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Review article

THE EFFECTS OF REPEATED SPRINT TRAINING ON JUMP, SPRINT, AND CHANGE OF DIRECTION PERFORMANCE IN MALE BASKETBALL PLAYERS

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ABSTRACT

Background: Increasing evidence suggests that repeated sprint training (RST) enhances performance in male basketball players, yet findings have not been quantitatively synthesized.

Purpose: To meta-analyze the effects of RST on countermovement jump (CMJ), linear sprint, and change-of-direction (COD) performance versus control.

Methodology: Systematic searches of PubMed, Web of Science, and Scopus identified peer-reviewed controlled trials of basketball players with baseline and follow-up measures. A random-effects meta-analysis was performed; study quality was assessed using the PEDro scale. Prespecified moderators were age, program duration, training frequency, inter-sprint recovery, and sprint direction; subgroup analyses explored heterogeneity.

Results: Nine studies ($n = 213$) met the inclusion criteria. Pooled effects were small-to-moderate: CMJ ($ES = 0.39$, 95% CI 0.04–0.74; $Z = 2.19$; $p = .03$), linear sprint ($ES = -0.40$, 95% CI -0.75 to -0.06; $Z = 2.29$; $p = .02$), and COD ($ES = -1.11$, 95% CI -1.73 to -0.50; $Z = 3.54$; $p = .0004$). Most subgroup differences were not significant ($p = .0004$ – 1.00), but in COD performance, the sprint subgroup ($ES = -1.02$, $p = .002$) and the COD subgroup ($ES = -1.68$, $p = .02$) showed larger effects and reached statistical significance.

Conclusions: RST can improve CMJ and COD in male basketball players, with a borderline improvement in linear sprint speed; the largest gains appear in COD. While most subgroup differences were non-significant, larger improvements in COD were observed in specific sprint and COD subgroups.

Limitations and Consequences: Evidence is limited by few trials, modest samples, and protocol variability, which may constrain generalizability.

Practical Implications: Adult athletes using ≤ 30 -s inter-sprint recovery and < 3 weekly sessions may experience larger benefits; coaches can integrate RST accordingly.

Originality: This is a focused quantitative synthesis of RST-induced neuromuscular adaptations in male basketball players.

Keywords: repeated sprint training, basketball, neuromuscular performance, countermovement jump, sprint speed, change of direction.

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INTRODUCTION

Basketball is characterized by high-intensity intermittent activity (Hoffman, 2003; Ramos-Campo et al., 2017), involving frequent and intense running, sprinting, change

of direction (COD), and jumping throughout the game (Ziv & Lidor, 2009, 2010). Players experience rapid and constant changes in actions, with an average of one medium or high-intensity sprint occurring every 21 sec-

onds and a change in action every 2 or 3 seconds (Ben Abdelkrim et al., 2007). Repeated sprints are considered essential in basketball and other team sports, as they accurately capture the essence of these sports (Buchheit et al., 2010; Spencer et al., 2005). In addition, specific basketball movements such as rebounding, layups, shooting, and defensive actions rely heavily on muscle strength, explosive power, speed, and agility. Therefore, strong leg muscles play a critical role in basketball performance, enabling players to execute these high-intensity actions effectively (Spencer et al., 2005). In short, athletes must focus on developing strength, acceleration, deceleration, and the ability to perform repetitive sprints (Petway et al., 2020).

Repeated Sprint Training (RST) has been gaining significant attention in team sports for its remarkable effectiveness in improving athletes' running ability (Bangsbo et al., 1991; Bishop et al., 2001; Figueira et al., 2021; Glaister, 2005). This training involves short, intense sprints lasting 3-10 seconds, followed by brief recovery periods of no more than 60 seconds between each sprint (Girard et al., 2011). Remarkably, this training seems to show its effectiveness, even with just six training sessions over two weeks; improvements can be observed (Taylor et al., 2016).

RST provides athletes with a highly effective means of training their maximum speed, acceleration, and deceleration abilities, aligning perfectly with the demands of basketball (Taylor et al., 2017). So, the capacity to perform repeated sprints is also considered a pivotal factor contributing to the success of talented young basketball players (te Wierike et al., 2014). Moreover, RST programs have been shown to enhance the vertical jumping

ability of team athletes, further adding to their benefits in sports conditioning (Aloui et al., 2022; Gantois et al., 2022), and have also been associated with a potential role in the development of sprint ability (Attene et al., 2015).

As of the current review, existing meta-analyses have explored the impact of RST on various field-based measures of athletic performance (Taylor et al., 2015). However, these analyses may not have directly addressed the unique aspects of RST in the basketball context. Moreover, no specific meta-analyses focusing exclusively on RST in basketball have been identified in the literature. Consequently, the need for a comprehensive meta-analysis dedicated solely to examining the outcomes of RST in basketball becomes apparent. Therefore, the primary objective of this systematic review and meta-analysis was to examine and compare the effects of RST-based interventions on vertical jump height, sprint speed, and change-of-direction ability in basketball players, compared with control groups receiving exclusively basketball skill training. We aimed to provide valuable insights to inform evidence-based training strategies for basketball athletes and to advance knowledge in this domain.

METHODOLOGY

The meta-analysis was executed following the guidelines outlined in the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021). The Prospero registration highlighted the omission of health-related outcomes assessment and confirmed the non-necessity of review registration. The methodology for our meta-analysis is detailed in Table 1, which outlines the inclusion and exclusion criteria.

Table 1. Selection criteria used in the Review

Category	Inclusion criteria	Exclusion criteria
Population	Basketball players, without any injuries and age limit	Not basketball players, history of injury within the last six months
Intervention	Repeated sprint training incorporating straight-line sprints or a change of direction	Lack of repeated sprint training component
Duration	The duration of the training program including repeated sprint training is greater than 5 weeks	The duration of the training program, including repeated sprint training, is lower than 5 weeks
Study design/comparator	Studies with a control group engaged in daily basketball technique training	Studies lacking a control group or with a different type of control group
Outcome	Outcome measurements, including sprint speed, t-test time, and countermovement jump height	Lack of relevant outcome measurements

Eligibility Criteria

To meet the inclusion criteria, articles had to include specific elements, including an RST intervention and outcome measures such as the Countermovement Jump (CMJ), sprint speed, and T-test time. Additionally, a comparison group undergoing daily basketball technique training was required as a control. CMJ, recognized as the most reliable and valid field tests for assessing explosive power in the lower limbs of physically active men, were integral components of the inclusion criteria (Markovic et al., 2004). Linear sprint speed represents the ability to generate high power levels over each stride to cover maximum distance in minimal time (Mero et al., 1992). Moreover, the agility T-test, which involves multidirectional, basketball-specific movements with four directional changes comprising sprinting, lateral shuffling, and backpedaling, is frequently employed by basketball coaches and researchers (Wen et al., 2018), was included to assess COD performance (Ben Abdelkrim et al., 2010; Delextrat & Cohen, 2009).

Furthermore, to meet the appropriate RST intervention criteria, the training program had to incorporate either straight-line sprints or a COD component; Inclusion criteria mandated that the intervention consist of a series of sprints lasting no longer than 15 seconds, with recovery intervals not exceeding 60 seconds

(definition as outlined by Buchheit and Laursen (Buchheit & Laursen, 2013)). The study participants had to be basketball players, and the intervention had to be implemented for at least 4 weeks. The control group, referred to as the CON group, consisted of athletes who engaged exclusively in basketball skills training without any additional training components.

Information Sources and Search Strategy

Electronic database searches were conducted, covering records up to June 2023, and were updated in July 2024, across multiple databases, including PubMed (which includes MEDLINE), SPORTDiscus, Web of Science, and SCOPUS. The search strategy was implemented using Boolean operators, namely OR and AND, and incorporated the following search terms: ["Basketball" OR "Basketball player"] AND ["Change of Direction" OR "COD" OR "Sprint" OR "Repeated sprint ability"] AND ["Training" OR "Intervention"]. The search was specifically limited to journal sources. Studies that did not fulfill these criteria, along with non-English publications, dissertations, books, magazine articles, non-peer-reviewed studies, and conference papers, were excluded from the review.

Study Records

The study selection process involved an initial review of article titles by the first author

(HH), followed by a thorough examination of article abstracts and full published articles. Two authors (HH and AS) collaborated to review and select articles that met the inclusion criteria for the final analysis. Excluded full-text articles were documented, along with the reasons for their exclusion. After the initial literature search, the selected articles underwent a consensus review by both reviewers, with any discrepancies resolved through discussion with the third author (SHS). Additionally, the references of the selected articles were screened to identify any additional studies on repetitive sprint training.

Data extraction from the gathered articles was performed by the first author, encompassing various aspects, including authors' names, study design, study participants, intervention details, outcome measurements, and effectiveness results. A form created in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) was used for this purpose.

Risk of bias assessment

The assessment of methodological quality in the reviewed studies used the Physical Therapy Evidence Database (PEDro) scale, which assigns scores from 0 (lowest quality) to 10 (highest quality). The evaluation of methodological quality adhered to the following criteria: scores of 3 were categorized as inadequate quality, scores ranging from 4 to 5 as moderate quality, and scores from 6 to 10 as high quality. The evaluation of methodological quality was performed by the primary authors. In cases of disagreement, a third author (SHS) made the final decision.

Statistical analysis

The analysis was conducted using RevMan version 5.3 (The Nordic Cochrane Centre, London, UK). To calculate the effect size (ES), Hedges' g was employed, which involves di-

viding the total change in CMJ, sprint, and T-test performance between the intervention RST group and the comparative intervention group by the combined standard deviation of the change scores for both groups. Effect sizes were denoted by the standardized mean difference (Hedges' g) and presented with 95% confidence intervals. Interpretation of the calculated effect sizes followed the conventions outlined for standardized mean difference by Hopkins et al. (Hopkins et al., 2009) (<0.2 = trivial; $0.2-0.6$ = small, $0.6-1.2$ = moderate, $1.2-2.0$ = large, $2.0-4.0$ = very large, >4.0 = extremely large). To assess variability between studies, the I^2 inconsistency statistic was used, expressing the percentage of variation between studies attributable to heterogeneity rather than chance. Thresholds for heterogeneity were categorized as low ($I^2 = 25\%$), medium ($I^2 = 50\%$), and high ($I^2 = 75\%$).

Moderator analyses

Moderator analyses were conducted using a random-effects model and an independent-computed single-factor analysis to identify potential sources of heterogeneity that could influence the impact of training. In addressing the documented limitations of meta-regression, subgroup analyses were preferred due to their suitability for small datasets with limited samples and few predictor variables (Schmidt, 2017).

The authors identified crucial factors influencing training effects, based on discussions and study characteristics. These factors included participant age, program length (in weeks), training frequency (sessions per week), recovery time per repetition, and sprint direction (linear sprint or change of direction). Given that a majority of studies utilized a training frequency of 2 or 3 sessions per week, the authors grouped them into these categories to facilitate comparison. Additionally, the authors calculated the mean total sessions, grouping stud-

ies into two groups: those with more than 16 sessions and those with fewer than 16. Other moderator variables were categorized to facilitate subgroup analyses as follows: participant age (12.4 - 26.3 years) was grouped into < 18 and ≥ 18 years; training duration (6–12 weeks) was grouped into < 8 and ≥ 8 weeks; recovery time per repetition (all ≤ 1 min) was grouped into < 30 s and ≥ 30 s. Furthermore, the authors delved into the type of training (linear vs. change-of-direction) as a potential moderator for athletes.

RESULTS

Study Record

In the initial identification phase, 1480 studies were identified. After eliminating duplicates (562) and adding records from other sources (3), 921 publications remained for the article selection process. 902 articles were excluded during the title and abstract selection phase. The remaining 21 records underwent a detailed assessment through full-text article review, resulting in the exclusion of 12 records. Finally, nine studies were deemed suitable for inclusion in the systematic review and meta-analysis (Figure 1).

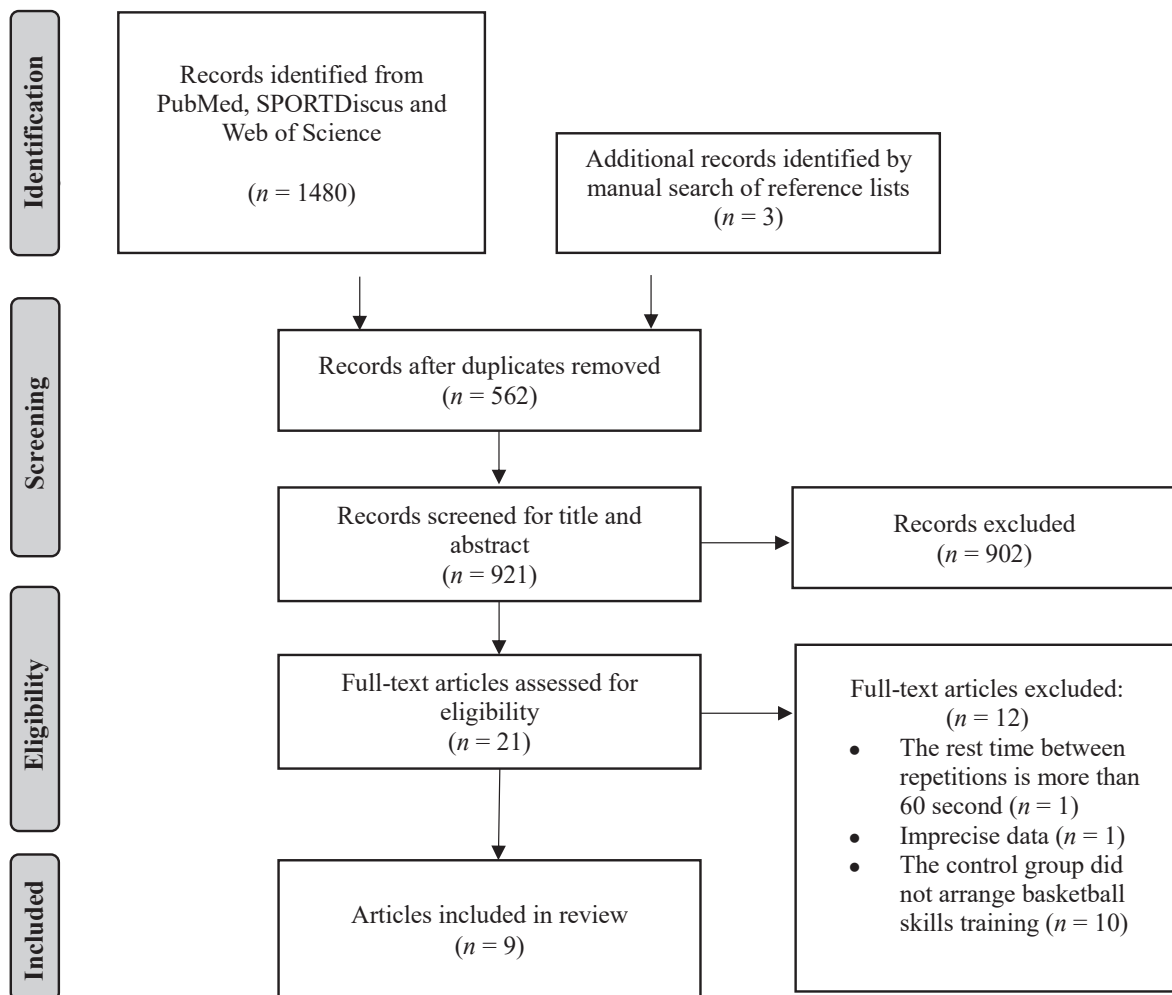


Figure 1. Flow chart of literature search and research selection

Study Characteristics

The participant characteristics and programming parameters for RST across the sev-

en studies included in the meta-analysis are detailed in Table 2.

Table 2. Characteristics of study participants of repeated sprint training and team basketball training.

Study	Study Group	N	Age (Years)	Height (cm)	Body mass (kg)	D	F	Exercise Type	Sets	Reps	Distance	Recovery	Response
Brini et al. 2020	RST	8	22.0 ± 2.8	1.86 ± 0.1	77.7 ± 7.7	12	2	COD training	3	8	6*5M	20s	CMJ ↓, T-test ↑
	CON	8	NR	NR	NR								
Brini et al. 2022a	RST	13	25.7 ± 1.7	196.1 ± 4.4	82.5 ± 5.9	8	2	COD training	3	8	6*5M	20s	CMJ ↑, T-test ↑
	CON	13	26.3 ± 2.1	197 ± 3.9	85.2 ± 3.1								
Brini et al. 2022b	RST	13	26.3 ± 2.1	192.7 ± 6	87.2 ± 4.2	8	2	DJ combined COD training	3	8	6*5M	20s	CMJ ↑, T-test ↑
	CON	13	26.3 ± 2.1	197 ± 3.9	85.2 ± 3.1								
Brini et al. 2023	RST	14	25.1 ± 2.3	196.4 ± 6	85.2 ± 5.7	8	2	COD, Drop jump	3	8	6*5M	20s	CMJ ↑, T-test ↑
	CON	14	26.0 ± 2.1	196.2 ± 3.5	85.4 ± 4.2								
Ersoy et al. 2020	RST	16	12.4 ± 0.2	NR	NR	8	3	Function speed training	NR	NR	10 M	60s	Linear sprint (20M) ↑
	CON	16	12.4 ± 0.3										
Gantois et al. 2019	RST	9	21.2 ± 2.3	180 ± 5.8	81.1 ± 12.6	6	2	RST	2,3	6	30M	20s	CMJ ↑, Linear sprint (30M) ↑
	CON	8											
Maggioni et al. 2018	RST	9	19 ± 1	1.82 ± 0.1	74 ± 10	8	3	Shuttle run	3	6	2*20M	20s	CMJ ↑, Linear sprint (20M) ↑, T-test ↑
	CON	9											
Okur et al. 2019	RST	13	15.1 ± 0.4	1.79 ± 0.1	69.8 ± 12.8	8	3	Speed training	1-3	4-6	10-120M	60s	T-test ↑, Linear sprint (15m) ↑
	CON	13	15.3 ± 0.5	1.80 ± 0.1	72.9 ± 9.2								
Saez de Villarreal et al. 2021	RST	10	14.2 ± 1.6	1.6 ± 0.1	52.5 ± 4.2	7	2	COD, Dribbling in a straight line	8	10	2*5M	60s	CMJ ↑, Linear sprint (20M) ↑
	CON	10	14.6 ± 0.86										
Song et al. 2023	RST	10	25.3 ± 1.8	1.8 ± 0.0	87 ± 7.6	6	2	Sprint training	3	7-10	15s	15s	CMJ ↑, Linear sprint ↑, T-test ↑
	CON	10	26.2 ± 1.7	1.8 ± 0.0	85 ± 7.6								

Note. D: Duration; F: Frequency (per wk.); RST: Repeated sprint training; COD: Change of direction; DJ: Drop jump; CMJ: Countermovement jump; NR: Non-reported

Methodological Quality

The selected studies underwent evaluation using the PEDro methodological quality scale. Four studies achieved a high-quality score of 6/10 (Brini et al., 2023; Brini et al., 2022; Gantois et al., 2019; Maggioni et al., 2019; Song et al., 2023), two studies attained

a moderate quality score of 5/10 (Brini et al., 2020; Okur et al., 2019; Sáez de Villarreal et al., 2021), and one study received a score of 4/10 (Ersoy et al., 2020). A comprehensive breakdown of the PEDro scale scores for each study is presented in Table 3.

Table 3. *Physiotherapy Evidence Database (PEDro) scale ratings for the studies.*

Study	Item number											Total (maximum of 10)
	1	2	3	4	5	6	7	8	9	10	11	
Brini et al. 2020	1	1	0	1	0	0	0	1	0	1	1	5
Brini et al. 2022a	1	1	1	1	0	0	0	1	0	1	1	6
Brini et al. 2022b	1	1	1	1	0	0	0	1	0	1	1	6
Brini et al. 2023	1	1	1	1	0	0	0	1	0	1	1	6
Ersoy et al. 2020	1	0	0	1	0	0	0	1	0	1	1	4
Gantois et al. 2019	1	1	1	1	0	0	0	1	0	1	1	6
Maggioni et al. 2018	1	1	1	1	0	0	0	1	0	1	1	6
Okur et al. 2019	1	1	0	1	0	0	0	1	0	1	1	5
Sáez de Villarreal et al. 2021	1	1	0	1	0	0	0	1	0	1	1	5
Song et al. 2023	1	1	1	1	0	0	0	1	0	1	1	6

Note. A detailed explanation for each PEDro scale item can be accessed at <https://www.pedro.org.au/english/downloads/pedro-scale>

Funnel plots were used to check potential publication bias for CMJ, sprint, and COD performance (Figures 2–4). The plots for CMJ and sprint performance appeared mostly symmetrical, suggesting a low risk of publication bias. In the COD funnel plot, a slight asymmetry was observed due to two studies (Brini et al., 2023; Brini et al., 2022) that reported very

large effects. After removing these studies, the heterogeneity decreased from 73% to 5%, and the plot became more balanced around the center. This finding suggests that the asymmetry was likely caused by heterogeneity rather than publication bias. Because fewer than ten studies were included in each analysis, the power of the funnel plot is limited (Sterne et al., 2011).

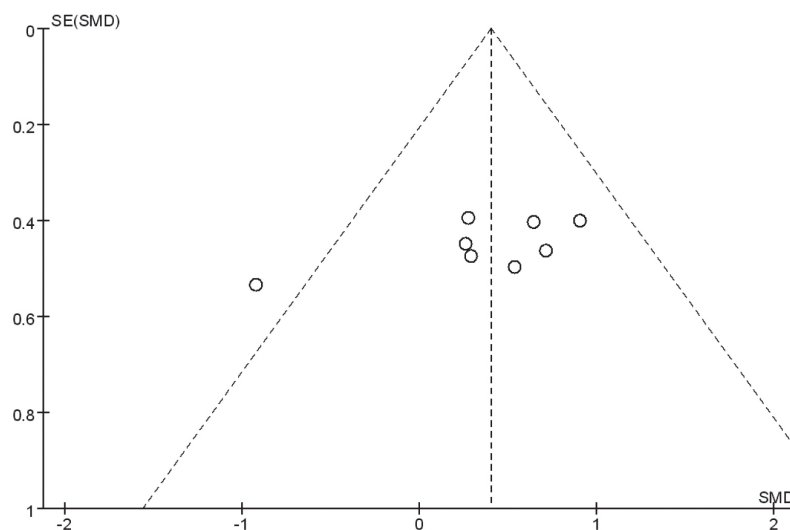


Figure 2. *Funnel plot of the effect of RST on basketball players' CMJ abilities.*

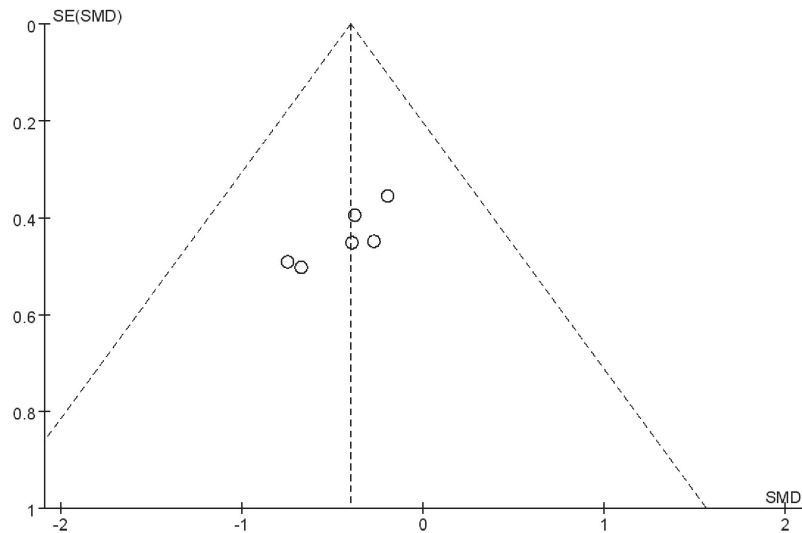


Figure 3. Funnel plot of the effect of RST on basketball players' sprint abilities.

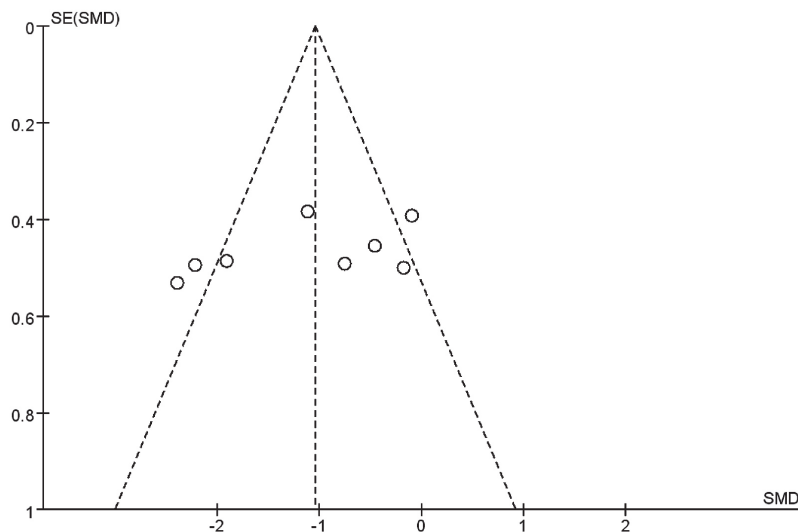


Figure 4. Funnel plot of the effect of RST on basketball players' COD abilities.

Main Effect

Countermovement Jump Performance

The analysis encompassed eight effects derived from 9 original studies that measured jump height in centimeters. A small but significant improvement in the performance of training programs correlated with CMJ performance (ES 0.39, 95% CI: 0.04 to

0.74, $Z = 2.19$, $p = .03$). There was a low heterogeneity among the studies ($I^2 = 21\%$, $p = .26$). The overall effect size within-model was small (ES = 0.43, 95% CI: 0.13 to 0.74, $p = .005$). These results are depicted in Figures 5 (RST vs. CON) and 6 (baseline vs. follow-up).

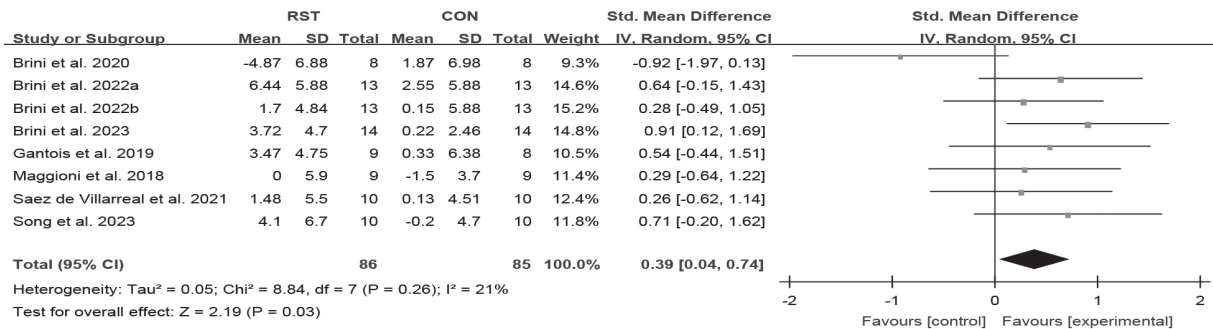


Figure 5. Forest plot of between-mode effect sizes with 95% confidence intervals (CIs) in counter-movement jump performance (cm).

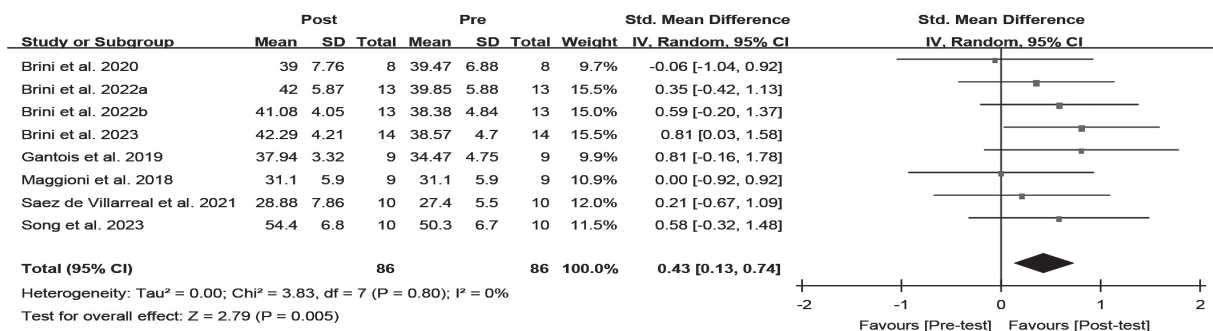


Figure 6. Forest plot of within-mode effect sizes with 95% confidence intervals (CIs) in counter-movement jump performance (cm).

Sprint Time

In the analysis of six effects from 9 original studies, linear sprint performance was measured in time (seconds). The findings suggest a small and significant impact on the time of linear sprint (ES -0.40, 95% CI: -0.75 to -0.06, Z = 2.29, p = .02). A low level of

between-study heterogeneity was observed (I² = 0%, p = .94). The within-model effect size was small (ES = -0.46, 95% CI: -0.80 to -0.11, Z = 2.58, p = .01). These results are visually presented in Figures 7 (RST vs. CON) and 8 (baseline vs. follow-up).

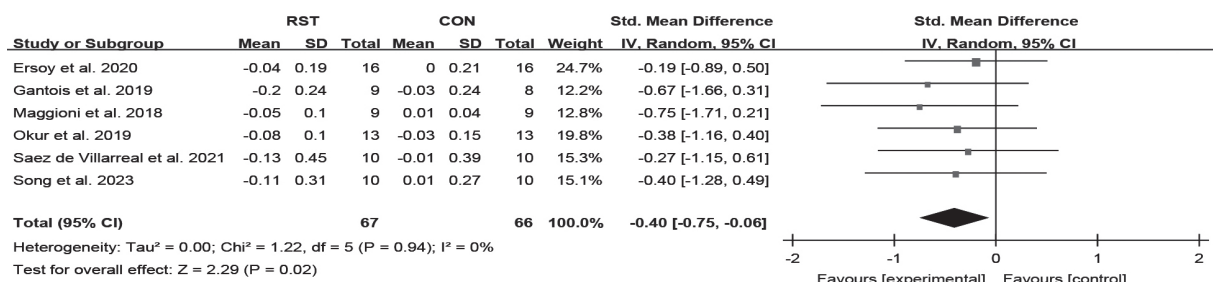


Figure 7. Forest plot of between-mode effect sizes with 95% confidence intervals (CIs) in time of sprint (s).

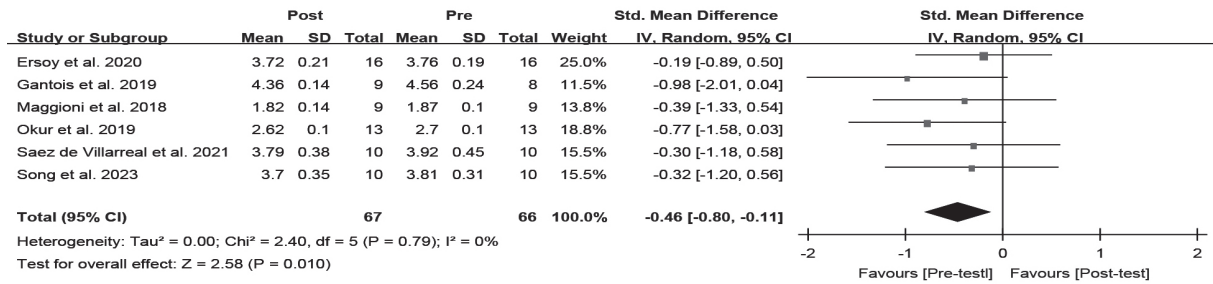


Figure 8. Forest plot of within-mode effect sizes with 95% confidence intervals (CIs) in time of sprint (s).

Change of direction Time

In the analysis of 8 effects across 9 original studies, COD performance was measured over time (in seconds). The training programs demonstrated a significant reduction in T-test time (ES = -1.11, 95% CI: -1.73 to -0.50, Z = 3.54, p = .0004). A significant level of

between-study heterogeneity was observed (I² = 73%, p = .0005). The within-model effect size was large (ES = -1.42, 95% CI: -2.21 to -0.64, Z = 3.55, p = .0004). These results are visually presented in Figures 9 (RST vs. CON) and 10 (baseline vs. follow-up).

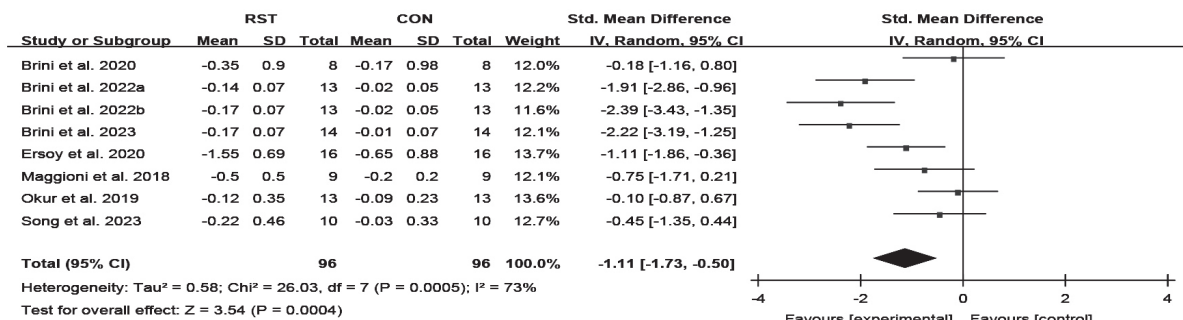


Figure 9. Forest plot of between-mode effect sizes with 95% confidence intervals (CIs) in the time of T-test (s).

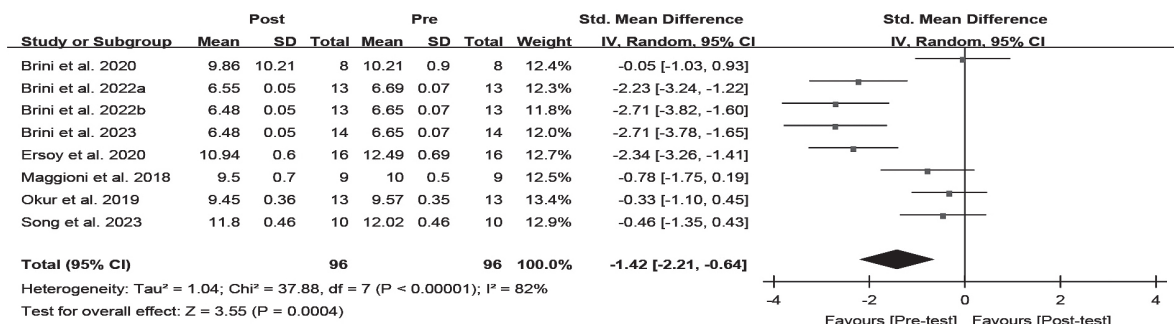


Figure 10. Forest plot of within-mode effect sizes with 95% confidence intervals (CIs) in the time of T-test (s).

Moderator analyses

Trivial to moderate differences were observed between each training type across subgroups in CMJ performance, while differences were small in sprint performance and small to large in COD performance. Subgroup analysis

revealed moderate between-group heterogeneity, particularly for training duration in COD performance (I² = 67.2%). In the analysis of CMJ and sprint performance, no significant heterogeneity was found within the subgroup. These results are visually presented in Table 4.

Table 4. Effect of moderator variables in repeated sprint training

Subgroup	Effect Size with 95% Confidence Interval	Effect Descriptor	Groups	Within-Group I ² (%)	With-in-Group p	Between-Group I ² (%)	Between-Group p	
CMI	<18 years	0.21 [-0.67, 1.09]	1	Not estimable	.64	0.0	.59	
	≥18 years	0.46 [0.14, 0.79]	7	0.0	.005			
	<8 weeks	0.51 [-0.01, 1.04]	3	0.0	.06	0.0	.72	
	≥8 weeks	0.39 [0.02, 0.77]	5	0.0	.04			
	<3 sessions/week	0.49 [0.16, 0.81]	7	0.0	.003	0.0	.33	
	≥3 sessions/week	0.00 [-0.92, 0.92]	1	Not estimable	1.00			
	<30 seconds/reps	0.46 [0.14, 0.79]	7	0.0	.005	0.0	.59	
	≥30 seconds/reps	0.21 [-0.67, 1.09]	1	Not estimable	.64			
	Line	0.69 [0.03, 1.35]	Moderate	2	0.0	.04	0.0	.40
	Change of direction	0.37 [0.02, 0.71]	Small	6	0.0	.04		
	<18 years	-0.28 [-0.72, 0.17]	Small	3	0.0	.23	0	.38
	≥18 years	-0.59 [-1.14, -0.05]	Small	3	0.0	.03		
	<8 weeks	-0.52 [-1.05, 0.01]	Small	3	0.0	.06	0.0	.55
≥8 weeks	-0.30 [-0.76, 0.15]	Small	3	0.0	.19			
<3 sessions/week	-0.52 [-1.05, 0.01]	Small	3	0.0	.06	0.0	.55	
≥3 sessions/week	-0.30 [-0.76, 0.15]	Small	3	0.0	.19			
<30 seconds/reps	-0.56 [-1.11, -0.02]	Small	3	0.0	.04	0.0	.44	
≥30 seconds/reps	-0.28 [-0.73, 0.16]	Small	3	0.0	.24			
Line	-0.42 [-0.83, -0.01]	Small	3	0.0	.05	0.0	.85	
Change of direction	-0.34 [-0.98, 0.30]	Small	3	0.0	.30			
<18 years	-1.32 [-3.28, 0.65]	Large	2	91	.19	0.0	.89	
≥18 years	-1.47 [-2.41, -0.52]	Large	6	81	.002			
<8 weeks	-0.46 [-1.35, 0.43]	Small	1	Not estimable	.31	67.2	.08	
≥8 weeks	-1.57 [-2.43, -0.70]	Large	7	82	.0004			
<3 sessions/week	-1.61 [-2.74, -0.48]	Large	5	84	.005	0.0	.57	
≥3 sessions/week	-1.42 [-2.21, -0.64]	Large	3	80	.06			
<30 seconds/reps	-1.47 [-2.41, -0.52]	Large	6	81	.002	0.0	.89	
≥30 seconds/reps	-1.32 [-3.28, 0.65]	Large	2	91	.19			
Line	-1.02 [-2.26, 0.21]	Moderate	3	84	.002	0.0	.43	
Change of direction	-1.68 [-2.75, -0.61]	Large	5	82	.02			
Sprint								
COD								

DISCUSSION

Countermovement jump performance

The results of between- and within-mode analyses show that RST had a small but significant effect on improving CMJ performance in male basketball players. These findings align with previous research that demonstrated a significant improvement in CMJ performance among hockey (Taylor & Jakeman, 2022) and soccer (Tønnessen et al., 2011) players following RST ($p < .05$). This outcome is predictable, considering the shared characteristics of CMJ and sprint movements, particularly at maximum speed, which prominently exhibit the stretch-shortening cycle (SSC) and underscore heightened leg muscle explosive power (Harrison et al., 2004).

Numerous studies consistently demonstrate the positive impact of RST on various aspects, including increased leg muscle explosive power, advancements in motor unit synchronization, and enhanced efficiency of the SSC (Bishop et al., 2011). The improvement in CMJ explosiveness can also be attributed to parameters such as reaction intensity and muscle strength (Panoutsakopoulos & Bassa, 2023). This may be because sprint training enhances knee extensor and flexor strength, contributing to improved CMJ height, and this muscle strength improvement may result from muscle hypertrophy induced by prolonged sprint training (Özgül et al., 2021).

Brini et al. (Brini et al., 2023; Brini et al., 2022) and Song et al. (Song et al., 2023) reported a moderate impact of RST on CMJ performance, other studies investigating CMJ (Gantois et al., 2019; Maggioni et al., 2019; Sáez de Villarreal et al., 2021) yielded only smaller effect sizes. In contrast, Brini et al. (Brini et al., 2020) even reported a negative effect; they found a decrease in the T/C ratio at the end of the training program, suggesting overtraining (Adlercreutz et al., 1986). This

catabolic state is associated with a decline in jump performance. Including COD training in long-term sprint training may place higher demands on the body, potentially leading to greater physical fatigue. Additionally, Mario et al. (Morio et al., 2011) noted a decrease in jump height with the regular performance of COD activities. However, these preliminary findings on compromised jump performance following COD training must be approached with caution and require further research for confirmation.

Exploring differences in CMJ performance across subgroups provides interesting insights. Concerning the programming characteristics of RST interventions, incorporating measures such as an adult players (more than 18 players) longer training duration (more than 8 weeks), shorter training frequency (less than three sessions per week), shorter inter-repetition recovery time (30 seconds or less), and including both linear sprint and COD exercises can enhance the effectiveness of CMJ performance ($p < .05$), although there is currently no evidence indicating that these factors, when combined, necessarily exhibit a synergistic effect.

In conclusion, the evidence offers valuable insights into the influence of training programs on VJ performance in basketball players. The overall small but significant impact suggests a positive correlation. While it remains unclear whether the decrease in bounce strength is due to excessive COD training, it provides coaches with valuable information to refine their planning strategies.

Sprint performance

The analysis of linear sprint performance across six effects from 9 original studies aimed to evaluate the impact of repeated sprint training on the time required for linear sprints, measured in seconds. The overall effect size suggests a small ($ES = -0.40$) and significant

influence on linear sprint time between the repeated sprint training and control groups. Within-model, the overall effect size remained small, with a within-model effect size ($ES = -0.46$). This consistent pattern of small effect sizes indicates a general trend of modest impact across the studies included in the analysis. The low level of between-study heterogeneity ($I^2 = 0\%$, $p = .74$) adds strength to the overall findings, suggesting a degree of consistency across studies. While the limited number of studies necessitates caution, these results align with previous review findings indicating that repeated-sprint training tends to yield greater improvements in best sprint time and mean sprint time (Bishop et al., 2011). Gantois et al. (Gantois et al., 2019) and Maggioni et al. (Maggioni et al., 2019) demonstrated a moderate effect in linear sprint performance after RST, further supporting the trend observed in this analysis.

The enhancements in sprint performance indices following RST come as no surprise, considering that sprint movements, especially at maximum speed, showcase characteristics of the stretch-shortening cycle and heightened explosive power in leg muscles (Harrison et al., 2004). Furthermore, the observed improvements in sprint performance can be linked to the familiar learning effect arising from the exercise specificity between the training regimen and the RST (Buchheit, 2012). In essence, the adaptations induced by training, combined with the inherent biomechanical advantages of sprint movements, synergistically contribute to an improved capacity for both singular sprint performance and repeated-sprint ability.

Subgroup analyses, considering various characteristics of training programs, offer insights into potential factors influencing linear sprint performance. Regarding the programming characteristics of RST interventions, several measures, including adult players, shorter

study duration (less than 8 weeks), reduced training frequency (less than three sessions per week), shorter inter-repetition recovery time (30 seconds or less), and linear sprints, appear to enhance the effectiveness of sprint performance. Notably, interventions with a recovery time of less than 30 seconds had a larger effect ($ES = -0.56$) than those with a recovery time of more than 30 seconds ($ES = -0.28$). This suggests that a shorter recovery time may have a more pronounced impact on reducing linear sprint time. Similarly, the training duration shows a pattern in which longer interventions do not necessarily have a greater impact on linear sprint times. This suggests that the relationship between training duration and linear sprint performance may be more nuanced and not linear. While these findings provide valuable insights, the need for additional studies to further validate and refine our understanding of the complex interactions between training program characteristics and linear sprint performance is evident.

In summary, the analysis of repeated sprint training's impact on linear sprint performance reveals a small and non-significant overall effect. However, for basketball players, the benefits extend beyond sprint performance alone. PST contributes to refining neural pathways, optimizing muscle efficiency, minimizing co-contractions, and positively influencing joint and sprint speed (McGill et al., 2010; Taylor et al., 2015). Electromyographical (EMG) data highlights the pivotal role of larger and proximal muscles, particularly the gluteus maximus, in faster running speeds and significant contributions to hip extension during all-out sprinting (Bartlett et al., 2014; Lieberman et al., 2006). Targeted training of the gluteus maximus muscle proves effective in enhancing dynamic stability, especially in the dominant leg and vertical jump of basketball players (Sánchez-Morales et al., 2023). While the spe-

cific mechanisms of these adaptations require further investigation, the observed improvements in jump height and sprint speed are likely linked to heightened contractile properties of leg extensor muscles. These adaptations play a crucial role in enabling superior force production during the rapid, dynamic movements inherent in basketball play. Coaches and practitioners can leverage these findings when designing training programs aimed at optimizing linear sprint performance in basketball athletes.

Change of direction performance

The analysis of 8 effects across 9 original studies aimed to assess the impact of RST on COD performance, measured in seconds. The overall results reveal a noteworthy improvement in COD for participants undergoing RST, with a significant effect size of -1.11 (95% CI: -1.73 to -0.50 , $Z = 3.54$, $p = .0004$). Particularly noteworthy is the very large effect size (ES = -2.22) reported by Brini et al. (Brini et al., 2023). Although a significant level of between-study heterogeneity emerged ($I^2 = 73\%$, $p = .0005$), indicating variability in results across studies, the within-model effect sizes remained consistently larger (ES = -1.42 , 95% CI: -2.21 to -0.64 , $Z = 3.55$, $p = .0004$).

COD tests inherently assess both sprint speed and agility. RST—characterized by repeated, high-intensity efforts with short recoveries—induces neuromuscular and metabolic adaptations such as improved eccentric strength, intermuscular coordination, and reactive control, all of which enhance COD performance (Born et al., 2016; Chaouachi et al., 2014). Moreover, the repeated accelerations and decelerations in RST improve athletes' ability to tolerate braking forces and re-accelerate quickly—key determinants of agility (Spiteri et al., 2015). These neuromechanical adaptations, including greater stretch–shortening cycle efficiency and neural drive (Fiorenza

et al., 2019), may explain the greater improvement observed in COD performance compared with line sprinting. Subgroup analyses provided additional insights into the influence of diverse programming parameters on the effectiveness of RST interventions. Notably, adult players, a longer study duration (exceeding 8 weeks), a shorter training frequency (less than three sessions per week), a shorter inter-repetition recovery time (less than 30 seconds), and the inclusion of a COD program may enhance the efficacy of sprint performance in RST interventions. However, regarding training duration, moderate heterogeneity was observed across subgroups ($I^2 = 67.2\%$), and ES values should be interpreted conservatively. This pronounced effect size may be influenced by the results from a single study (Ersoy et al., 2020), potentially impacted by heterogeneity.

Due to the limited number of included articles, our meta-analysis conducted subgroup analyses only for the sprint training and COD training groups. The results of the subgroup analyses showed that the COD group presented a larger effect (ES = -1.68 , 95% CI: -2.75 to -0.61 , $p = .02$) than the line-sprint group (ES = -1.02 , 95% CI: -2.26 to 0.21 , $p = .02$). The observed difference between COD and linear sprint performance may be partly explained by the principle of training specificity. RST protocols incorporating COD components often involve multidirectional accelerations, decelerations, and turns that closely replicate the demands of COD tests such as the T-test. Therefore, neuromuscular and mechanical adaptations developed—such as enhanced eccentric strength, improved stretch–shortening cycle function, and refined motor coordination—are more likely to transfer effectively to COD performance than to straight-line sprinting (Born et al., 2016; Spiteri et al., 2015).

The short rest intervals in RST not only enhance speed and agility but also contribute to

the development of aerobic endurance. $\text{VO}_2\text{-max}$ is significantly correlated with the RST fatigue index ($r = -0.57, p < .05$) (Gharbi et al., 2015). A higher VO_2max helps athletes recover faster between repeated sprints by improving their ability to tolerate and remove hydrogen ions (H^+) from working muscles and by supporting the quick restoration of phosphocreatine (PCr) and ATP stores after exercise (Bogdanis et al., 1996).

As a high-intensity intermittent exercise, RST promotes muscle reoxygenation and improves oxygen extraction and utilization (Buchheit & Ufland, 2011). During repeated sprints, muscle oxygen saturation (SmO_2) typically drops to around 40% and recovers to about 80% during passive rest, indicating a strong aerobic metabolic involvement (Paulauskas et al., 2020). Generally, the T-test requires a longer duration and more directional changes than linear sprinting, thereby placing greater demands on endurance. These physiological mechanisms may provide a more comprehensive explanation for why the effect size of RST on COD in the straight-line subgroup is smaller than that in the COD subgroup ($ES = -1.02$ vs. -1.68), yet remains substantially greater than its effect on straight-line sprint performance ($ES = -1.02$ vs. -0.34 or -0.42).

In addition, five of eight studies used RST protocols incorporating COD movements, which may have further emphasized multidirectional acceleration patterns. As COD tasks require both sprinting and directional changes, these combined demands could explain the greater overall gains in COD performance compared with pure linear sprint outcomes. Nevertheless, considering the relatively high within-group heterogeneity ($I^2 = 82\text{--}84\%$), these findings should be interpreted with caution.

In summary, the findings indicate a significant enhancement in COD performance with RST. The subgroup analyses provide valuable

insights into how various training parameters may influence RST effectiveness, offering a helpful guide for coaches to optimize training protocols.

Limitations

Our meta-analysis results offer support for the effectiveness of repeated-sprint training in significantly enhancing CMJ, sprint, and COD performance in basketball players. However, it is essential to consider certain factors when interpreting these findings. Firstly, heterogeneity among the included studies has been recognized, with observed heterogeneity ranging from low to high, especially in fitness parameters associated with COD outcomes. Moreover, the relatively modest sample size in our meta-analysis might have influenced both the observed effect sizes and the uncertainty around them, as indicated by the width of our confidence intervals (Fagard et al., 1996). Secondly, the influence of muscle architecture and maturation on sprint and jump performance can vary significantly during maturation (Radnor et al., 2022). However, in our meta-analysis, participants ranged in age from teenagers to professional athletes. Due to limited research and a scarcity of studies addressing this aspect, the potential impact of maturity factors on training was not comprehensively examined. Thirdly, differences in the training protocols within our meta-analysis, involving straight lines, single or multiple COD maneuvers, and varying distances covered, may introduce unique effects on the observed outcomes (Attene et al., 2015).

CONCLUSIONS

Repeated sprint training effectively enhances countermovement jump, linear sprint, and change-of-direction performance in basketball players, with the greatest impact observed in change of direction. Training adult players less than three times per week with

short rest intervals (<30 s) appears most effective. Although COD improvements appeared greater than linear sprint gains, this may reflect the multidirectional demands of RST rather than a true superiority of agility over speed enhancement. Therefore, conclusions should be drawn with caution. Future research should examine RST protocols that isolate linear and multidirectional sprinting and include electromyographic (EMG) assessments to further elucidate neuromuscular mechanisms.

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