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Review article

The Effect of Combined Strength, Plyometric, and Sprint Training on Repeated Sprint Ability in Team-Sport Athletes: A Systematic Review and Meta-Analysis

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Abstract

Repeated sprint ability (RSA) is crucial for success in team sports, and involves both neuromuscular and metabolic factors. While single-mode training (SGL; e.g., sprint training) and combined training (CT; e.g., sprint + plyometric) can improve RSA, whether CT offers additional benefits compared to SGL or active controls maintaining routine training (CON) remains uncertain in team-sport athletes. This study evaluates the effect of CT versus SGL and CON on the RSA of team-sport athletes. A comprehensive search was conducted in five electronic databases. Thirteen studies involving 394 males and 28 females, aged 14 to 26 years, were included. The random effects model for meta-analyses revealed greater improvement in RSA mean after CT compared to SGL (Hedge's g effect size [g] = -0.46; 95 % confidence interval [CI]: -0.82, -0.10; $p < 0.01$) and CON (g = -1.39; 95% CI: -2.09, -0.70; $p < 0.01$). CT also improved RSA best compared to CON (g = -1.17; 95% CI: -1.58, -0.76; $p < 0.01$). The GRADE analyses revealed low- to very-low certainty of evidence in all meta-analyses. Subgroup analysis revealed that plyometric + sprint training yielded greater RSA mean (g = -1.46) and RSA best (g = -1.35) improvement than plyometric + resistance + sprint training and resistance + sprint training. The effects of CT on RSA did not differ according to age (≥ 18 vs. < 18), sports (e.g., soccer vs. basketball vs. handball), or RSA test type (linear sprint vs. sprint with change-of-direction). Studies showed an overall high risk of bias (ROB 2). In conclusion, CT may be improving team-sport athletes' RSA more effectively than SGL (small effect size) and CON (large effect size), particularly when CT involves plyometric + sprint training.

Key words: Physical fitness, athletic performance, plyometric exercise, team sports, resistance training.

Introduction

Team sports such as soccer, basketball, rugby, and handball, exhibit typical intermittent characteristics, with alternating high-intensity activities (e.g., running, jumping, sprinting, and changing of directions) and periods of lower-intensity activities (e.g., jogging and walking) (Stølen et al., 2005; Bradley et al., 2009; Austin et al., 2013; Castagna et al., 2018). Athletes in team sports are required to repeatedly perform short-duration (explosive) sprints (≤ 10 s) and maintain optimal average sprint performance with a relatively short recovery times (≤ 60s**)** (Glaister, 2005; Spencer et al., 2005; Carling et al., 2012). This ability is known as repeated sprint ability (RSA) (Girard et al., 2011). In the Australian Football League, players execute three high-intensity efforts every 60 s, with elite players averaging a minimum of one sprint per minute (Brewer et al., 2010). In soccer, numerous scoring opportunities frequently emerge following a series of maximal effort sprints, underscoring the significance of superior RSA in goal scoring (Faude et al., 2012). Although technical and tactical factors predominantly dictate overall performance in team sports, enhancing RSA can positively affect an athlete's physical performance during critical match stages (Buchheit et al., 2010d; Turner and Stewart, 2013; Schimpchen et al., 2016). Consequently, to fulfill the ongoing demands for high-intensity sprints throughout a match, team-sport athletes require exceptional RSA (Padulo et al., 2015).

RSA is a complex physical requirement for team-sport athletes, influenced by neuromuscular factors such as neural drive, motor unit recruitment, muscle activation, and proprioceptive input. (Bishop et al., 2011; Buchheit and Mendez-Villanueva, 2014). It is also influenced by metabolic factors including phosphocreatine recovery, lactate H^+ buffering, and anaerobic capacity (Gabbett, 2007; Girard et al., 2011). Therefore, improving RSA performance depends on a combination of interacting factors (Rampinini et al., 2009; Krustrup et al., 2010). Studies indicate that targeted training, including plyometric (PT) (Negra et al., 2020; Chaabene et al., 2021) and resistance training (RT) (Edge et al., 2006; Hill-Haas et al., 2007), can improve RSA by enhancing neuromuscular function, such as muscle strength and motor unit recruitment, and boosting running economy (Radnor et al., 2018; Støren et al., 2008). Additionally, interval sprint and repeated sprint training (Mohr et al., 2007; Buchheit et al., 2010b; Hoffmann et al., 2014) can increase the capacity for sustained high-intensity efforts, augment aerobic capacity, and improve phosphocreatine resynthesis, addressing metabolic constraints (Schneiker et al., 2008; Buchheit et al., 2010c). Although different training methods can address these limiting factors (related to RSA), the high density of competitions in team sports seasons makes it challenging to implement these methods independently. However, combined training (CT) integrates different training methods more efficiently, enhancing multiple physical qualities.

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CT is an increasingly popular program, with the most common type being complex training, which typically includes high-load RT and low-load explosive PT within the same session (often set-by-set) (Ebben, 2002). This approach is more effective at enhancing speed, strength, and power compared to performing RT or PT alone (Ronnestad et al., 2008; Guadalupe-Grau et al., 2009; Zghal et al., 2019). However, CT may include various combinations of training methods from RT, speed drills, aerobic endurance training, power training, and other methods, all of which can improve performance to varying degrees (Ribeiro et al., 2021). Performance improvements may be attributed to the conditioning activity, usually a high-load resistance training exercise that increase skeletal muscle excitation following the stimulus, thus enhancing subsequent training performance (e.g., post-activation performance enhancement - PAPE) (Prieske et al., 2020). For instance, an acute physiological, mechanical, or psychological response to a set of high-intensity deep squats with high loads (at relatively slow speeds) may enhance strength and/or speed in subsequent low-load, high-velocity exercises (e.g., sprints or jumps) (Cormier et al., 2022). Thus, the chronic performance gains from CT may result from potentiated acute responses to training sets.

Regarding the effect of CT on RSA in team-sport athletes, Beato et al. (2018) showed that combined sprint training (ST) and PT improved sprinting performance compared to isolated ST in young soccer players (range: -0.51 to -0.29 vs. -0.22 to -0.15, for 10 m, 20 m, and 40 m intervals). Similarly, PT + RT has proven effective in increasing Neuromuscular performance (20-m sprint, Squat Jump [Power, velocity, force and height]) (Fischetti et al., 2019). Additionally, PT + RT + ST can improve repeated sprint mean and best time (Spineti et al., 2016; Hammami et al., 2019a). Conversely, sprint speed was reduced after PT+RT (Kobal et al., 2017), with no RSA enhancement after RT+PT+ST (Hammami et al., 2017). Therefore, research results have shown inconsistency regarding the potential of CT to enhance RSA.

To date, only Thapa et al. (2022) have systematically reviewed the effect of CT on RSA in soccer players, and reported a non-significant effect. However, the systematic review included only three studies (two from the same research team), and included very specific CT interventions (i.e., contrast format) (Thapa et al., 2022). Although other meta-analysis have investigated the effects of CT on specific populations such as basketball (Uysal et al., 2023) and soccer players (Oliver et al., 2023), comprehensive analyses of its effect on RSA across various team sports are still scarce. Given the debated effect of the CT program and the lack of meta-analysis addressing CT's influence on team-sport athletes' RSA. A comprehensive summary of the available evidence can help to clarify the role of CT on RSA in team-sport athletes.

The purpose of this study was to compare the intervention effects on team-sport athletes' RSA among CT, specific controls undergoing SGL (such as resistance, plyometrics, sprint, etc.), and active controls maintaining regular training (CON). Additionally, CT was categorized based on three different types (i.e., PT + ST, PT + RT + ST, and RT + ST) to explore the optimal CT program for enhancing RSA in team-sport athletes.

Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The study was preregistered on the Open Science Framework (OSF), with the registration document accessible via the following link: https://doi.org/10.17605/OSF.IO/2EU97.

Search strategy

A comprehensive search strategy was implemented across five electronic databases: PubMed/MEDLINE, Web of Science, Cochrane Library, SPORTDiscus, and Scopus in this systemically conducted review. Training interventions are classified and defined as (1) strength/resistance training: training exercises aimed at improving the ability to generate maximum external force through high-load, low-velocity movements (e.g., squats, deadlifts) (Stone, 1993); (2) plyometric training: training exercises aimed at improving the ability to effectively utilize the stretch-shortening cycle (SSC) and explosive transition from eccentric to concentric muscle actions (e.g., drop jumps, hurdle jumps, horizontal jumps) (Taube et al., 2012); (3) sprint training: specific exercises that more closely mimic RSA demands, such as maximum velocity linear sprints, repeated sprint training, sprint interval training, and change-of-direction sprints, aiming to develop optimal sprint speed, recovery ability between sprints, and neuromuscular function (Taylor et al., 2015; Nygaard Falch et al., 2019); (4) combined training: interventions that combine strength/resistance, plyometric, and/or sprint training. The search timeframe spanned from each database's inception to 7 January 2024, complemented by a subsequent search on 1 March 2024. Following the PICOS principle (Population, Intervention, Comparison, Outcome, Study) (Considine et al., 2017), we identified keywords via an initial trial filtering of literature to delineate terms associated with population, intervention, and performance outcomes, such as "team sports", "invasion sports", "athletes", "players", "training", intervention, "combined training", "complex training", "resistance training", "plyometric", "change of direction", "sprints training", "repeated sprints training", "sprints interval training", "high-intensity interval training. These search terms were amalgamated using the Boolean operators AND and OR. The supplementary material 1 provides detailed information on the search strategy for each database. Furthermore, we explored Google Scholar and the reference lists of all eligible articles and reviews to identify additional relevant studies.

Selection process and eligibility criteria

All records from the databases were imported into reference management software (EndNote X9, Clarivate Analytics, 2018). Duplicate records were removed by an independent researcher (LHX). The remaining records were then screened based on inclusion/exclusion criteria. The primary researchers (LHX and ZW) conducted a two-step screening process. Initially, the screening was based on titles and abstracts. The second phase involved full-text screening. Study eligibility was determined through the PICOS approach. The inclusion and exclusion criteria are detailed in Table 1.

Data extraction and interpretation

The author (LHX) independently extracted relevant information. The extracted content included author details (names and publication year), study design, participant characteristics (sample size, average age, gender, sport, level), intervention details (exercise type, duration, program, control group), RSA test parameters (distance, sets, repetitions, interval, inter-set rest, presence of directional changes or straight-line sprints), and pre-and post-intervention test data (RSA best time, meantime, total time, and fatigue index). In cases where articles were missing any relevant information (i.e., pre-post-test data), attempts were made to contact the authors via email to request the necessary details. The collected information was presented in tabular form within a standard data extraction model. A second researcher (ZW) thoroughly cross-verified the extracted data. When collecting RSA data for pre-post intervention tests, both RSA mean and RSA total results were considered as the same indicator (since RSA mean is obtained by dividing the RSA total by the number of sprint repetitions). The RSA mean was selected for synthesis if a study reported both the RSA mean and the RSA total.

Risk of bias

The risk of bias was assessed by two authors independently (LHX and LR) as suggested by the Cochrane Collaboration, with a senior researcher (ZMX) solving eventual disagreements. The researchers performed several trials to become familiarized with the risk of bias (ROB2) tool (Higgins et al., 2019).

Certainty of evidence

The overall certainty of the evidence for each outcome was assessed using the Recommendation, Assessment, Development, and Evaluation (GRADE) tool (Schünemann et al., 2019). The overall certainty of the evidence was categorized as 'very low', 'low', 'moderate', or 'high'. The grading was completed by one reviewer (LR) and reviewed by a second (LHX).

Summary measures, synthesis of results, and publications bias

This meta-analysis employed the inverse variance method and synthesized main effects using the DerSimonian-Laird random-effects model. The Jackson method calculated tau^2, tau, and confidence intervals (DerSimonian and Laird, 1986). We extracted the mean difference (MD), standardized mean difference (Hedge's *g*), and 95% confidence interval (CI) from each study to calculate the pooled effect size. Given that outcome measures often involve various testing units, and previous research suggests the priority use of Hedge's *g* (Nagashima et al., 2019), this study uses Hedge's *g*, corrected for bias with an exact formula for each study, as the effect size measure, notably since most included studies have a small sample size. Hedge's *g* categories are as follows: < 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 huge (Hopkins et al., 2009). Improvements in RSA performance is typically quantified by reductions in time (seconds) or decreases in the fatigue index (percentage). According to the Cochrane Handbook, if a study includes multiple control groups (such as SGL and CON), and comparisons need to be made between the CT intervention group and each control group separately, the sample size should be divided proportionally to enable comparisons among multiple groups (Cumpston et al., 2019).

The I^2 statistic (I^2) was used as the primary source of information to report the impact of heterogeneity, with I^2 values < 25%, 25 - 75%, and > 75% indicating low, moderate and high heterogeneity, respectively (Nakagawa et al., 2017).

Table 1. Inclusion and exclusion criteria.

	Inclusion criteria	Exclusion criteria
Population	Team-sport athletes of any gender and level (invasion sports on the field or court).	Non-team sports (e.g., solo, squash, or combat sports), ice, beach, or water team sports, game officials, non-athletes.
Intervention	The combined training intervention is defined as athletes performing neuromuscular training (such as plyometrics and resistance training) combined with metabolic training (such as sprinting, interval training) on the same training day or within the same training session. These interventions lasted for at least 4 weeks.	The intervention group did not involve studies that utilized combinations of training methods such as plyometrics, resistance training, sprinting, or repeated sprint training. Acute interventions lasting < 4 weeks.
Comparator	Active control (CON) (i.e., players participating keeps regular training) or a specific control group with single-mode training (SGL) (i.e., players participating resistance, plyometrics, sprint, repeated sprints, etc.).	No control groups.
Outcome	The study includes pre- and post-intervention assessment of at least one RSA parameter: RSA best, RSA mean, and RSA fatigue index (i.e., assessed by fatigue index and/or sprint attenuation scores). The pre- and post-testing modalities must be a running RSA test performed on the ground.	The pre-test or post-test lacks the outcomes of the RSA test and is an RSA test in a laboratory environment, such as cycling.
Study design	The study design must have at least two groups and be a randomized controlled trial.	Non-randomized controlled trials, single-arm experiments, and observational studies.

Subgroup analyses to explore sources of heterogeneity and moderating factors were conducted on results with significant differences from more than two studies. The subgroup analyses primarily focused on the subjects and the intervention plans (Hopkins and Batterham, 2018). Specifically, the moderating factors for subjects were categorized by age into adults (average age ≥ 18) and adolescents (average age < 18), and by sport into soccer, basketball, and handball, where futsal and mixed team sports with only one study each were not compared. The intervention strategies were classified based on CT types: plyometric + sprint training (PT + ST), plyometric + resistance training + sprint training (PT + RT + ST), and resistance + sprint training (RT + ST). Additionally, we conducted subgroup analyses based on the RSA test mode: one COD sprint, multiple COD sprint, and linear sprint. Due to the limited number of studies meeting the inclusion criteria, subgroup analyses on training duration and frequency could not be conducted.

Funnel plots (Peters et al., 2008) combined with Egger's test were used to explore publication bias (Egger et al., 1997), with $p > 0.05$ implying no publication bias. When Egger's test suggests potential publication bias, the trim-and-fill method was employed to estimate and correct for potential publication bias, thereby enhancing the objectivity and comprehensiveness of the results. Statistical analyses and plotting were conducted using the "meta" and "metafor" packages in R (version 4.3.0) (Viechtbauer, 2010). Statistical significance was set at $p < 0.05$, and a trend toward statistical significance was considered when $0.10 > p > 0.05$.

Results

Figure 1 presents the PRISMA flow diagram detailing the screening process. The initial database search yielded 1056 publications, and an additional 11 from Google Scholar and previous studies' references. After duplicates removal, 319 publications remained and were screened by titles and abstracts. Thereafter, 68 full-text publications were screened, and 13 studies were included (Spineti et al., 2016; Hammami et al., 2017; 2019a; 2019b; Torres-Torrelo et al., 2018; Sanchez-Sanchez et al., 2019; Aloui et al., 2021a; 2021b; 2022; Brini et al., 2022; 2023; Gaamouri et al., 2023b; Derraa, 2023). Of note, two studies (Torres-Torrelo et al., 2017; Torres-Torrelo et al., 2018) reported analogous data, thus only the study presenting more comprehensive data was included (Torres-Torrelo et al., 2018).

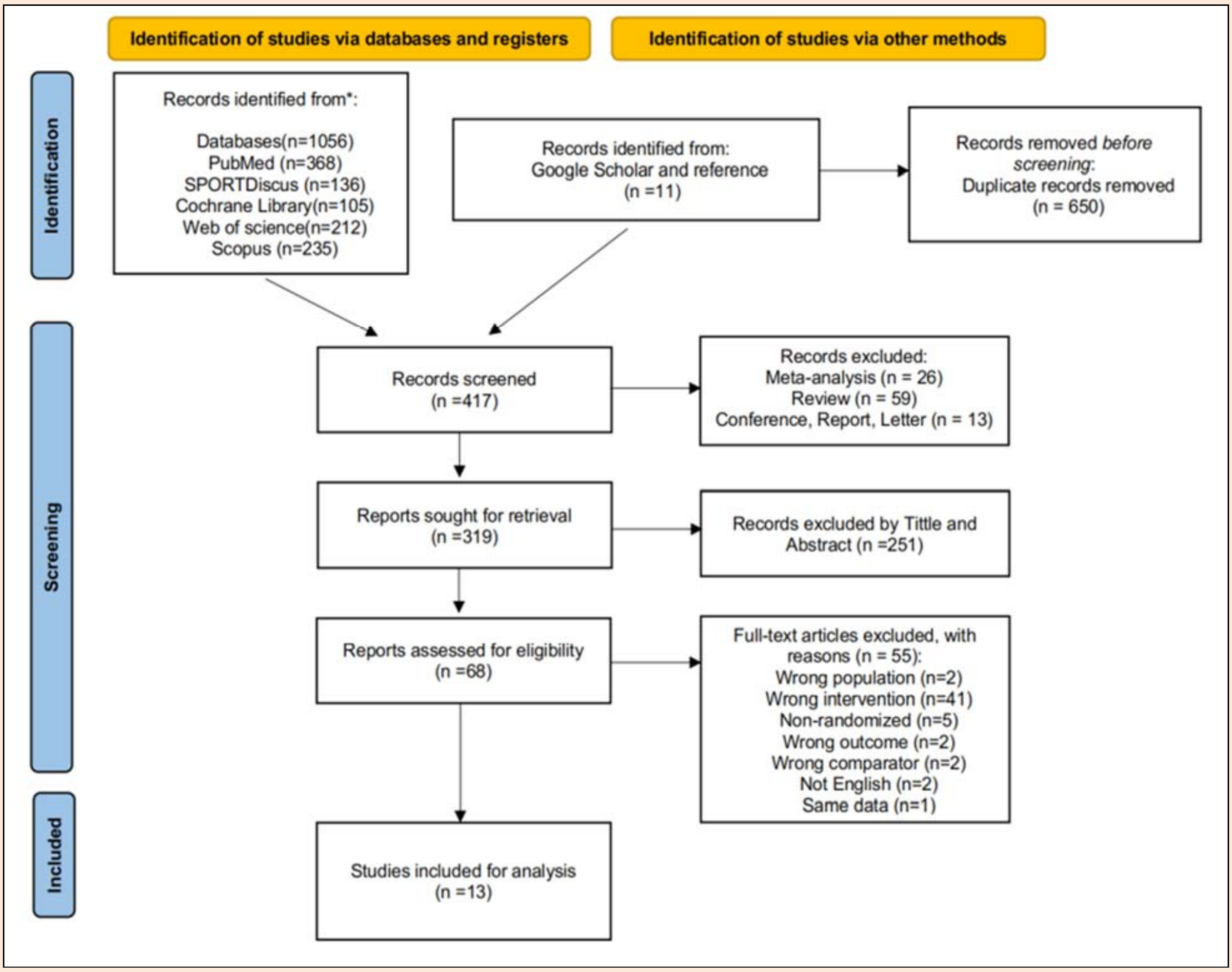

Figure 1. Summary PRISMA (preferred reporting items for systematic reviews and meta-analyses) flowchart identifying the study selection process.

Study characteristics

The included studies comprised 13 CT intervention groups (n = 185), along with 7 SGL groups (n = 88) and 11 CON groups (n = 149). Table 2 details study characteristics, including participant details, types, and contents of intervention and controls, in addition to RSA testing methods and results. The predominant gender among the study participants was male (n = 394), with a single study including female participants (n = 28). The studies primarily covered team-sport athletes including soccer (n = 188), basketball (n = 94), handball (n = 84), futsal (n = 34), and mixed team-sport athletes (n = 22, a mix of soccer and basketball). The participants were aged between 14 and 26 years. Eight studies utilized a CT type of PT + ST, three studies implemented a combination of PT + RT + ST, and two studies followed an RT + ST. Eight studies employed One COD Sprint, three studies employed Multiple COD Sprint, and two studies employed Linear Sprint. The total intervention duration ranged from 5 to 10 weeks, with a frequency of 2 to 3 times per week.

Table 2. Study characteristics.

	Characteristics of participants				Detail of intervention			Detail of test and outcomes	
Study	S	Sample size (n)	Age (years)	Level and sport	Frequency /Duration	Combine type	Programs of combined and single training	RSA test	Outcomes
Aloui et al.2022	M	CT, n =17 CON, n =17	14.6 ± 0.5 14.6 ± 0.4	National First Divisional soccer	2/8	PT+ST	1. 6x 0.4 m hurdle jumps+ 15 m sprint; 2. 6x Lateral hurdles+ 10 m sprint; 3. 6x bouncy strides+ 15 m sprint; 4. 6x single-leg hop +10 m sprint; All 1 set/3-6 reps	6x 20+20 m running sprints with 180◦ turns shuttle; rest=25 s	Best Mean Fatigue index
Aloui et al.2021a	M	CT, n = 18 CON, n = 16	16.6 ± 0.5 16.6 ± 0.5	National First Division soccer	2/8	PT+COD	1. 6x 0.5 m hurdles+15 m COD sprint; 2.6x 0.4 m lateral hurdle+10 m COD sprint; 3.6x bouncy strides+ 15 m COD sprint; 4.6x 0.5 m drop jumps+10m s COD sprint; All 1 set/3-6 reps	6x 20+20 m running sprints with 180◦ turns shuttle; rest=20 s	Best Mean Total Fatigue index
Aloui et al.2021b	M	CT, n = 18 CON, n = 16	17.5 ± 0.6 17.5 ± 0.6	National First Divisional soccer	2/8	PT+ST	Participants wear weighted vest (8% body mass): 1. 6x 0.5 m hurdles+15 m sprint; 2. 6x 0.4 m lateral hurdles+ 10 m sprint; 3. 6x bouncy strides+ 15 m sprint; 4. 6x 0.5 m drop jumps+ 10m sprint; All 1 set/3-6 reps	6x 20+20 m running sprints with 180◦ turns shuttle; rest=25 s	Best Mean
Brini et al.2022	M	CT, n = 13 PT, n = 13 RST, n = 13 CON, n = 13	26.10 ± 1.82 26.02 ± 2.37 25.75 ± 1.76 26.35 ± 2.11	First Division basketball	2/8	PT+RST	CT: drop jumps + 6x5m 90◦ COD sprint; 3 sets/8-10reps; PT: 50 cm drop jumps; 3 sets/10-12reps; RST: 6x5m 90◦COD sprint; 3 sets/8-10reps	10x 6x5m sprints with 3x 180° + 2x 90° COD; rest=30 s	Best Total Fatigue index
Brini et al.2023	M	CT, n =14 PT, n = 14 CON, n = 14	25.1 ± 2.3 24.8 ± 1.7 26.0 ± 2.1	First Division basketball	2/8	PT+RST	CT: drop jumps + 6x5m 90◦ COD sprint; 3 sets/8-10reps; PT: (5 vertical+5 horizontal jumps); 3 sets/10-12reps	10x 6x5m sprints with 3x 180° + 2x 90° COD; rest=30 s	Best Total Fatigue index
Derraa et al.2023	M	CT, n = 10 CON, n =10	17.6 ± 0.52 17.5 ± 0.53	Jijel State Honors League soccer	3/6	PT+COD	Hurdles, bounds, hops, CMJs, broad jumps + COD (45°, 60°, 90°, 135°, 180°) or curve sprint; 4-5 sets	6x 20 m straight line sprints; rest=25 s	Best Mean Total Fatigue index
Gaamouri et al.2023b	M	CT, n = 15 CON, n = 13	16.5 ± 0.4 16.7 ± 0.3	Elite Division of National handball	2/8	PT+ST	1. 6× 40 cm hurdles +5 s sprint at 130% aerobic max; 2. 6×30 cm extended-leg hurdles +5 s sprint at 130% aerobic max; 3. 6 ×horizontal jumps+5 s sprint at 130% aerobic max; 4. 3 right-leg+3 left-leg hops+5s sprint at 130% aerobic max; All 2 sets/8reps	6x 15+15 m running sprints with 180◦ turns shuttle; rest=20 s	Best Mean Fatigue index

Abbreviations ordered alphabetically. F female, M male, S sex, COD change of direction training, CON reguler training or reguler training group, CT combined training or combined training group, HIIT high intensity interval training, PT plyometric training, RT resistance training, RSA repeated sprint ability, RST repeated sprint training, ST sprint training.

Table 2. Continued.

Study	Characteristics of participants				Detail of intervention			Detail of test and outcomes	
	S	Sample size (n)	Age (years)	Level and sport	Frequency /Duration	Combine type	Programs of combined and single training	RSA test	Outcomes
Hammami et al.2019a	F	CT, n = 14 CON, n = 14	16.6 ± 0.3 16.6 ± 0.3	Elite handball	2/10	RT+PT+ST	1 .6x half-squat at 85% 1RM + 6x 40 cm hurdle jumps + 10 m sprints; 2. 6x thigh press at 85% 1RM + 6x horizontal jumps + 10 m sprints 6x thigh press at 85% of 1RM + 6 horizontal jumps +10 m sprints; 3. 8s isometric half-squat at 75% 1RM + 6x single-foot hops (3 right, 3 left) + 10 m sprints; 4. 6x calf extensions at 90% 1RM + 6x 30 cm extended-leg hurdle jumps + 10 m sprints; All 4reps	6x 20+20 m running sprints with 180◦ turns shuttle; rest=20 s	Best Mean Total Fatigue index
Hammami et al.2017	M	CT, n = 16 RT, n = 16 CON, n = 12	16.0 ± 0.5 16.2 ± 0.6 16.8 ± 0.2	NR soccer	2/8	RT+PT+ST	CT: (rising sets 70-90% 1RM back half squat +3x CMJ at Tuesday, descending sets 90%-10% back half squat+3 x CMJ+1x 15 m sprint at Thursday); 3-5 sets/3-8reps; RT: (rising sets 70-90% 1RM back half squat at Tuesday, descending sets 90%-10% 1RM back half squat at Thursday); 3-5 sets/3-8reps	6x 20+20 m running sprints with 180◦ turns shuttle; rest=20 s	Best Mean Total Fatigue index
Hammami et al.2019b	M	CT, n = 14 CON, n = 14	14.5 ± 0.3 14.6 ± 0.2	First Division National handball	2/8	PT+COD	1. 3 right hops + 3 left hops + COD sprint; 2. 6x 0.3 m lateral hurdles (3 left, 3 right) + COD sprint; 3. 6x horizontal jumps (3 left, 3 right) + COD sprint; 4. 6x 0.4 m hurdles + COD sprint	7 × agility-T test running sprints; rest = 25 s	Best Mean Total Fatigue index
Sanchez-Sanchez et al.2019	M	CT, n = 12 HIIT, n = 10	22.5 ± 2.2 22.5 ± 2.2	Amateur team sports	2/5	RT+HIIT	CT: (30 s 90-100% HRmax) 2 sets/8reps +(backwards lunges, unilateral hamstring "kicks", kBox3 half-squats); 2-3 sets/6reps; HIIT:(30s 90-100% HRmax); 2 sets/8reps	6x 15+15 m running sprints with 180◦ turns shuttle; rest=30 s	Best Mean Fatigue index
Spineti et al.2016	M	CT, n = 12 RT, n = 10	18.4 ± 0.4 18.4 ± 0.4	First Brazilian League Division soccer	3/8	PT+RT+ST	CT: 1. CMJ, barrier front jumps, single barrier front jumps, diagonal cone hops; 2. high pull, straight sprints, knee-up sprints, zig-zag sprints; 3. box CMJ, box-to-box depth jumps; All 2 sets/4-10reps; RT: 1.12-15RM Smith machine squats, Olympic bar knee-flexion deadlifts, stiff-legged deadlifts, knee extension, knee flexion, and hip adduction machines; 2. 8-10RM Smith machine squats, Olympic bar knee-flexion deadlifts, stiff-legged deadlifts, knee extension machine; 3. 4-6RM Smith machine squats, Olympic bar knee-flexion deadlifts, stiff-legged deadlifts; All 2-4 sets	6x 20+20 m running sprints with 180◦ turns shuttle; rest=20 s	Best Mean Fatigue index
Torres-Torrelo et al.2018	M	CT, n = 12 RT, n = 12 CON, n = 10	22.9 ± 5.1 23.8 ± 2.4 24.7 ± 4.7	Spanish Third Division futsal	2/6	RT+COD	Full squat (38.4 ± 4.6 to 52.1 ± 5.9 kg) 2-3 sets/4-6 reps + 10 s COD with 5-10kg load 2-5 sets. RT: Full squat (36.8 ± 8.0 to 49.6 ± 8.3 kg) 2-3 sets/4-6 reps.	9x 20 m straight line sprints; rest=25 s	Best Mean Fatigue index

Abbreviations ordered alphabetically. F female, M male, S sex, COD change of direction training, CON reguler training or reguler training group, CT combined training or combined training group, HIIT high intensity interval training, PT plyometric training, RT resistance training, RSA repeated sprint ability, RST repeated sprint training, ST sprint training.

Risk of bias

Regarding the randomization process (D1), although all the included studies were randomized crossover trials, only 2 studies explicitly reported the randomization methods. The remaining 11 studies were classified as having some concerns due to the lack of information on the randomization process. The studies included in this review were classified as having low bias risk due to issues related to the timing of participant identification or recruitment (D2), deviations from the intended interventions (D3), and missing outcome data (D4). In the field of sports training, implementing blinding is nearly impossible due to participants' direct involvement in the training. Typically, the same person serves as both the researcher and the outcome assessor. However, there was no reported blinding of outcome assessors among the 13 studies. This could lead to bias and distortion of research outcomes, decreasing internal validity and credibility. With one individual overseeing multiple aspects of the study, the lack of blinding for outcome assessors may introduce subjective bias, impacting the accuracy and reliability of study findings. Hence, we assessed all studies with a high risk of bias in the measurement of outcome (D5). Selective outcome reporting (D6) was present in almost all studies to some extent. All the included studies (n = 13) had a high risk of bias (Supplementary Figure 1).

Meta-Analysis Results

Repeated sprint ability mean

Thirteen studies (Spineti et al., 2016; Hammami et al., 2017; 2019a; 2019b; Torres-Torrelo et al., 2018; Sanchez-Sanchez et al., 2019; Aloui et al., 2021a; 2021b; 2022; Brini et al., 2022; 2023; Gaamouri et al., 2023b; Derraa, 2023) assessed RSA mean, involving 13 CT groups, 7 SGL groups and 11 CON groups (total n = 422). CT improved RSA mean compared to the combined sub-groups SGL and CON (g = -0.99; 95% CI: -1.44, -0.54; p < 0.001; Figure 2). High heterogeneity was observed (Tau^2 = 0.695; Chi^2 = 70.20; df = 17; p < 0.001; I^2 = 76%; PI: -2.82, 0.84). The sensitivity analysis indicated stability in the pooled effect size (g = -0.99; 95% CI: -1.44, -0.54; p < 0.001; Supplementary Figure 2). Egger's test showed potential publication bias in the primary pooled effect size (p = 0.015), as depicted in the funnel plot in Supplementary Figure 3. After applying the trim-and-fill method, no potential unpublished studies were identified, implying a balance between published and expected published studies. Both before and after trim-and-fill, the pooled result for the outcome (RSA mean) remained significant at p < 0.001, indicating stability in the pooled effect size. When compared to SGL, CT improved RSA mean (7 datasets; g = -0.46; 95% CI: -0.82, -0.10; I^2 = 0%; p = 0.01). When compared to CON, CT significantly improved the RSA mean (11 datasets; g = -1.39; 95% CI: -2.09, -0.70; I^2 = 84%; p < 0.01).

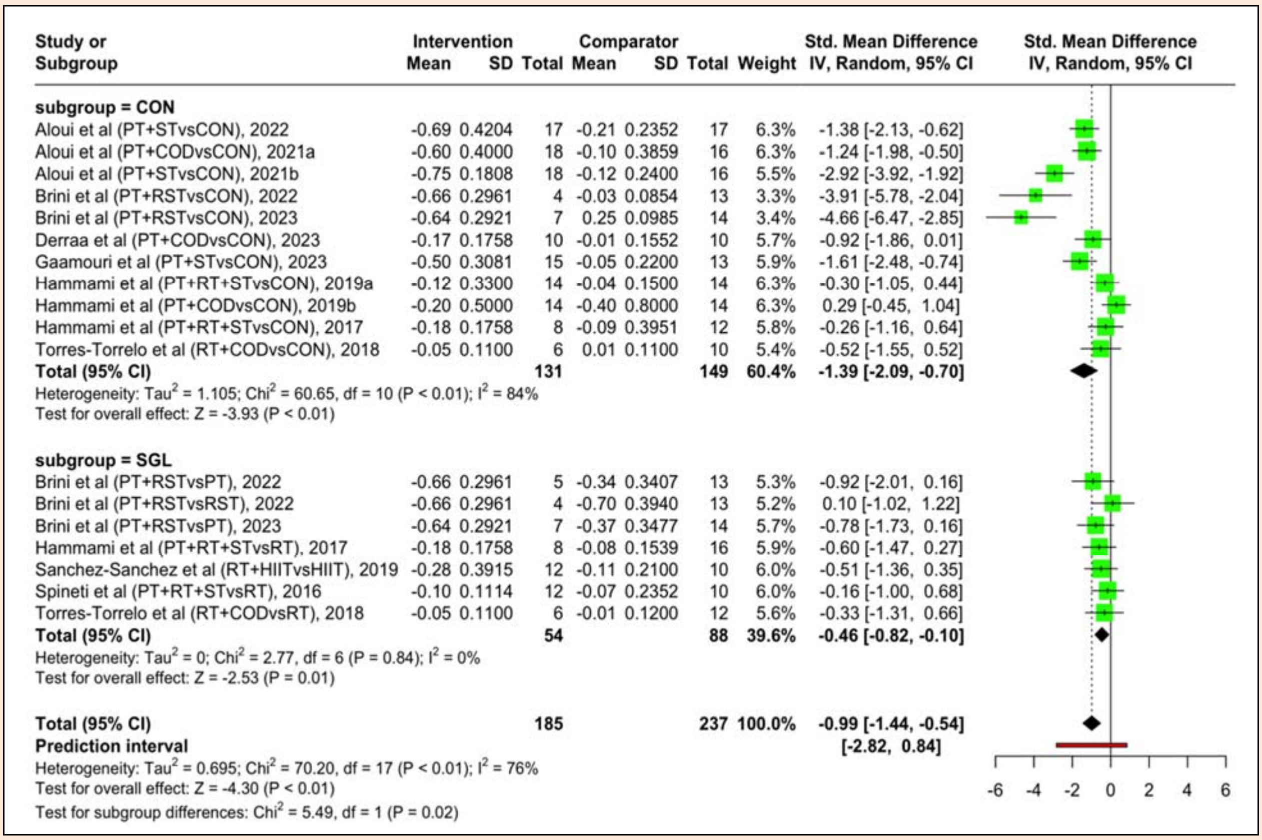

Figure 2. The forest plot illustrates the effect of combined training compared to regular training (top) and single-mode training (bottom) on athletes' repeated sprint ability mean. COD: change of direction training; CON: regular training or regular training group; HIIT: high intensity interval training; PT: plyometric training; RT: resistance training: RST repeated sprint training; ST: sprint training; SGL: single mode training or single mode training group.

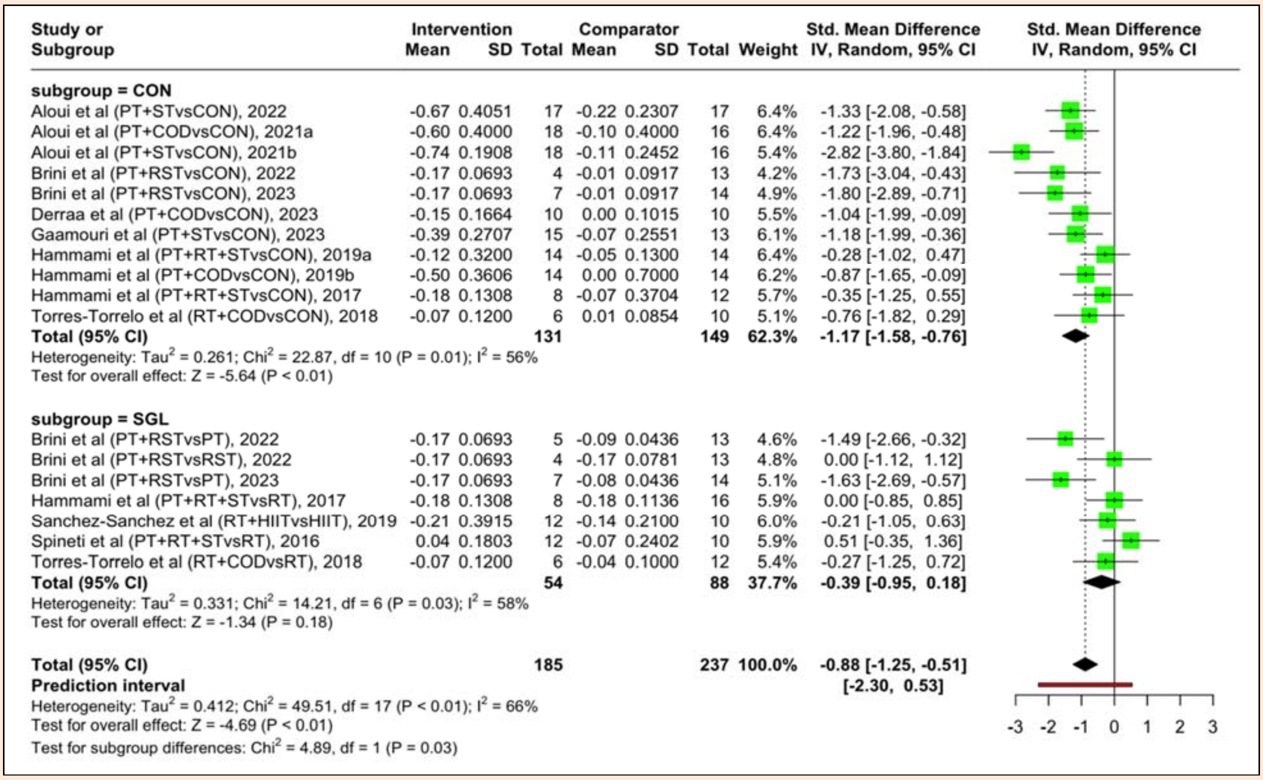

Figure 3. The forest plot illustrates the effect of combined training compared to regular training (top) and single-mode training (bottom) on athletes' repeated sprint ability best. COD: change of direction training; CON: regular training or regular training group; HIIT: high intensity interval training; PT: plyometric training; RT: resistance training: RST repeated sprint training; ST: sprint training; SGL: single mode training or single mode training group.

Repeated sprint ability best

Thirteen studies (Spineti et al., 2016; Hammami et al., 2017; 2019a; 2019b; Torres-Torrelo et al., 2018; Sanchez-Sanchez et al., 2019; Aloui et al., 2021a; 2021b; 2022; Brini et al., 2022; 2023; Gaamouri et al., 2023b; Derraa, 2023) assessed RSA best, involving 13 CT groups, 7 SGL groups and 11 CON groups (total n = 422). CT improved RSA best compared to the combined sub-groups SGL and CON (g = -0.88; 95% CI: -1.25, -0.51; p < 0.001; Figure 3). Moderate heterogeneity was observed (Tau^2 = 0.412; Chi^2 = 49.51; df = 17; p < 0.001; I^2 = 66%; PI: -2.30, 0.53). The sensitivity analysis indicated stability in the pooled results (g = -0.88; 95% CI: -1.25, -0.51; p < 0.001; Supplementary Figure 4). Egger's test showed no potential publication bias in the primary pooled effect size (p = 0.293), as depicted in the funnel plot in Supplementary Figure 5.

When compared to SGL, no significant effect was noted for CT on RSA best (7 datasets; g = -0.39; 95% CI: -0.95, 0.18; I^2 = 58%; p = 0.18). When compared to CON, CT significantly improved the RSA best (11 datasets; g = -1.17; 95% CI: -1.58, -0.76; I^2 = 56%; p < 0.01).

Repeated sprint ability fatigue index

Twelve studies (Spineti et al., 2016; Hammami et al., 2017; 2019a; 2019b; Torres-Torrelo et al., 2018; Sanchez-Sanchez et al., 2019; Aloui et al., 2021a; 2022; Brini et al., 2022; 2023; Gaamouri et al., 2023b; Derraa, 2023) assessed RSA fatigue index, involving 12 CT groups, 7 SGL groups and 10 CON groups (total n = 388). CT did not improve RSA fatigue index compared to the combined sub-groups SGL and CON (g = 0.07; 95% CI: -0.25, 0.38; p = 0.672; Figure 4). Moderate heterogeneity was observed (Tau^2 = 0.228; Chi^2 = 34.33; df = 16; p = 0.005; I^2 = 53%; PI: -1.01, 1.14). The sensitivity analysis indicated stability in the pooled results (g = 0.07; 95% CI: -0.25, 0.38; p = 0.672; Supplementary Figure 6). Egger's test showed no potential publication bias in the primary pooled effect size (p = 0.115), as depicted in the funnel plot in Supplementary Figure 7. CT did not improve the RSA fatigue index when compared to SGL (7 datasets; g = 0.02; 95% CI: -0.63, 0.66: I^2 = 68%: p = 0.96) or CON (10 datasets: g = 0.09; 95% CI: -0.25, 0.44; I^2 = 42%; p = 0.59).

Moderator variables effect

The effects of the moderator variables are displayed in Table 3. Compared with SGL and CON, the CT type of PT + ST (g = -1.46) significantly and more substantially effects the RSA mean (p < 0.01). The effects of the CT types of PT + RT + ST (g = -0.33) were similar to RT + ST (g = -0.45). Adolescent athletes (< 18 years old) and adults (≥ 18 years old) similarly improved performance (g = -0.97 vs. -1.06, respectively; between-group p = 0.86). No differences were observed between sports (p = 0.35) and RSA test (p = 0.41) (see Supplementary Figures 8 – 11).

Compared to SGL and CON, the CT type of PT + ST (g = -1.35) had a significantly greater effect on RSA best (p < 0.01). RT + ST (g = -0.38, p = 0.18) had a greater effect than PT + RT + ST (g = -0.04, p = 0.84), but the effect was not significant. No significant difference in the moderating factors of age (p = 0.56), sport (p = 0.42), and RSA test (p = 0.37) (see Supplementary Figures 12 – 15).

Certainty of evidence

According to the GRADE assessment (Table 4) the quality of evidence varied from low to very low.

Discussion

The main objectives of this meta-analysis were to investigate the effect of CT on RSA in team-sport athletes and to determine the optimal CT protocol for enhancing RSA in these athletes. The results of the meta-analyses indicate that, compared to SGL and CON, CT improved both RSA mean and RSA best. However, the effect of CT on the RSA fatigue index did not show a statistically significant difference. Additionally, PT + ST seems to be the most effective protocol for enhancing RSA when compared to RT + ST and PT + RT + ST. The effect of CT on athletes' RSA did not dependent on athletes' age, sports type, and RSA test.

Effects of combined training on RSA

This study revealed that compared to SGL and CON, CT enhances team-sport athletes' RSA mean and best time. Previous evidence on CT's effect on RSA was limited. In contrast to our findings, the meta-analysis by Thapa et al. (2022) found non-significant RSA changes among soccer players following CT. This discrepancy could be due to the active control groups, which either maintained regular specific training (Faude et al., 2013; Hammami et al., 2017; Miranda González et al., 2021) or combined RT with a regular specific training (Spineti et al., 2016; Kobal et al., 2017). Regular specific training alone or in combination with other methods (Stølen et al., 2005; Silva et al., 2015;) can influence RSA, masking the CT's benefits. Additionally, the inclusion of only three studies on soccer players' RSA, each with a small number of participants, may reduce the statistical power, potentially leading to inconclusive results. This could explain the non-significant difference observed between the CT and control groups.

Moreover, faster linear sprint speed can positively impact team-sport athletes' RSA (Lockie et al., 2020). Studies have shown that there is a small to large correlation between short-distance sprint performance (0-5 m, 0 - 10 m, 0 - 20 m) and RSA performance (r = 0.44 - 0.86) (Ingebrigtsen et al., 2014; Lockie et al., 2019). This suggests that sprint performance may contribute to RSA. The available evidence suggests that CT (i.e., RT + PT) can improve female team-sport athletes' short sprint performance (Hughes et al., 2023). Specifically, substantial improvements were observed in acceleration (i.e., 0 - 10 m) and short sprint distances (0 - 20 m). The findings of Nicholson et al. (2021) also raise the level of evidence for CT. They found that CT programs (e.g., ST and strength/jumping-related exercises), were effective in improving single sprinting performance (effect size medium to large), especially 0-10m and 0 - 20m. Therefore, the greater improvement in RSA observed in this study following CT may be partly attributed to the influence of CT on linear sprint performance. However, given the complexity of CT, it may also be influenced by other factors.

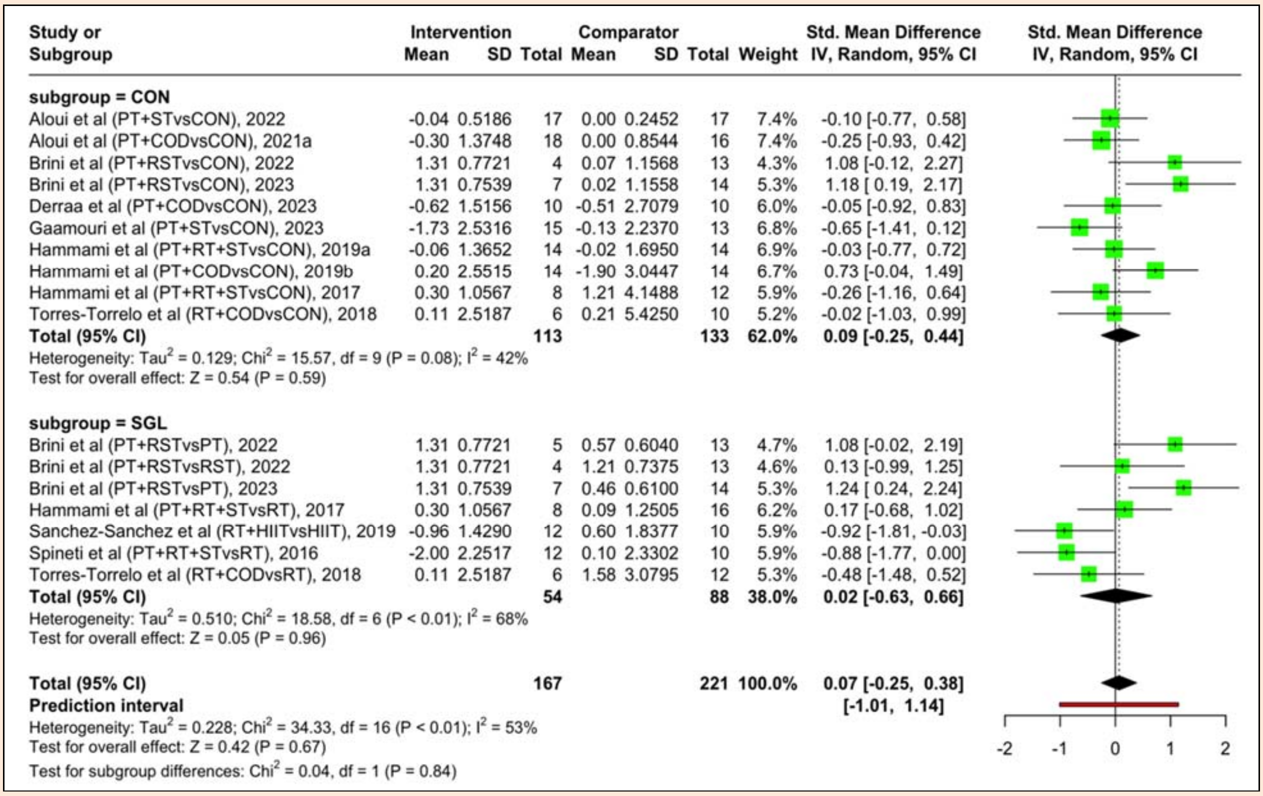

Figure 4. The forest plot demonstrates the effect of combined training versus regular training (top) and single-mode training (bottom) on athletes' repeated sprint ability fatigue index. COD: change of direction training; CON: regular training or regular training group; HIIT: high intensity interval training; PT: plyometric training; RT: resistance training: RST repeated sprint training; ST: sprint training; SGL: single mode training or single mode training group.

Table 3. Moderator variables.

	Moderator		K(N)	Hedges' g	95% confidence interval Lower limit	95% confidence interval Upper limit	p-value Within groups	p-value Between groups
RSA Mean	Age	< 18 years	8	-0.97	-1.55	-0.39	**<0.01**	0.86
		≥ 18 years	5	-1.06	-1.81	-0.30	**<0.01**	
	Sports	Soccer	6	-1.05	-1.68	-0.42	**<0.01**	0.35
		Basketball	2	-1.87	-3.39	-0.35	**0.02**	
		Handball	3	-0.52	-1.57	0.53	0.33	
	CT	PT + ST	8	-1.46	-2.17	-0.76	**<0.01**	**0.02**
		PT + RT + ST	3	-0.33	-0.74	0.09	0.12	
		RT + ST	2	-0.45	-1.00	0.09	0.10	
	RSA test	One COD sprint	8	-0.98	-1.51	-0.45	**<0.01**	0.41
		Multiple COD sprint	3	-1.45	-2.75	-0.15	**0.03**	
		Linear sprint	2	-0.60	-1.17	-0.04	**0.04**	
RSA Best	Age	< 18 years	8	-0.99	-1.48	-0.50	**<0.01**	0.56
		≥ 18 years	5	-0.78	-1.34	-0.19	**<0.01**	
	Sports	Soccer	6	-0.88	-1.64	-0.13	**0.02**	0.42
		Basketball	2	-1.32	-1.99	-0.65	**<0.01**	
		Handball	3	-0.76	-1.28	-0.23	**<0.01**	
	CT	PT + ST	8	-1.35	-1.73	-0.97	**<0.01**	**<0.01**
		PT + RT + ST	3	-0.04	-0.46	0.37	0.84	
		RT + ST	2	-0.38	-0.92	0.17	0.18	
	RSA test	One COD sprint	8	-0.75	-1.35	-0.16	**0.01**	0.37
		Multiple COD sprint	3	-1.21	-1.76	-0.67	**<0.01**	
		Linear sprint	2	-0.70	-1.27	-0.12	**0.02**	

CT: combined training; PT: plyometric training; RT: resistance training; RSA: repeated sprint ability; ST: sprint training; Bold values: $p < 0.05$, denoting statistical significance.

Table 4. GRADE* analyses.

Outcome	No of participants (studies)	Risk of Bias	Certainty assessment: Inconsistency	Indirectness	Imprecision	Other	Mean effect † (95% CI)	GRADE*
CT vs. SGL+CON								
RSA mean	422 (13 RCTs)	Serious	Serious	Not Serious	Not Serious	None	-0.99 (-1.44 to -0.54)	□□○○ LOW
RSA best	422 (13 RCTs)	Serious	Serious	Not Serious	Not Serious	None	-0.88 (-1.25 to -0.51)	□□○○ LOW
RSA fatigue index	388 (12 RCTs)	Serious	Serious	Not Serious	Serious	None	0.07 (-0.25 to 0.38)	□○○○ Very LOW
CT vs. SGL								
RSA mean	142 (7 RCTs)	Serious	Not Serious	Serious	Not Serious	None	-0.46 (-0.82 to -0.10)	□□○○ LOW
RSA best	142 (7 RCTs)	Serious	Serious	Serious	Serious	None	-0.39 (-0.95 to 0.18)	□○○○ Very LOW
RSA fatigue index	142 (7 RCTs)	Serious	Serious	Serious	Serious	None	0.02 (-0.63 to 0.66)	□○○○ Very LOW
CT vs. CON								
RSA mean	280 (11 RCTs)	Serious	Serious	Serious	Not serious	None	-1.39 (-2.09 to -0.70)	□○○○ Very LOW
RSA best	280 (11 RCTs)	Serious	Serious	Serious	Not serious	None	-1.17 (-1.58 to -0.76)	□○○○ Very LOW
RSA fatigue index	246 (10 RCTs)	Serious	Serious	Serious	Very serious	None	0.09 (-0.25 to 0.44)	□○○○ Very LOW

* Certainty of evidence according to Grading of Recommendations, Assessment, Development and Evaluations (GRADE): High: We are very confident in the estimated effect. Moderate: Our confidence in the estimated effect is moderate. Low: We have limited confidence in the estimated effect. Very low: We have very little confidence in the estimated effect. † Mean effect calculated as the difference between the CT intervention group and SGL/CON group in how much their RSA changed from baseline to follow-up. RCTs: randomized controlled trial.

Indeed, according to Bishop et al. (2011), RSA performance relies mainly on (1) single sprint performance (i.e., RSA best), that involves underlying factors such as stride length and frequency, and (2) the ability to recover between sprints (metabolic capacity). CT methods focused on enhancing single sprint performance (e.g., strength training) and metabolic capacity (e.g., repeated sprint training) might prove effective to enhance RSA. Strength and power training can improve single sprint performance by several mechanisms. RT can increase the mean work done in a repeated sprint rest (~12%), and the performance in the first sprint (8-9%) (Edge et al., 2006). Furthermore, RT with high metabolic demand (i.e., blood lactate concentration ≥ 10 mmol/L) improved RSA. The improvements in strength and H^+ regulation capacity may enhance RSA (Hill-Haas et al., 2007).

Similarly, PT enhanced RSA in young female handball players (Gaamouri et al., 2023a), probably after neuromuscular adaptations allowing greater force production during the concentric phase of movement following rapid eccentric muscle actions, thereby enhancing sprint performance (Davies et al., 2015). Furthermore, ST, particularly after repeated sprints, can enhance athletes' intermittent sprint performance, RSA, and maximal oxygen uptake (Thurlow et al., 2023). Aerobic fitness improvements may help adenosine triphosphate to phosphocreatine resynthesis, and buffer metabolic by-products during between-sprints rest periods (Haseler et al., 1999; McGawley and Bishop, 2015). Therefore, the integration of these training methods may be considered in future CT programs, ultimately enhancing RSA performance.

Given that the above studies explain the effects of individually applying these trainings, such as RT, PT, or repeated sprint training, on enhancing RSA, we discuss the potential reasons for CT's enhancement of RSA as follows: Isolated PL or RT programs can induce mechanical and physiological adaptations leading to improvements in the best (first) sprint in a RSA test, with CT (e.g., PL+RT) potentially enhancing such adaptations/improvements (Sale, 2002; Robbins, 2005). According to the principle of training specificity, physiological and biomechanical adaptations to an intervention program are contingent on the specific characteristics of the training (Reilly et al., 2009). For example, PT utilizes SSC muscle actions and may enhance eccentric muscular activation, potentially aiding to specific movements (e.g., sprint, short shuttle runs, and changes of direction) in RSA test (Slimani et al., 2016). Therefore, CT might provide more central nervous system stimulation, thereby promoting better neural adaptations, such as better intermuscular coordination and synchronization of muscle fiber recruitment (Hoffman et al., 2004; Tricoli et al., 2005), increased peak force, peak power, and muscle-tendon stiffness (Haugen et al., 2019), and enhanced running stride and frequency (Lockie et al., 2012). Overall, these factors may increase the rate of force development and the efficiency of the SSC, which in turn will benefit RSA.

Therefore, the CT program is an effective training approach for team-sport athletes, offering various options for coaches and athletes to develop RSA. However, further research is needed to determine the optimal combination of exercises to enhance repeated sprint performance.

Moderator variables

Regarding athletes' age, post-CT intervention improvements in RSA were similar between adolescent athletes (< 18 years) and adults (≥ 18 years), with no significant differences. Study suggested that physical growth with age seems to significantly enhance athletic performance (Armstrong et al., 2001), suggesting that training may bring greater benefits to adult athletes' RSA. However, our study revealed similar improvements in RSA performance between adolescents and adults, implying that CT may be suitable for both.

Regarding athletes' sports, we observed no significant difference in CT effects among different team-sport athletes (e.g., soccer, basketball, handball). However, the 95% CI ranges for these analyses were large, possibly due to (1) small sample sizes, resulting in less precise statistical analyses, and (2) differences between participants in terms of physical fitness, training background, and competition demands that may have affected the consistency of the CT effects. Future studies are encouraged to apply CT to larger samples of team-sport athletes.

Regarding the type of CT, our findings indicate that, in contrast to RT + ST or PT + RT + ST, the PT + ST markedly enhanced team-sport athletes' RSA mean (g = -1.46 [large effect size]) and RSA best (g = -1.35 [large effect size]). To ascertain the reasons behind the superior improvements achieved by the PT + ST, we investigated the effect of each training component combination on RSA. First, a previous meta-analysis on PT in soccer players showed significant improvements in both RSA best and RSA mean (Ramirez-Campillo et al., 2021). These improvements were attributed to increased muscle activation capacity (Markovic and Mikulic, 2010;), greater muscle cross-sectional area and strength (Malisoux et al., 2006; Grgic et al., 2021), and enhanced efficiency of the SSC (Taube et al., 2012; Radnor et al., 2018). These adaptations potentially enhance single sprint capacity, thereby improving RSA.

Further analysis of the included studies revealed that the specific exercises within ST, including linear sprints, change-of-direction sprints, repeated sprint training, and high-intensity interval training, all target and improve the neuromuscular and metabolic limiting factors of RSA (as mentioned in the Introduction section). Taylor et al.'s (2015) systematic review supported the efficacy of repeated sprint training in beneficially impacting repeated sprint ability, aligning with Bishop et al. (2011) assertion that repeated sprint training is the most suitable method for RSA enhancement. Moreover, research has demonstrated that repeated sprint training can elevate maximal oxygen uptake (VO2 max), with a reported 5.0-6.1% increase following 5 - 12 weeks of intervention (Ferrari Bravo et al., 2008). Consequently, as aerobic capacity improves, so does the recovery ability between sprints (Gharbi et al., 2015). The significant improvement in RSA observed with CT (PT + ST) might attributed to the acute responses in the early training phase (as mentioned in the introduction section). It is widely recognized that conditioning activity before the PAPE must be as biomechanically similar as possible to the subsequent exercises designed to enhance function (Blazevich and Babault, 2019). This is often related to exercise goals or directions with similar movement patterns (e.g., vertical vs. horizontal oriented) (Loturco et al., 2018). Therefore, exercises emphasizing strength application in similar directions (e.g., horizontal or vertical jumping) are expected to result in acute or chronic improvements in activities where hip extensors play a key role (e.g., sprinting) (Loturco et al., 2018). However, the reason for the non-significant improvement in RSA with the combination of RT + ST and PT + RT + ST is unclear. It may be due to their synergistic effects and interference with the metabolic, determinants of RSA (Coffey et al., 2009).

Another possible reason is the limited number of studies available, with only three on PT + RT + ST and two on RT + ST examining the effects of RSA. Future research should focus on conducting more studies in this area. Overall, the CT type of PT +ST bolsters single sprint performance and augments inter-sprint recovery with more training specificity, elucidating its superior efficacy over other CT types.

Regarding the RSA testing, we observed that different testing modes did not significantly affect the effectiveness of CT. Direct comparisons between linear and COD RSA testing have indicated that while sprint speeds decrease with the introduction of COD, the overall physiological load may increase due to higher levels of lactate accumulation, potentially influencing RSA test performance to some extent (Buchheit et al., 2010a; Alemdaroğlu et al., 2018). We reviewed Kyles et al.'s (2023) recommendations from their systematic review on RSA testing protocols. For linear sprint testing, they suggested incorporating a 30-meter sprint into RSA testing for team-sport athletes. This recommendation was based on research indicating that sprints involving team-sport athletes typically cover distances ≤ 30 m (Stølen et al., 2005; Rampinini et al., 2007; Andrzejewski et al., 2015). For COD sprint testing, Kyles et al. (2023) noted that most protocols employed a single COD involving a 180° directional change. COD is a very neuromuscular demanding task, elite soccer players change direction frequently in matches, emphasizing the importance of COD in RSA testing (Sweeting et al., 2017; Dos'Santos et al., 2020; 2021). Among the studies we included, 2 utilized linear RSA testing with a 20-meter sprint distance, 8 utilized a single COD test, and 3 employed multiple COD sprints, aligning with the requirements of short-distance and multiple sprinting in team sports. Given the substantial variability in protocol designs due to the lack of a gold standard protocol for assessing RSA, both linear and COD RSA tests may be effective considering the diverse demands of different sporting contexts. This analysis supports the findings of our study: both linear and COD sprints can be utilized to examine the effects of CT training on RSA.

Limitations and future research

While this meta-analysis presents interesting findings, it's important to acknowledge its potential limitations. First, the search was limited to the English languages, peer-reviewed publications, and randomized controlled trials, potentially introducing selection and publication bias; though this approach guaranteed the quality of the included literature. Second, it is important to note that most of the samples were derived from national league team-sport athletes; thus, caution should be applied in generalizing the conclusions and applying them to athletes at other levels. Third, owing to the small number of studies fulfilling the inclusion criteria, subgroup analyses involving moderators such as sex, training duration, and frequency were not performed, preventing a more detailed exploration of diverse CT schemes. Fourth, of the 13 studies included in this analysis, only one focused on female team-sport athletes.

Future research should concentrate on female athletes and investigate potential gender differences in the effects of CT on RSA or other physical performance measures. Lastly, the included studies on CT interventions varied greatly, and the limited number of studies, as well as the limited number of studies involving athletes from different sports, might have contributed to the heterogeneity in the meta-analysis. The limited study pool and the inclusion of athletes from various sports potentially contributed to heterogeneity in the meta-analysis. Future studies should consider employing network meta-analysis methods and expanding the population and performance indicators included, to explore the effect of CT in comparison to various other training methods on athletes' physical performance.

Conclusion

Combined training, especially incorporating plyometric and sprint training, significantly enhances repeated sprint ability in team-sport athletes compared to single-mode and routine training. These findings support the use of multifaceted training programs to improve critical performance metrics in team sports. Physical fitness professionals and coaches could consider this as an appropriate strategy because it allows for the simultaneous combination of multiple training methods to produce a small to moderate training effect on RSA performance in terms of addressing the limiting factors of the neuromuscular and metabolic capacity of RSA. However, due to the low certainty of evidence, further research is warranted to confirm these results and refine training methodologies.

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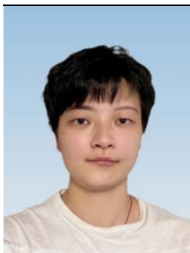

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Key points

- Combined strength (CT) improved repeated sprint ability (RSA) performance compared to single-mode training (SGL) and active controls maintaining routine training (CON).
- This study recommends that coaches prioritize the incorporation of combined training strategies into athletes' training regimens to optimize RSA development, especially emphasizing PT (e.g., horizontal or vertical, unilateral, or bilateral, or drop jumps) +ST (e.g., linear sprints, change of direction sprints, repeated sprints, high-intensity interval sprints) combinations.
- The favoring effects of CT were noted across different ages and sports. The RSA tests involving linear and non-linear sprints seem equally sensitive to examine the effects of CT.

Supplementary Materials

1. Search syntax.

PubMed/MEDLINE
("team sports"[All Fields] OR "invasion sports"[All Fields] OR ("athlete s"[All Fields] OR "athletes"[MeSH Terms] OR "athletes"[All Fields] OR "athlete"[All Fields] OR "athletically"[All Fields] OR "athlets"[All Fields] OR "sports"[MeSH Terms] OR "sports"[All Fields] OR "athletic"[All Fields] OR "athletics"[All Fields]) OR ("player"[All Fields] OR "player s"[All Fields] OR "players"[All Fields])) AND (("training"[All Fields] OR "intervention"[All Fields]) AND ("combined training"[All Fields] OR "combination"[All Fields] OR "complex training"[All Fields] OR "contrast training"[All Fields] OR "Strength training"[All Fields] OR "resistance training"[All Fields] OR "plyometric"[All Fields] OR "jump training"[All Fields] OR "change of direction"[All Fields] OR "sprints training"[All Fields] OR (("repeatabilities"[All Fields] OR "repeatability"[All Fields] OR "repeatable"[All Fields] OR "repeated"[All Fields] OR "repeatibility"[All Fields]) AND ("sprint"[All Fields] OR "sprinted"[All Fields] OR "sprinting"[All Fields] OR "sprints"[All Fields]) AND ("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields])) OR (("sprint"[All Fields] OR "sprinted"[All Fields] OR "sprinting"[All Fields] OR "sprints"[All Fields]) AND ("interval"[All Fields] OR "intervals"[All Fields]) AND ("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields])) OR "agility training"[All Fields] OR "high intensity interval training"[All Fields] OR "small side game"[All Fields])) AND ("Repeated Sprint Ability"[All Fields] OR "Repeated Sprint Ability"[All Fields] OR "repeated sprint test"[All Fields] OR "repeated sprint ability test"[All Fields] OR "repeated sprint performance"[All Fields])

Web of Science (Core Collection)
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Scopus

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Cochrane library

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#4 #1 AND #2 AND #3 105

SPORTDiscus

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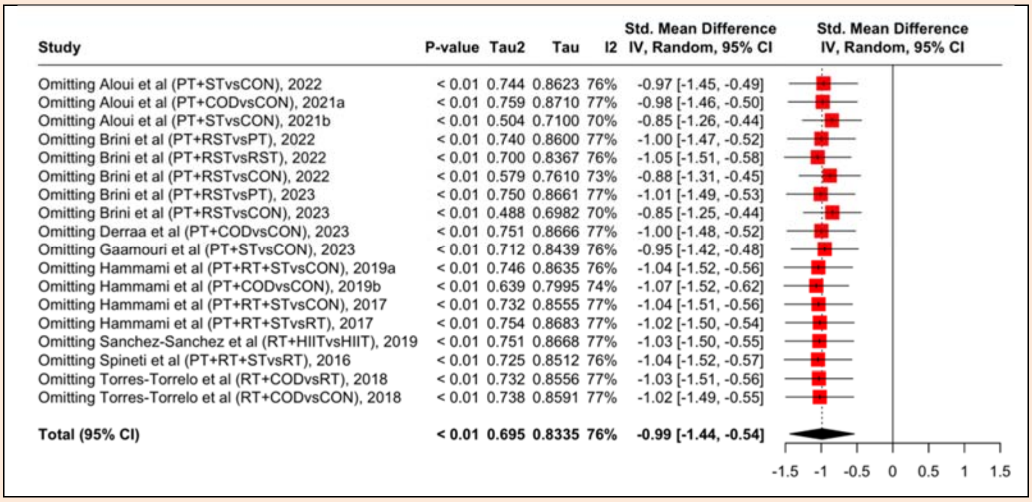
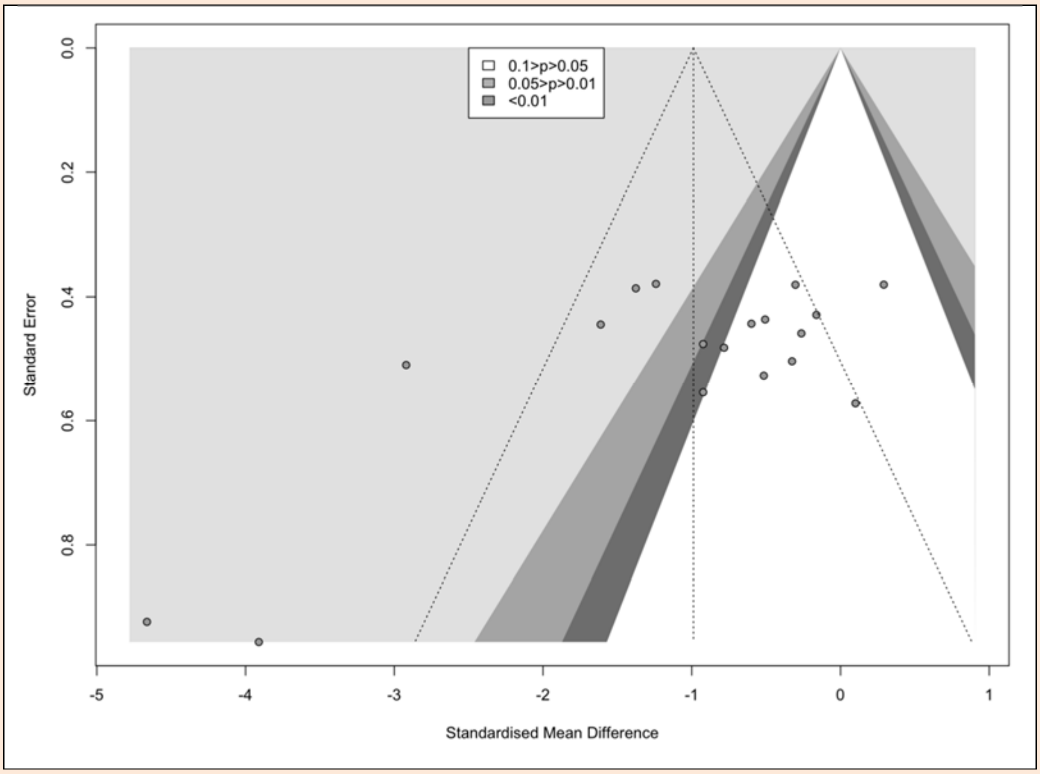
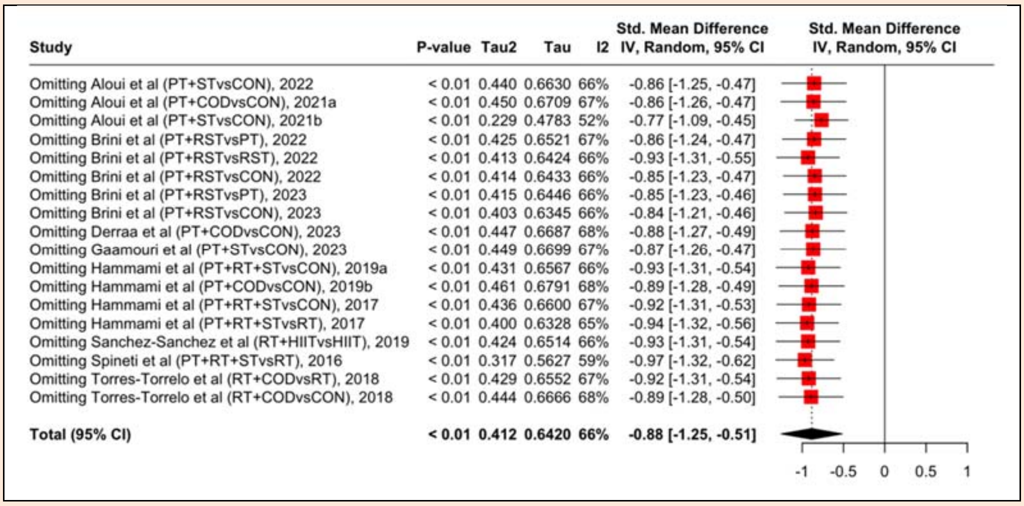
Supplementary Figure 1. **Risk of bias assessment.**



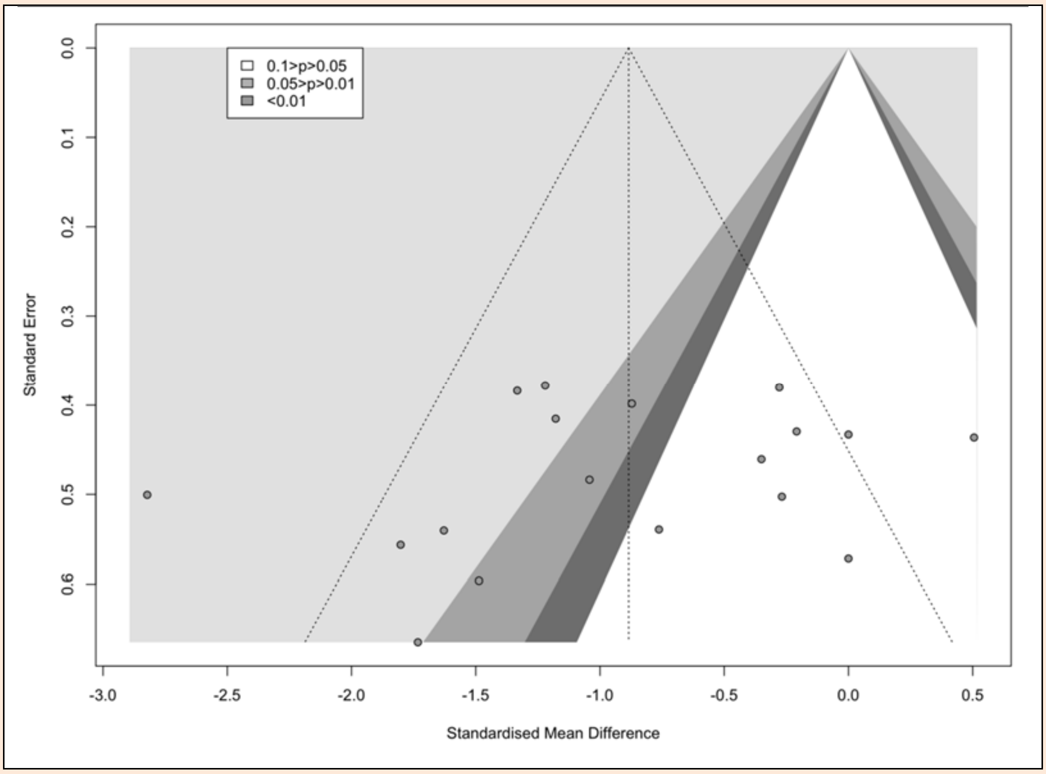
Supplementary Figure 2. Sensitivity analysis of RSA mean.



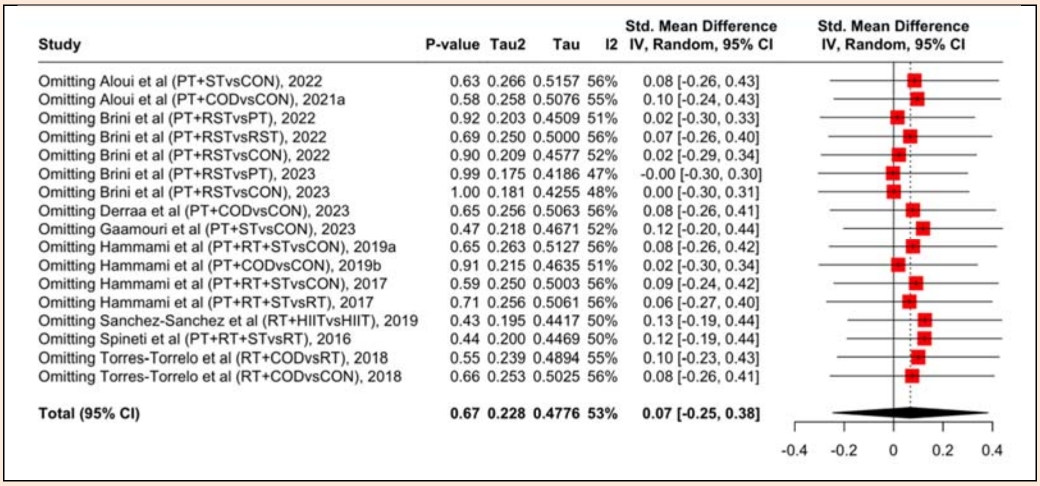
Supplementary Figure 3. Funnel plot of RSA mean.



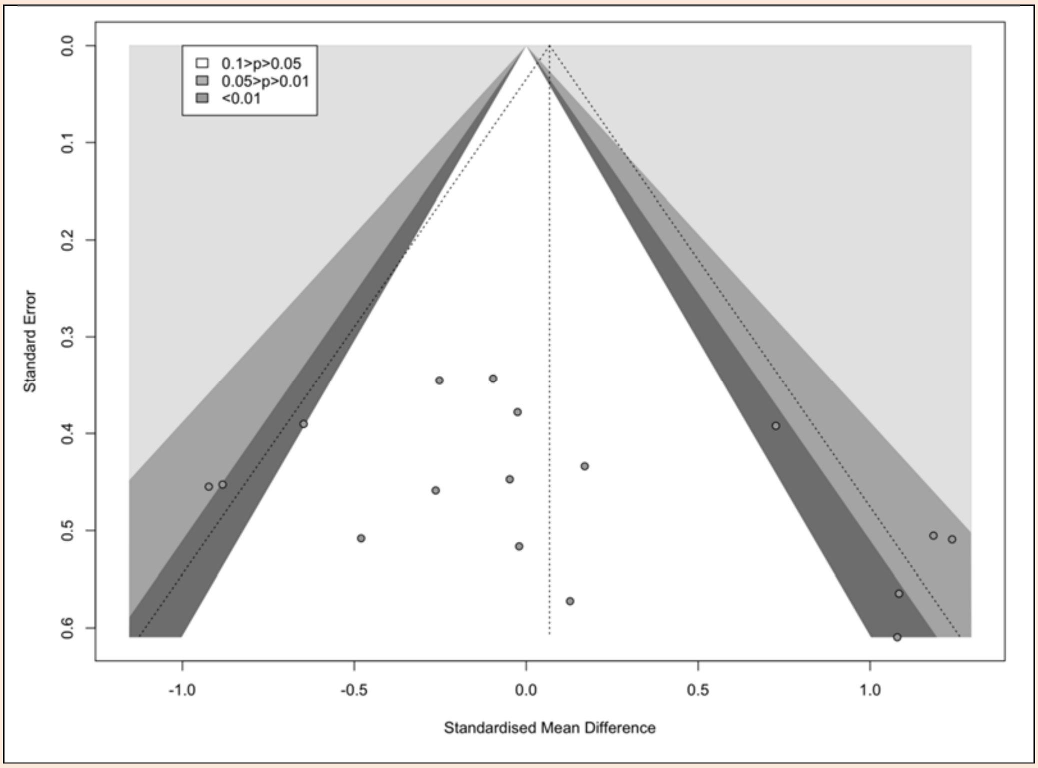
Supplementary Figure 4. Sensitivity analysis of RSA best.



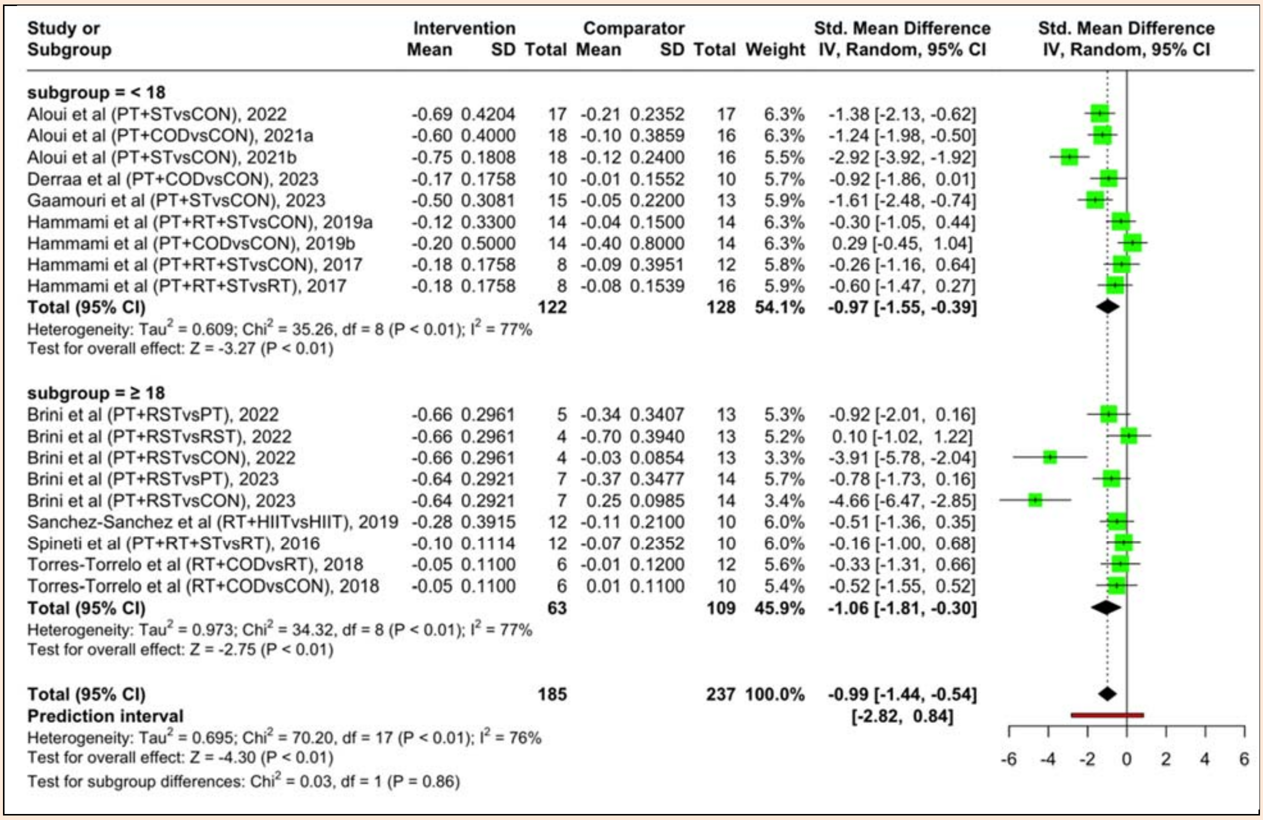
Supplementary Figure 5. Funnel plot of RSA best.



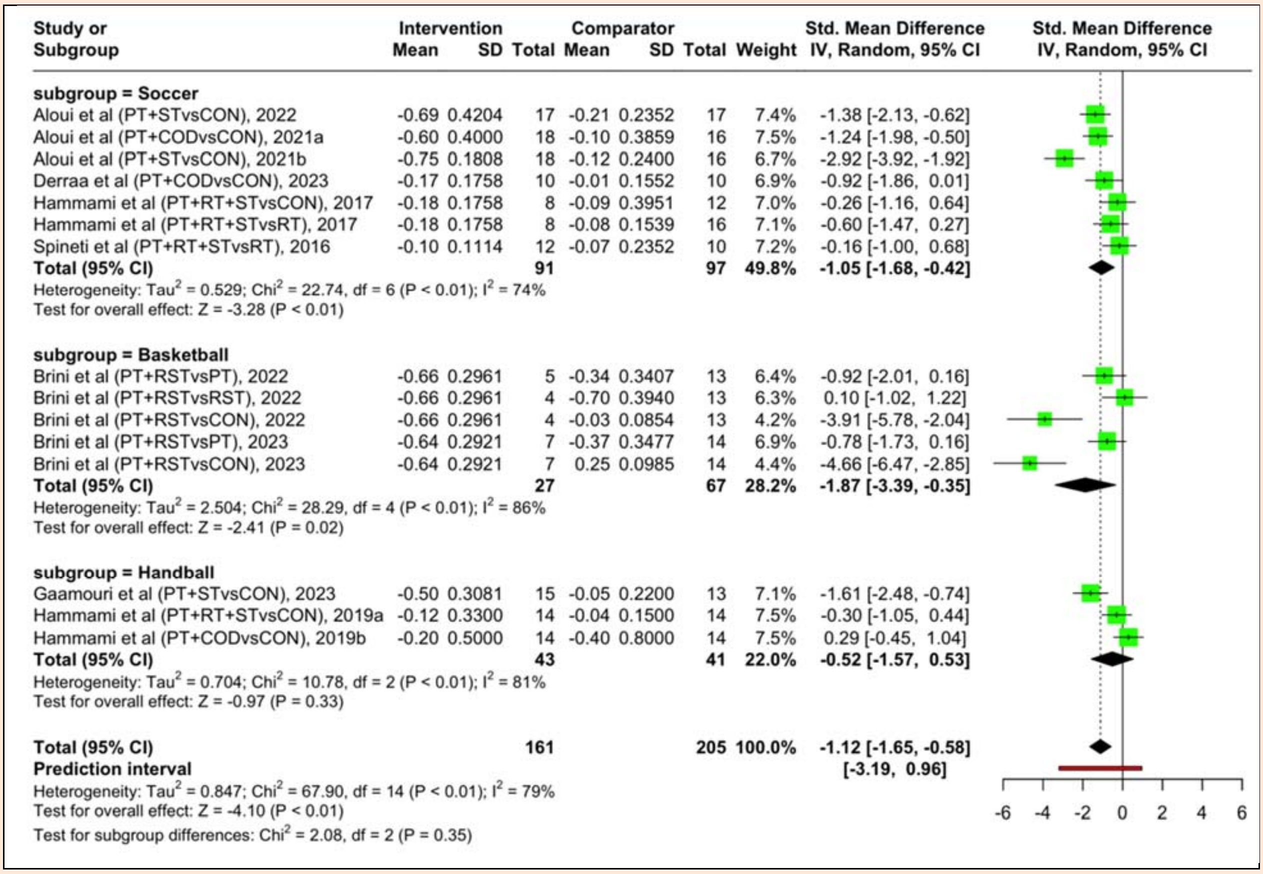
Supplementary Figure 6. Sensitivity analysis of RSA fatigue index.



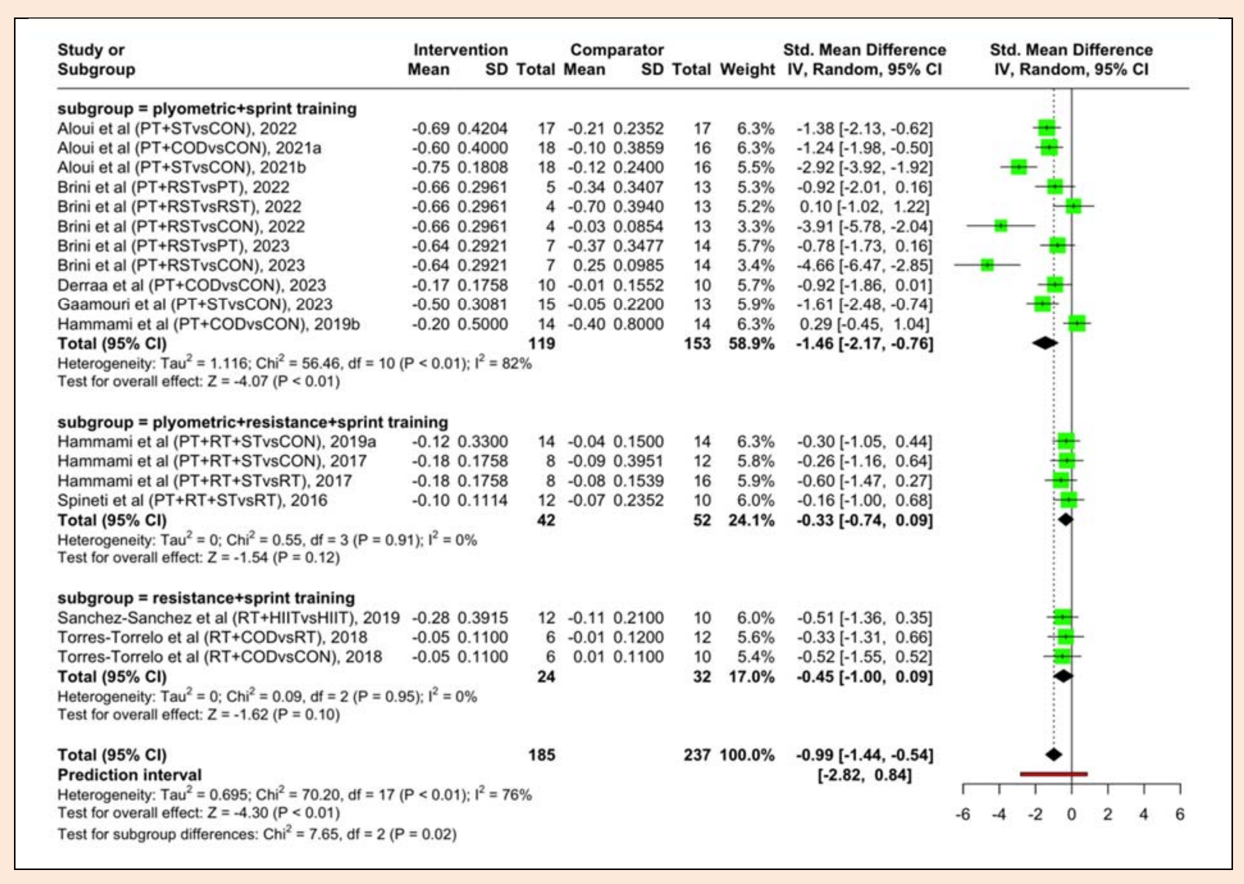
Supplementary Figure 7. Funnel plot of RSA fatigue index.



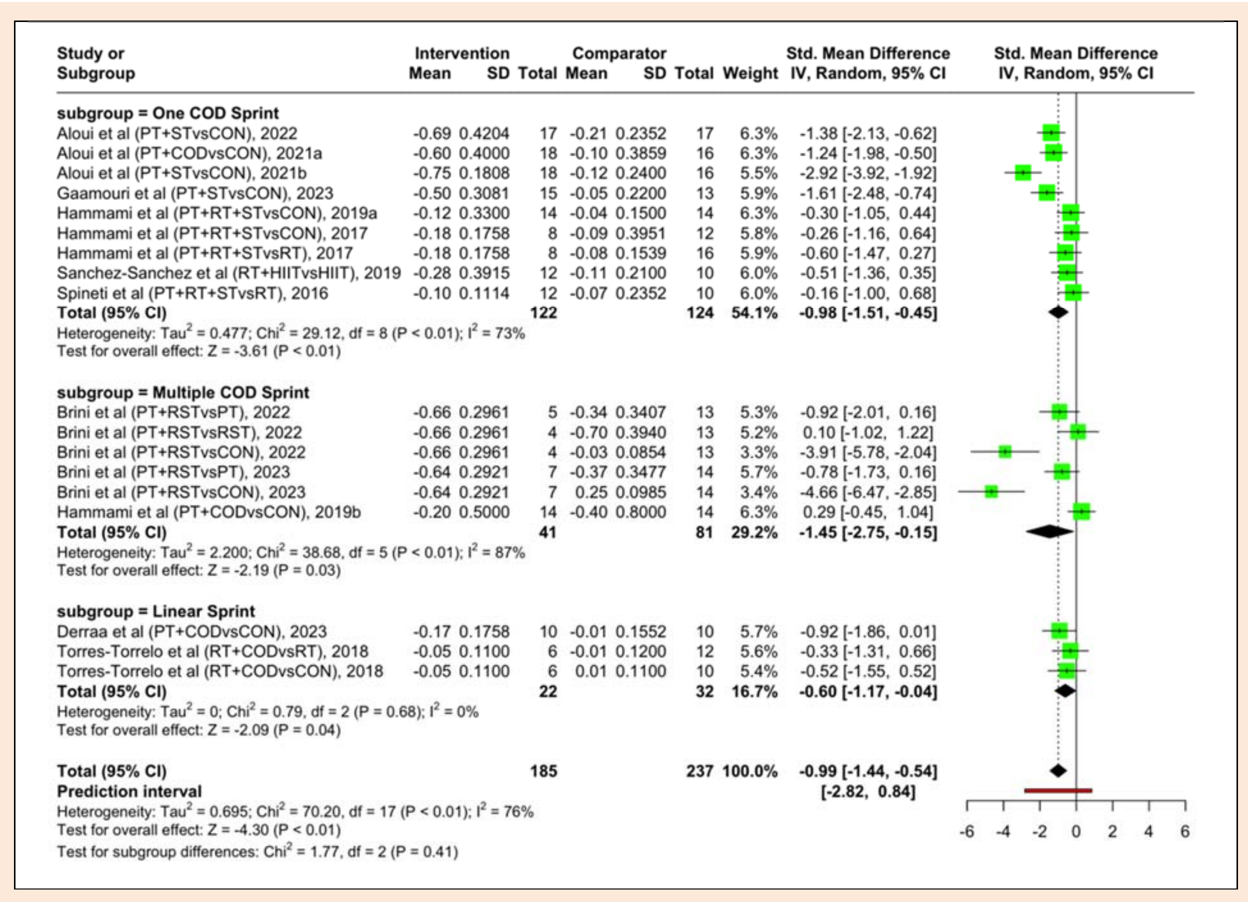
Supplementary Figure 8. Subgroup analysis of RSA mean (chronological age).



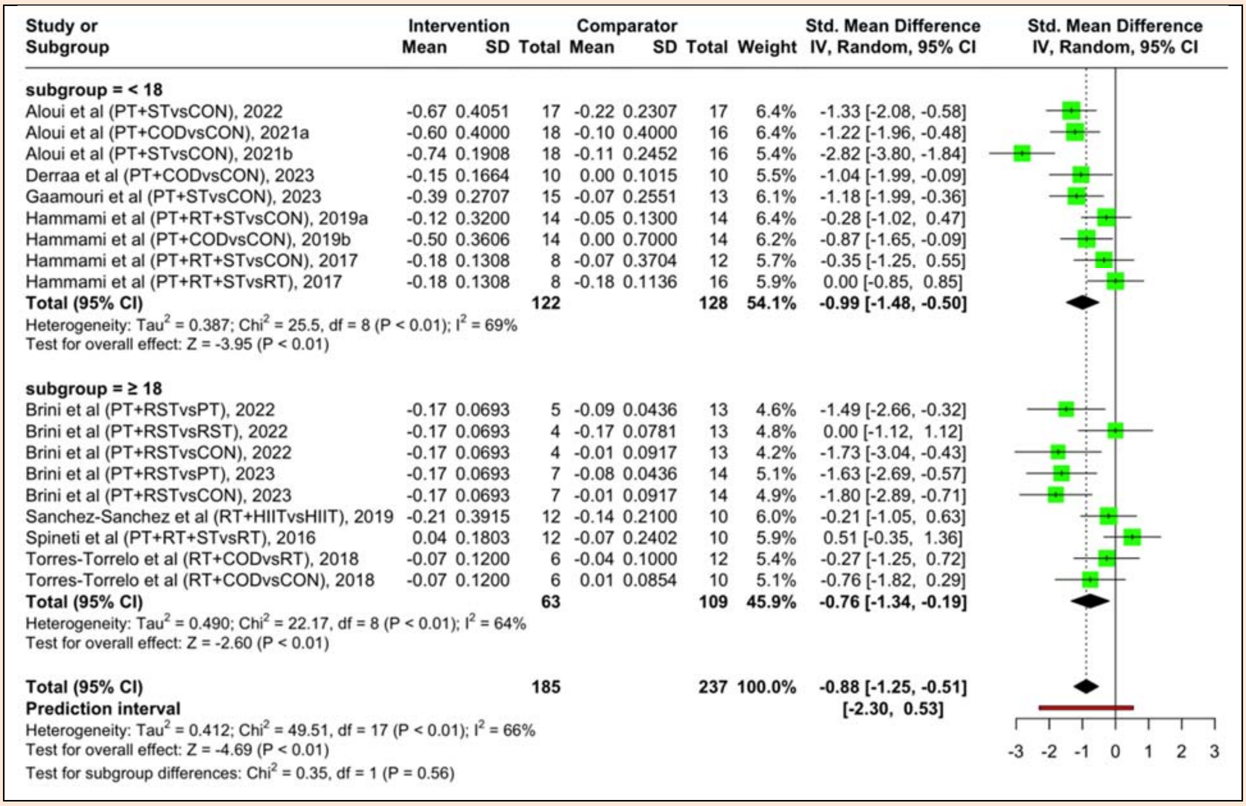
Supplementary Figure 9. Subgroup analysis of RSA mean (type of sports).



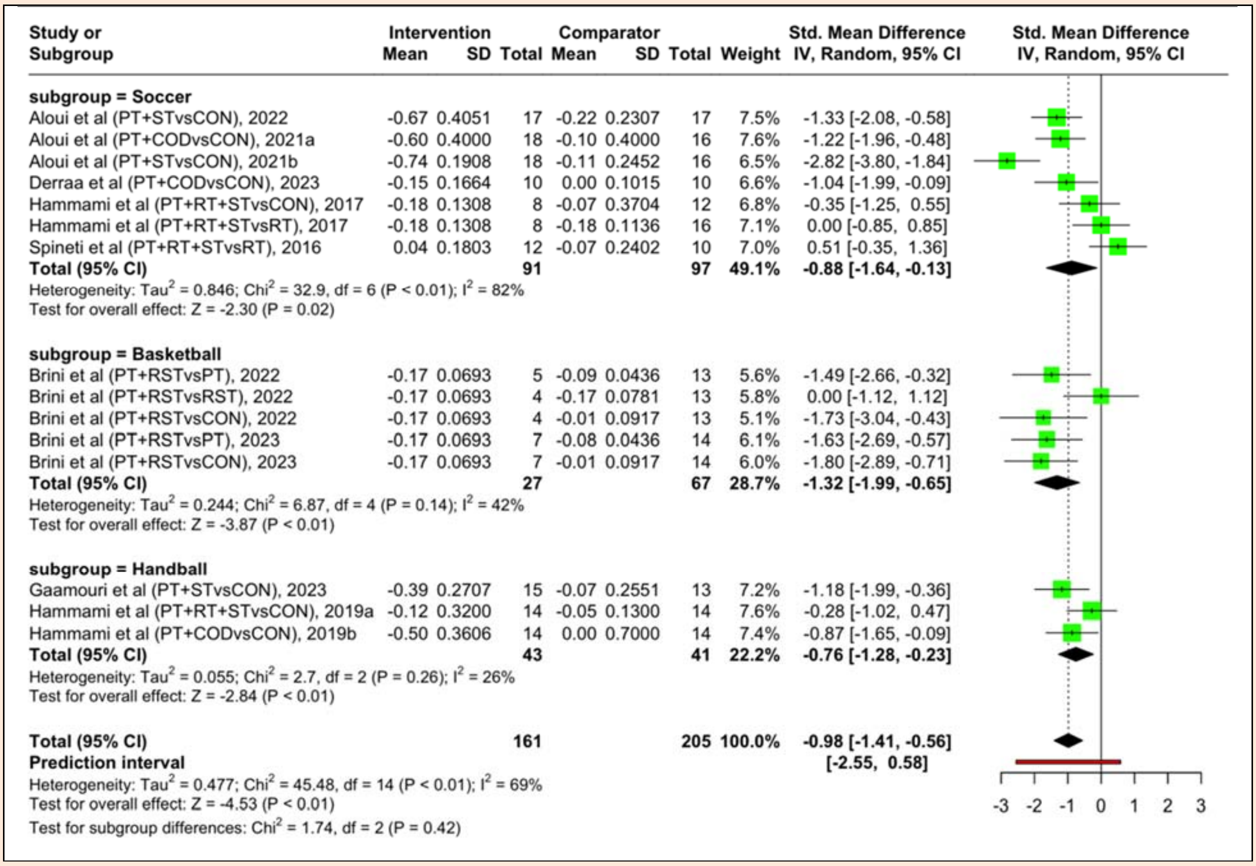
Supplementary Figure 10. Subgroup analysis of RSA mean (combined training type).



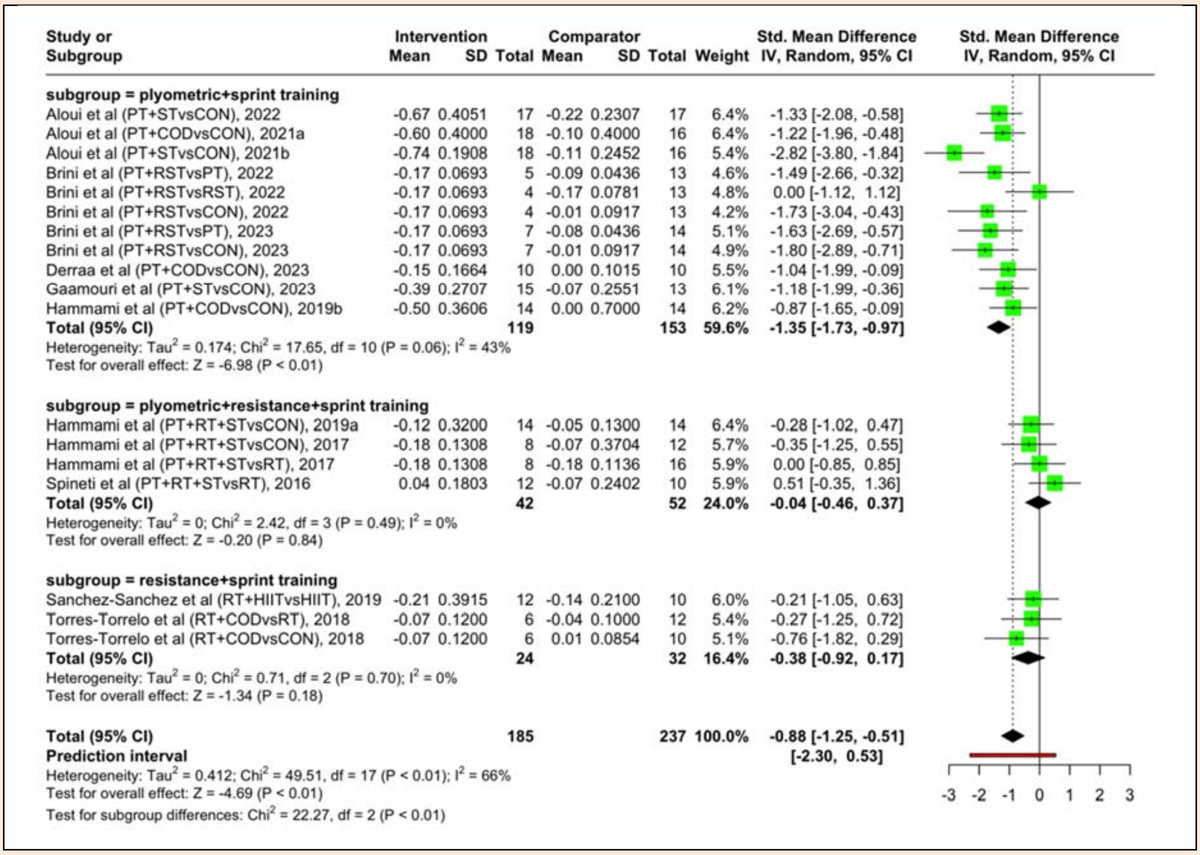
Supplementary Figure 11. Subgroup analysis of RSA mean (type of RSA test).



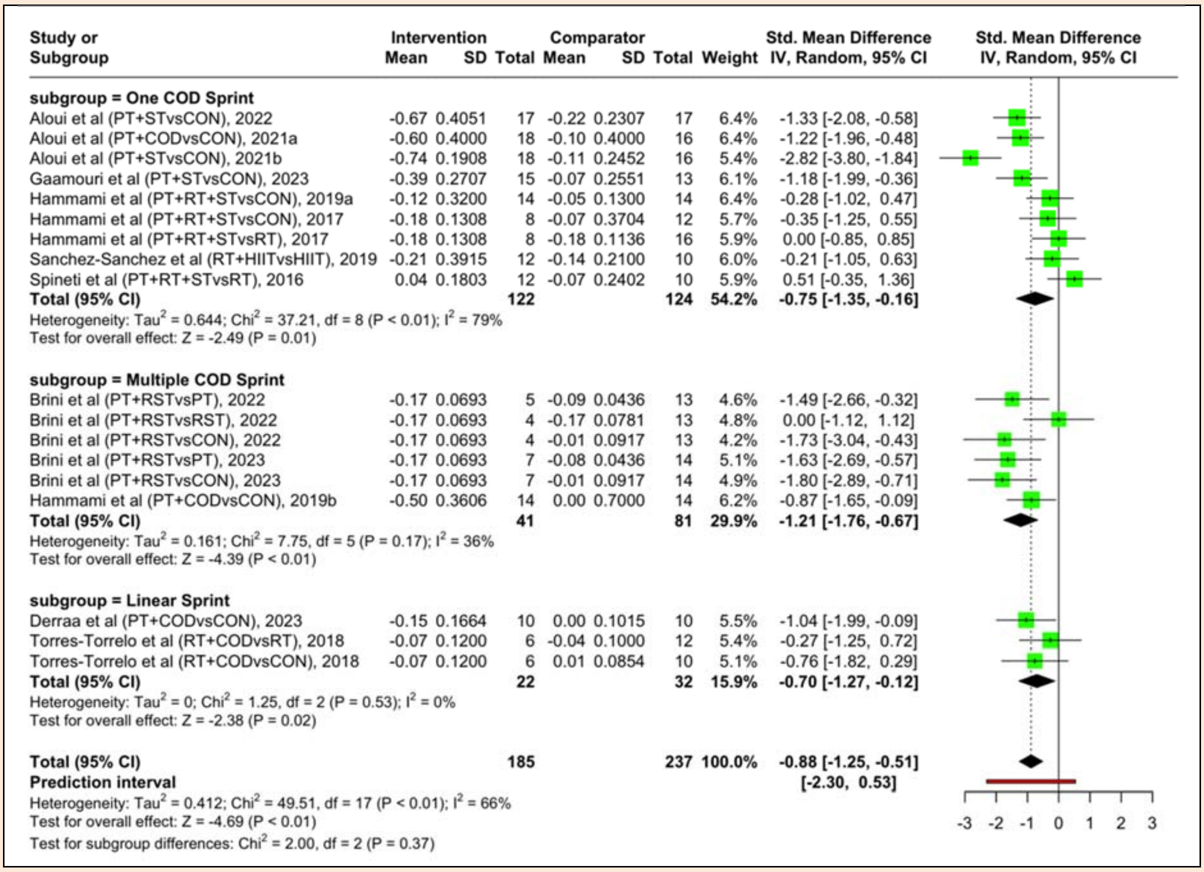
Supplementary Figure 12. **Subgroup analysis of RSA best (chronological age).**



Supplementary Figure 13. **Subgroup analysis of RSA best (type of sport).**



Supplementary Figure 14. Subgroup analysis of RSA best (combined training type).



Supplementary Figure 15. Subgroup analysis of RSA best (type of RSA test).