a systematic review and meta-analysis. *Sports Medicine* **54(4)**:953–974 DOI 10.1007/s40279-023-01959-1.

Thurlow F, McLaren SJ, Townshend A, Weakley J. 2025. The application of repeated-sprint training. *Strength & Conditioning Journal*.

Thurlow F, Weakley J, Townshend AD, Timmins RG, Morrison M, McLaren SJ. 2023. The acute demands of repeated-sprint training on physiological,

neuromuscular, perceptual and performance outcomes in team sport athletes: a systematic review and meta-analysis. *Sports Medicine* **53(8)**:1609–1640 DOI 10.1007/s40279-023-01853-w.

Tian XL. 2020. Effects of reentry repeated sprint training on athletic ability and lower limb muscle explosive power of adolescent basketball players. *Hubei Sports Science and Technology* **39(08)**:700–706.

Young MM, Tønnessen E, Haugen TA, Enoksen E. 2013. The effect of repeated agility training *vs.* repeated sprint training on elite female soccer players' physical performance. *Kinesiologia Slovenica* **19(3)**:29–42.

Zagatto AM, Ardigo LP, Barbieri FA, Milioni F, Dello Iacono A, Camargo BHF, Padulo J. 2017. Performance and metabolic demand of a new repeated-sprint ability test in basketball players: does the number of changes of direction matter? *Journal of Strength and Conditioning Research* **31(9)**:2438–2446 DOI 10.1519/JSC.0000000000001710.

Zhao ZW. 2022. The difference of the effect of rapid stretching compound training and repeated sprinting training on the sprint ability of young football players. Master's degree thesis, Shanghai Institute of Physical Education, Shanghai.

Zhou Z, Xin C, Zhao Y, Wu H. 2024. The effect of multi-directional sprint training on change-of-direction speed and reactive agility of collegiate tennis players. *PeerJ* **12**:e18263 DOI 10.7717/peerj.18263.