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Review article

Effects of Strength and Plyometric Training on Vertical Jump, Linear Sprint, and Change-of-Direction Speed in Female Adolescent Team Sport Athletes: A Systematic Review and Meta-Analysis

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Abstract

This systematic review and meta-analysis examines the effects of strength training (ST) and plyometric training (PT) on vertical jump (VJ), linear sprint (LS), and change-of-direction speed (CODS) in female adolescent team sport athletes. Additionally, it explores potential moderator variables, such as programming variables and participant characteristics, that may influence these training effects. Eligibility criteria: Randomized controlled trials examining the effects of ST or PT interventions lasting ≥4 weeks on VJ, LS, or CODS in female adolescent team sport athletes (aged 10 - 19 years) were included. A systematic search was conducted in PubMed, Web of Science, Cochrane, Embase, and SPORTDiscus from inception to August 28, 2024. The risk of bias of the included studies was assessed using the latest version of the Cochrane risk-of-bias tool for randomized trials (ROB-2). Meta-analyses were performed in Stata15.0 using random-effects models. Subgroup analyses were conducted based on the participant characteristics (age, height, weight, and type of sports) and programming variables (duration, frequency, and total sessions). Twenty-six studies involving 705 female adolescent team sport athletes were included. Meta-analyses revealed that ST and PT exhibited significant ($p < 0.05$) and moderate to large effects on VJ (ST, ES: 0.74, moderate; PT, ES: 0.87, moderate), LS (ST, ES: -1.26, large; PT, ES: -1.23, large), and CODS (ST, ES: -1.16, moderate; PT, ES: -1.20, moderate). Subgroup analysis indicated that for ST, training protocols of ≥ 10 weeks, ≤ 2 sessions/week, or ≤ 20 sessions were more effective. ST also showed greater benefits for athletes > 15 years old (LS), ≥ 163 cm (LS, CODS), ≥ 63 kg, and handball players. For PT, protocols of > 9 weeks, > 14 sessions (VJ), or ≥ 18 sessions (CODS) were more effective, with handball players responding best to PT. The overall risk of bias of the included studies was judged as moderate. The certainty of evidence was rated as moderate to high based on the GRADE approach. Both ST and PT are effective in improving VJ, LS, and CODS in female adolescent team sport athletes. Longer duration, lower frequency, or fewer sessions of ST produce better effects. Older and more mature athletes are better adapted to ST, likely due to increased muscle mass, hormonal factors, and neuromuscular adaptations. Longer duration or more sessions of PT produce better effects. Handball players showed a greater response to both ST and PT than athletes of other sports, according to observed trends.

Key words: Resistance training, Plyometric exercise, Exercise test, Physical conditioning, Physical fitness.

Introduction

Team sports (e.g., basketball, football, volleyball, and handball) are characterized by intermittent high-intensity efforts (Bangsbo, 1994; Ben Abdelkrim et al., 2010; Bishop and Girard, 2013; Chelly et al., 2011). A variety of repeated high-intensity movements such as sprint, jump, and change of direction are required throughout the match (Datson et al., 2014; Faude et al., 2012; Luteberget and Spencer, 2017; Pereira et al., 2018; Scanlan et al., 2015; Stojanović et al., 2018; Taylor et al., 2017), which, often driven by strength, explosiveness, and speed, not only are critical to the success in the match (Chaouachi et al., 2009; Duncan et al., 2006; Gabbett, 2000; Ostojic et al., 2006; Stølen et al., 2005) but also determine the athletic performance in key scenarios such as retaining or regaining possession of the ball, creating offensive opportunities, executing fast breaks, and contesting aerial duels (Datson et al., 2014; Faude et al., 2012; Hughes et al., 2023). Research also suggests that sprint speed, change-of-direction speed (CODS), and jump ability are important indicators for assessing the sporting potential (i.e., future success in competitive settings) of adolescent players, which are not only closely related to current athletic performance but key factors for the future development into elite athletes (Keiner et al., 2021; Reilly et al., 2000; Vaeyens et al., 2006). These abilities contribute to essential game-related actions such as acceleration, rapid directional changes, and explosive movements, which are critical for success in higher levels of competition. In addition, adolescence is a critical period of physical development, in which the neuromuscular system is highly plastic (Lloyd and Oliver, 2012). Therefore, targeted training of strength, explosiveness, and speed during this period can improve the current athletic performance and also lay a solid foundation for future sports performance (Faigenbaum and Myer, 2010; Lloyd and Oliver, 2012; Radnor et al., 2018). The physical development and athletic performance of female adolescent athletes are influenced by specific physiological characteristics. Changes in sex hormone levels during adolescence may affect muscular strength and neurological adaptations (Carmichael et al., 2021; Lloyd and Oliver, 2012), resulting in unique challenges for females in developing strength and explo-

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siveness. Therefore, designing/selecting training programs specifically for female adolescents is of particular importance. However, there is a lack of sex-specific meta-analytical evidence focusing on female adolescent team sport athletes, which limits the development of targeted training strategies.

Strength training (ST) and plyometric training (PT) are widely recognized as effective means for enhancing athletic performance and contributing to long-term sports development in adolescent athletes (Lloyd et al., 2016). Compared with adults, adolescent athletes exhibit distinct physiological and neuromuscular characteristics, including ongoing musculoskeletal development, lower baseline strength levels, and heightened neural plasticity (Lloyd et al., 2014; Lloyd and Oliver, 2012). These differences influence their responses to ST and PT, necessitating tailored training strategies rather than direct extrapolation from adult data. Research suggests that ST helps improve strength, jump, and speed performance in adolescent athletes by increasing muscular strength and maximal power output (Chelly et al., 2009; Comfort et al., 2014; Peñailillo et al., 2016). PT enhances neuromuscular coordination and explosiveness by rapid stretch-shortening cycle (SSC) movements (Radnor et al., 2018; Ramirez-Campillo et al., 2018; Taube et al., 2012). The positive response of adolescents to ST and PT, including significant improvements in muscular strength, power, sprint performance, jump ability, and change-of-direction, has been well documented in many recent meta-analyses (Behm et al., 2017; Behringer et al., 2011; Harries et al., 2012; Lesinski et al., 2016; Michaleff and Kamper, 2011; Moran et al., 2017; Peitz et al., 2018; Slimani et al., 2018). However, these studies either focused solely on male adolescents or did not distinguish female adolescents from males in their effect estimates. Given that male and female athletes exhibit distinct strength development trajectories, neuromuscular adaptations, and injury susceptibility, failing to account for these differences may result in suboptimal training recommendations and performance outcomes (Hunter and Senefeld, 2024; Thompson and Han, 2019). Due to gender differences in biomechanical and physiological characteristics, it may not be reasonable to apply evidence from male athletes to female athletes (Emmonds et al., 2019). Consequently, training programs should be tailored to address these sex-specific differences to maximize effectiveness and minimize injury risk. Few studies are available now on female adolescents, and there is a lack of adequate scientific guidance regarding training protocols and performance assessment in practice. To our knowledge, only two meta-analyses were conducted to independently assess the effects of ST or PT on physical fitness in female adolescents (Moran et al., 2019; Moran et al., 2018). However, these studies focused on general adolescents and single performance variables, rather than trained female team sport athletes. As shown in previous research, adolescents' responses to these trainings vary by population, type of training, and outcomes (Behm et al., 2017; Lesinski et al., 2016). For example, Behm et al. found that the increases in strength and explosiveness are milder in trained adolescent athletes than in untrained ones, which is attributed to differences in baseline fitness and training history (Behm et al., 2017). As far as we know, no systematic reviews and meta-analyses have been conducted on the effects of ST and PT on the physical fitness in female adolescent team sport athletes. Therefore, this systematic review and meta-analysis intends to investigate the effects of ST and PT on vertical jump (VJ), linear sprint (LS), and CODS in female adolescent team sport athletes and compare the independent effects between the two training programs. Furthermore, it aims to explore the moderator variables (programming variables and participant characteristics) with potential impacts on the training effects. This review uniquely focuses on female adolescent team sport athletes, offering novel insights for evidence-based training. The findings are expected to offer practical guidelines on the two trainings for coaches and athletes.

Methods

Study registration

This study was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement (Page et al., 2021), and was prospectively registered with PROSPERO (CRD42024589413).

Data sources and search strategy

A systematic search was conducted in databases that fully covered sports science literature (PubMed, Web of Science, Cochrane, Embase, and SPORTDiscus) from their inception to August 28, 2024 using medical subject headings (MeSH) and free terms, with no restrictions on region, year or language of publication. The search strategy is detailed in Supplementary Material 1.

Eligibility criteria

Inclusion criteria

Population (P): healthy female adolescent (10-19 years, as defined by the World Health Organization) athletes of team sports (e.g., football, basketball, volleyball, and handball), with no restrictions on the athletes' competitive performance to make the analysis more comprehensive.

Intervention (I): ST or PT for at least four weeks, since previous studies have reported beneficial effects with this duration (Hammett and Hey, 2003; Lloyd et al., 2012).

Comparison (C): active controls.

Outcome (O): at least one of the following measures of physical fitness pre- and post-training intervention: VJ, LS, or CODS.

Study design (S): randomized controlled trials on the intervention effects.

Exclusion criteria

Population (P): female adolescent team sport athletes with health problems (e.g., injury, and recent surgery).

Intervention (I): 1) ST or PT for less than four weeks; 2) interventions that combined ST or PT with other training modalities (e.g., ST + PT, and PT + sprint training) were excluded to isolate the independent effects of each intervention.

Comparison (C): lack of active controls.

Outcome (O): lack of baseline and/or follow-up data, and no reports on VJ, LS, or CODS.

Study design (S): 1) Non-randomized controlled trials; 2) crossover trials; 3) acute studies < 4 weeks.

Study selection and data extraction

The studies retrieved were imported into Endnote 21.0, where duplicate records were automatically removed and manually screened for any remaining duplicates. We screened the titles and abstracts initially for potentially eligible studies, and then downloaded and read the full text to finally identify the eligible studies. A standardized data extraction form was developed to extract the following data: title, first author, year of publication, DOI/PMID, author's country, type of sports, type of interventions, presence or absence of experience in PT/ST, training programs (duration, frequency, total sessions, mean session duration, intensity, number of sets, repetitions, and rest between sets), number of cases, total participants, age, height, weight, percentage of body fat, body mass index, test protocols and outcomes. In addition, means and standard deviations of variables of physical fitness pre- and post-training (VJ, LS, and CODS) were extracted. To prevent overstatement of effects, the results of the test with the longest duration were included for the analysis in the case of multiple CODS tests in one study (Garcia-Ramos et al., 2018). LS speed was measured over a distance of 15-40 meters (Rumpf et al., 2011), and the results of the test with the longest distance (e.g., 40 meters) were included in the case of multiple distances/splits. In the case of multiple VJ tests in one study, the results of the countermovement jump test were preferably extracted as they were more representative of jump performance in actual sports (Markovic and Jaric, 2007; McMahon et al., 2017). However, if a study only reported squat jump or drop jump instead of countermovement jump, the available data were included in the analysis to ensure comprehensive coverage of jump performance metrics. In cases where the required data were not fully or properly reported, the study authors were contacted for clarification. The study outcomes were not subjected to additional analysis if the authors failed to respond after two attempts or were unable to provide the necessary data. When data were presented as figures, validated software ($r = 0.99$, $p < 0.001$) (Drevon et al., 2017) (WebPlotDigitizer; https://apps.automeris.io/wpd/) was used to extract the numerical data. Two reviewers (HL, XZ) independently performed study selection and data extraction using a standardized and piloted data extraction form. The results were cross-checked, and any discrepancies, particularly those concerning outcome metrics, were resolved through discussion and consensus. If disagreement persisted, a third reviewer (CX) was consulted.

Risk of bias and certainty of evidence

The risk of bias was assessed at the study level using the latest version of the Cochrane risk-of-bias tool for randomized trials (ROB-2) (Flemyng et al., 2023) from five domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Each item was rated as low risk, high risk, or some concerns. The quality of each included study was independently assessed by two reviewers (HL, XZ), and discrepancies were resolved by consultation with a third reviewer (CX).

The Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach was applied to assess the certainty of the evidence for each outcome (Schünemann et al., 2013). This method evaluates five domains, namely risk of bias, inconsistency, indirectness, imprecision, and publication bias, to determine the certainty of the evidence. The certainty is classified into four levels: high, moderate, low, or very low. Downgrading was considered when there were serious concerns in one or more domains. Upgrading was applied when there was a large magnitude of effect, evidence of a dose–response relationship, or when all plausible confounding would reduce a demonstrated effect. The evaluation was independently conducted by two reviewers (HL, XZ) and cross-checked by a third reviewer (CX).

Statistical analysis

Effect sizes (ES) were calculated by comparing the differences in performance variables between the training group and the control group pre- and post-intervention. Post-intervention standard deviation values were used to standardize the data. The random-effects model was employed to account for differences between studies that might impact training effects (Deeks et al., 2019; Kontopantelis et al., 2013). Represented by Hedge's g, ES values were presented with standardized mean differences with their 95% confidence intervals (95% CIs) to adjust for a small sample size. The following scale was used to interpret the ES magnitudes: trivial (< 0.2), small (0.2 - 0.6), moderate (> 0.6-1.2), large (> 1.2 - 2.0), very large (> 2.0 - 4.0), and extremely large (> 4.0) (Hopkins et al., 2009). The sample size in the active control group was proportionately split to facilitate inter-group comparisons in studies with more than one intervention group (Higgins et al., 2008). The I^2 statistic was adopted to evaluate the study heterogeneity, with low, moderate, and high levels represented by values of < 25%, 25% - 75%, and > 75%, respectively (Higgins and Thompson, 2002). By excluding low-quality studies, sensitivity analyses were conducted to verify the result reliability. The publication bias was assessed (with at least 10 studies) by funnel plots and Egger's tests (Egger et al., 1997); the trim and fill method was utilized if the publication bias was present (Duval and Tweedie, 2000).

In addition, subgroup analyses were conducted besides the main analysis to explore potential influencing factors on the intervention effects. Different participant characteristics and variables of training programs were selected and could be considered as having a potential influence on the intervention effects. Since age and biological maturity affect explosiveness in female adolescents (Emmonds et al., 2017), age, height, and weight were selected as moderator variables. Females typically reach their full adult height around the age of 15 (Georgopoulos et al., 2001). Therefore, participants were categorized into < 15- and > 15-year-old groups, allowing for a comparison between those still undergoing maturational changes and those who had largely completed them. They were also grouped by height in the same way (> 163 and < 163 cm), as 163 cm is an approximation of the mean height of females at full maturity (Pellett, 1990). The weight of athletes varied across the type of team sports, so participants were grouped by weight using a median-split technique. The three factors were possibly important determinants of training adaptations in female adolescents. In addition, participants were categorized according to the type of sports to investigate the adaptations of athletes of different sports to the training program. Training duration (weeks), frequency (sessions/week), and total sessions were selected as the moderator variables based on the principle of frequency, intensity, time, and type (FITT) (Pescatello et al., 2015). Where appropriate, these moderator variables were divided using the median-split technique (Moran et al., 2019; Moran et al., 2018). If a given moderator variable was described in at least three studies, the median was calculated. Instead of using the global median for a given moderator (e.g., the median of training duration from all included studies), median values were calculated using only those studies that provided data for the outcome under analysis to minimize heterogeneity. The same random-effects model as in the main analysis was applied in subgroup analyses. Stata15.0 was adopted, and statistical significance was set to $p < 0.05$.

Results

Study selection

The number of studies included and excluded at each stage of the screening is shown in Figure 1. 7,925 studies were initially identified, of which 3,625 duplicate publications (from different databases) were removed. After a review of titles and abstracts, the full text of 41 studies was downloaded and read. After 15 studies were excluded (one due to male participants; three due to inappropriate age of participants; six due to inappropriate intervention; one due to inappropriate study design; one due to male and female data grouped; one due to insufficient data; two due to no useful data [no usable outcome metrics], 26 eligible studies were finally included into this meta-analysis (Arazi et al., 2018; Attene et al., 2015; Gaamouri et al., 2023a; Gaamouri et al., 2024; Gaamouri et al., 2023b; Genc H, 2019; Haghighi et al., 2024; Hammami et al., 2019; 2020; 2022a; 2022b; Hammami and Zmijewski, 2024; I, 2020; Idriss et al., 2022; Idrizovic et al., 2018; Martel et al., 2005; Meszler and Váczi, 2019; Ortega et al., 2020; Ozbar et al., 2014; PA, 2015; Paes et al., 2022; Pedersen et al., 2019; Rojano Ortega et al., 2022; Rubley et al., 2011; Turgut et al., 2016; Váczi et al., 2022).

Study characteristics

All included studies involved 705 female adolescent team sport athletes, including 302 handball players, 156 volleyball players, 136 football players, and 111 basketball players. Of these, 197 attended ST, and 183 attended PT, with the remaining 325 as active controls. The training duration ranged from 5 to 20 weeks, mostly (96%) ≤ 12 weeks. The training frequency was 1-3 sessions/week, mostly (65%) 2 sessions/week. Total sessions ranged from 8 to 36 sessions, mostly (54%) ≥ 20 sessions. The participant characteristics and details of the training programs in the included studies are described in Table 1.

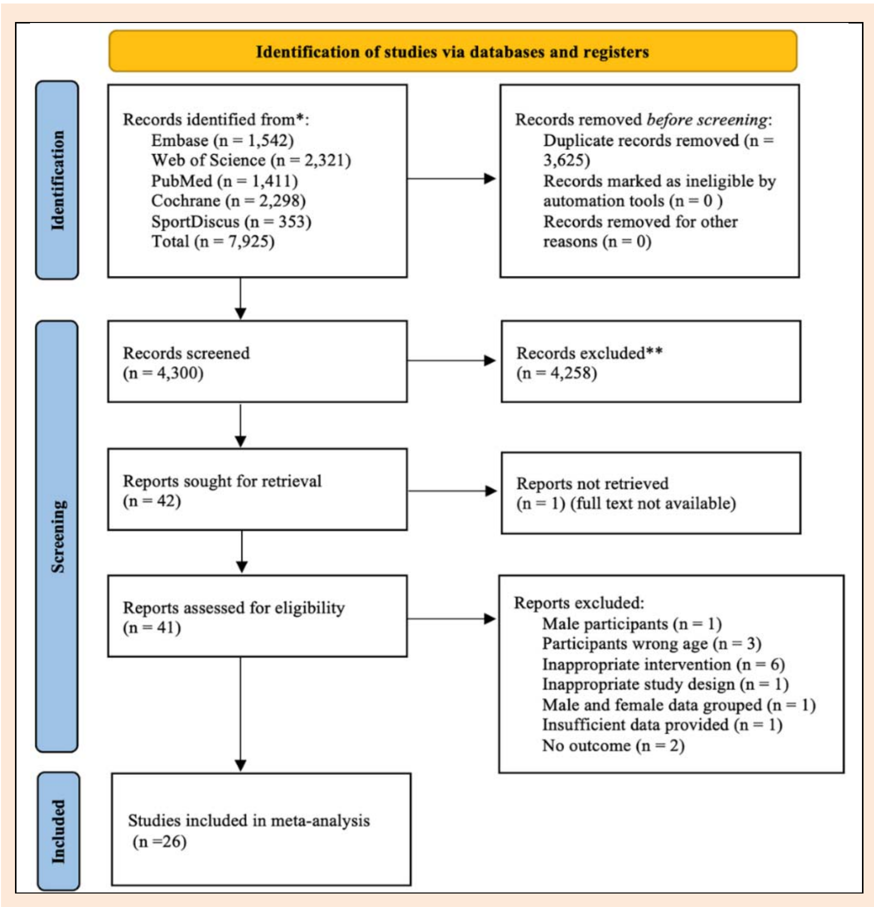

Figure 1. Flowchart of screening process.

Table 1. Characteristics of studies included in the systematic review.

Study	Country	Programming variables								N	No. of cases	Participant characteristics				Types of sports	Exercise test and outcomes measured
		Dur. (weeks)	Freq. (per week)	Total Sessions (n)	Mean session duration (min)	Intensity	No. of Sets	Rep. (n)	Rest between sets (s/min)			Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)		
Plyometric training																	
Rubley et al. (2011)	USA	12	1	12	NR	L	1-4	5-20	NR	16	1.PT: 10 2.CG: 6	13.4 (±.5)	162.5 (±5.67)	50.84 (±5.1)	NR	Soccer	VJ (height, cm)
Ozbar et al. (2014)	Turkey	8	1	8	60 min	L to H	4-5	5-15	3-5min	18	1.PT: 9 2.CG: 9	1.PT: 18.3 (±2.6) 2.CG: 18.0 (±2.0)	1.PT: 163.1 (± 5.3) 2.CG: 159.4 (±5.1)	1.PT: 58.8 (±7.8) 2.CG: 54.4 (±6.1)	BMI: 1.PT: 22.1 (±2.7) 2.CG: 21.4 (±2.8)	Soccer	CMJ (height, cm); 20 m sprint (time, s)
Idriss et al. (2022)	Algeria	10	3	30	15±3 min	M to H	NR	NR	NR	22	1.PT: 11 2.CG: 11	1.PT: 15.16 (± 0.93) 2.CG: 15.08 (±0.19)	1.PT: 153.0 (±6.47) 2.CG: 151.5 (±5.57)	1.PT: 50.33 (±6.11) 2.CG: 49.66 (±6.02)	NR	Football	SJ, CMJ (height, cm)
Meszler & Váczi (2019)	Hungary	7	2	14	20 min	H	2-6	4-10	2 min	18	1.PT: 9 2.CG: 9	1.PT: 15.8 (±1.2) 2.CG: 15.7 (±1.3)	1.PT: 176.4 (± 8.6) 2.CG: 177.5 (±7.4)	1.PT: 63.5 (±8.6) 2.CG: 66.1 (±8.9)	NR	Basketball	T-sprint test, Illinois agility test (time, s); CMJ
Cengizhan (2015)	Turkey	6	3	18	120 min	NR	3	NR	NR	20	1.PT: 10 2.CG: 10	1.PT: 14.8 (±1.14) 2.CG: 14.9 (±0.99)	1.PT: 161.2 (±5.07) 2.CG: 164.6 (±7.77)	1.PT: 54.3 (±8.64) 2.CG: 59.7 (± 15.83)	1.PT: 20.86 (±2.88) 2.CG: 21.79 (±4.32)	Basketball	Illinois, hexagon and, T test agility test(time, s); 20 m, 30 m sprint(time, s)
Attene et al. (2015)	Italy	6	2	12	at least 20 minutes	NR	2-3	6-10	1 min	36	1.PT: 18 2.CG: 18	1.PT: 14.83 (±.92) 2.CG: 15.20(±.92)	1.PT: 163.0 (± 8.62) 2.CG: 165.0 (±5.70)	1.PT: 51.89 (±9.69) 2.CG: 57.50 (±5.70)	1.PT: 19.35 (±2.16) 2.CG: 21.12 (±2.83)	Basketball	CMJ and SJ(height, cm)
Paes et al. (2022)	Brazil	6	2	12	30-60 min	NR	1-6	5-15	30 s	21	1.PT: 11 2.CG: 10	1.PT: 14.45 (±.69) 2.CG: 15.30 (±1.16)	1.PT: 160.0 (±7.0) 2.CG: 163.0 (±8.0)	1.PT: 53.72 (±9.01) 2.CG: 59.98 (±16.74)	NR	Basketball	20 m sprint (time, s); Illinois agility test(time, s)
Haghighi et al. (2024)	Iran	6	2	12	NR	NR	2-4	4-8	NR	16	1.PT: 8 2.CG: 8	1.PT: 14.6 (±1.5) 2.CG: 15.1(±1.8)	1.PT: 168.3 (±8.7 2.CG: 165.8 (±9.7)	1.PT: 61.7 (±10.3) 2.CG: 56.7 (±13.6)	1.PT: 21.9 (±3.9) 2.CG: 20.6 (±5.6)	Basketball	20 m sprint (time, s); change of direction (time, s)

Data are presented as mean ± SD. ST: Strength training; PT: Plyometric training; CG: Control group; Dur.: durations; Freq.: frequency; Rep.: repetitions; BMI: Body mass index; 1 RM: One repetition maximum; SJ: Squat jump; VJ: Vertical jump; CMJ: Countermovement jump; NR: Non-reported; N: Total population; L: Low; M: Moderate; H: high.

Table 1. Contiue….

Study	Country	Programming variables								N	No. of cases	Participant characteristics				Types of sports	Exercise test and outcomes measured
		Dur. (weeks)	Freq. (per week)	Total Sessions (n)	Mean session duration (min)	Intensity	No. of Sets	Rep. (n)	Rest between sets (s/min)			Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2) or BF (%)		
Plyometric training																	
Martel et al. (2005)	USA	6	2	12	45 min	NR	2-5	NR	30 s	19	1.PT: 10 2.CG: 9	1.PT: 15 (±1) 2.CG: 14 (±1)	1.PT: 167 (± 9) 2.CG: 164 (±8)	1.PT: 64 (±13) 2.CG: 57 (±8)	NR	Volleyball	VJ (height, cm)
Idrizovic et al. (2018)	Montenegro	12	2	24	40-60 min	L to H	4-6	1-5	2-5 min	30	1.PT: 13 2.CG: 17	16.6 (±0.6)	173.3 (±4.2)	59.4 (±8.1)	NR	Volleyball	20 m sprint (time, s); CMJ (height, cm)
Rojano Ortega et al. (2022)	Spain	7	2	14	45 min	L/M	2-3	8-15	1 min	28	1.PT: 14 2.CG: 14	1.PT: 16.07 (±1.07) 2.CG: 15.71 (±.73)	1.PT: 166.8 (±1.89) 2.CG: 165.6 (±4.86)	1.PT: 67.82 (±5.53) 2.CG: 61.30 (±7.23)	NR	Volleyball	CMJ (height, cm)
Turgut et al. (2016)	Turkey	12	3	36	NR	NR	1-3	30 s-60 s	30 s-60 s	16	1.PT: 8 2.CG: 8	1.PT: 15.0 (±1.0) 2.CG: 14.4 (±1.3)	1.PT: 166 (±6) 2.CG: 161 (±5)	1.PT: 59.4 (±8.3) 2.CG: 50 (±7.8)	BMI: 1.PT: 21.4 (±1.9) 2.CG: 19.1 (±2.0)	Volleyball	30 m sprint (time, s); hexagonal obstacle test and zigzag test (time, s)
Hammami et al. (2020)	Tunisia	10	2	20	NR	NR	2-3	6	30 s	34	1.PT: 17 2.CG: 17	1.PT: 15.8 (±.2) 2.CG: 15.8 (±.2)	1.PT: 166 (±3) 2.CG: 167 (±4)	1.PT: 64.2 (±3.3) 2.CG: 63.0 (±3.8)	BF: 1.PT: 25.2 (±3.8) 2.CG: 26.0 (±3.3)	Handball	5 m, 10m, 20 m, 30 m sprint(time, s); modified Illinois test(time, s); SJ, CMJ, CMJ with arms(height, cm)
Gaamouri et al. (2023a)	Tunisia	10	2	20	NR	NR	2-3	6	30 s	28	1.PT: 14 2.CG: 14	1.PT: 15.7 (±.2) 2.CG: 15.8 (±.2)	1.PT: 165 (±3) 2.CG: 167 (±3)	1.PT: 63.8 (±3.3) 2.CG: 63.3 (±4.1)	BF: 1.PT: 25.4 (±4.1) 2.CG: 24.6 (±1.8)	Handball	Modified agility T-test(time, s); SJ, CMJ (height, cm)
Hammami et al. (2019)	Tunisia	9	2	18	NR	NR	10	6-8	0 s	41	1.PT: 21 2.CG: 20	1.PT: 13.5 (±.3) 2.CG: 13.3 (±.3)	1.PT: 142 (4) 2.CG: 143 (±4)	1.PT: 42.6 (±4.6) 2.CG: 42.3 (±4.5)	BF: 1.PT: 12.3 (±3.4) 2.CG: 14.7 (±3.9)	Handball	5 m, 10 m, 20 m, 30 m sprint(time, s); modified Illinois test, T test(time, s); SJ, CMJ, CMJ with arms (height, cm)

Data are presented as mean ± SD. ST: Strength training; PT: Plyometric training; CG: Control group; Dur.: durations; Freq.: frequency; Rep.: repetitions; BF: Body fat; BMI: Body mass index; 1 RM: One repetition maximum; SJ: Squat jump; VJ: Vertical jump; CMJ: Countermovement jump; NR: Non-reported; N: Total population; L: Low; M: Moderate; H: high

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Study	Country	Programming variables								N	No. of cases	Participant characteristics				Types of sports	Exercise test and outcomes measured
		Dur. (weeks)	Freq. (per week)	Total Sessions (n)	Mean session duration (min)	Intensity	No. of Sets	Rep. (n)	Rest between sets (s/min)			Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2) or BF (%)		
Strength training																	
Váczi et al. (2022)	Hungary	20	1-2	30	NR	NR	2-3	5-15	NR	23	1.ST: 13 2.CG: 10	1.ST: 11.3 (±.5) 2.CG: 10.9 (±.5)	1.ST: 150 (±6.6) 2.CG: 146.4 (±3.4)	1.ST: 41.5 (±7.0) 2.CG: 41.1 (±5.6)	NR	Handball	CMJ (height, cm)
Hammami & Zmijewski (2024)	Tunisia	10	2	20	45 min	NR	3-5	12	NR	36	1.ST(1): 12 2.ST(2): 12 3.CG: 12	1.ST(1): 16.2 (±.3) 2.ST(2): 16.2 (±.4) 3.CG: 16.3 (±.3)	1.ST(1): 167.1 (± 3.7) 2.ST(2): 165.5 (±3.2) 3.CG: 167.6 (±3.6)	1.ST(1): 64.3 (±4.0) 2.ST(2): 63.8 (±3.3) 3.CG: 63.5 (±4.4)	BF: 1.ST(1): 23.3 (±1.0) 2.ST(2): 23 .0 (± 1.1) 3.CG: 23.9 (± 1.4)	Handball	10 m, 20 m sprint(time, s); modified Illinois test (time, s); SJ, CMJ (height, cm)
Hammami et al. (2022a)	Tunisia	10	2	20	NR	NR	3-5	10	30 s	26	1.ST: 13 2.CG: 13	1.ST: 15.7 (±.2) 2.CG: 15.8 (±.2)	1.ST: 170 (±4) 2.CG: 167 (±4)	1.ST: 64 (±3) 2.CG: 64 (±4)	BF: 1.ST: 25.3 (±1.7) 2.CG: 26.6 (±3.4)	Handball	5 m, 10 m, 20 m, 30 m sprint (time, s); modified Illinois test (time, s); SJ, CMJ, CMJ with arms (height, cm).
Genc et al. (2019)	Turkey	8	3	24	60 min	NR	2	10-35	3 min	20	1.ST: 10 2.CG: 10	1.ST: 17.80 (±1.4) 2.CG: 17.60 (±1.89)	1.ST: 153.2 (±5.8) 2.CG: 166.6 (±5.8)	1.ST: 60.03 (±7.9) 2.CG: 63.30 (±6.3)	BMI: 1.ST: 22.07 (±1.91) 2.CG: 22.21 (±2.07)	Handball	Pro agility test, 505 agility test (time, s); VJ (height, cm); 10 m, 30 m sprint (time, s).
Gaamouri et al. (2024)	Tunisia	10	2	20	45 min	NR	3-5	12	NR	30	1.ST: 16 2.CG: 14	1.ST: 15.80 (±.30) 2.CG: 15.80 (±.20)	1.ST: 167 (±3.4) 2.CG: 167 (±.3.2)	1.ST: 64.10 (±3.50) 2.CG: 63.40 (±4.10)	BF: 1.ST: 22.00 (±2.70) 2.CG: 22.70 (±1.90)	Handball	T test(time, s); SJ, CMJ (height, cm).
Gaamouri et al. (2023b)	Tunisia	10	2	20	NR	NR	3-5	10	30 s	34	1.ST: 17 2.CG: 17	1.ST: 15.7 (±.2) 2.CG: 15.8 (±.2)	1.ST: 1.69 (±4.2) 2.CG: 1.67 (±3.5)	1.ST: 63.4 (±3.8) 2.CG: 63.0 (±3.8)	BF: 1.ST: 21.5 (±1.8) 2.CG: 21.7 (±2.5)	Handball	T test(time, s); SJ, CMJ(height, cm).

Data are presented as mean ± SD. ST: Strength training; PT: Plyometric training; CG: Control group; Dur.: durations; Freq.: frequency; Rep.: repetitions; BF: Body fat; BMI: Body mass index; 1 RM: One repetition maximum; SJ: Squat jump; VJ: Vertical jump; CMJ: Countermovement jump; NR: Non-reported; N: Total population; L: Low; M: Moderate; H: high

Table 1. Contiue….

Study	Country	Programming variables: Dur. (weeks)	Freq. (per week)	Total Sessions (n)	Mean session duration (min)	Intensity	No. of Sets	Rep. (n)	Rest between sets (s/min)	N	No. of cases	Participant characteristics: Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2) or BF (%)	Types of sports	Exercise test and outcomes measured
Strength training																	
Hammami et al. (2022b)	Tunisia	10	2	20	NR	NR	3-5	12	NR	30	1.ST: 15 2.CG: 15	1.ST: 15.7 (±.3) 2.CG: 15.7 (±.2)	1.ST: 166.5 (±3.5) 2.CG: 167 (±4.1)	1.ST: 64.1 (±3.6) 2.CG: 63.3 (±3.9)	BF: 1.ST: 27.3 (±3.6) 2.CG: 26.5 (±3.3)	Handball	5 m, 10 m, 20 m, 30 m sprint (time, s); modified Illinois test (time, s); SJ, CMJ, CMJ with arms (height, cm)
Ortega et al. (2020)	Colombia	12	3	26	NR	NR	4	10	3 min	46	1.ST(1): 15 2.ST(2): 13 3.CG: 18	13.6 (±1.2)	157 (±6.6)	46.7 (±5.3)	BMI: 17.6 (±1.4)	Soccer	30 m sprint (time, s); SJ, CMJ (height, cm)
Ince, (2020)	Turkey	6	2	12	NR	70%-90% of 1 RM	2-7	5	2 min	33	1.ST(1): 11 2.ST(2): 11 3.CG: 11	1.ST(1): 15.80 (±1.03) 2.ST(2): 15.22 (±1.20) 3.CG: 15.14 (±0.38)	1.ST(1): 164.50 (±3.96) 2.ST(2): 167.78 (±3.53) 3.CG: 165.29 (±5.25)	1.ST(1): 60.88 (± 8.26) 2.ST(2): 62.02 (±7.20) 3.CG: 61.32 (±5.89)	BMI: 1.ST(1): 22.48 (± 3.35) 2.ST(2): 23.52 (±2.41) 3.CG: 20.79 (±1.63)	Volleyball	5 m, 20 m sprint (time, s); T test (time, s); SJ, CMJ (height, cm)
Arazi et al. (2018)	Iran	8	3	24	NR	30%-90% of 1 RM	1-3	1-10	20 s-30 s	30	1.ST(1): 10 2.ST(2): 10 3.CG: 10	1.ST(1): 18.2 (±2.4) 2.ST(2): 18.7 (±1.5) 3.CG: 19.1 (±2.7)	1.ST(1): 161 (± 6) 2.ST(2): 166 (±5) 3.CG: 163 (±5)	1.ST(1): 54.5 (±6.6) 2.ST(2): 56.5 (±9.0) 3.CG: 54.0 (±7.5)	NR	Volleyball	VJ (height, cm); 20 m sprint (time, s); change of direction (time, s)
Pedersen et al. (2019)	Norway	5	2	10	NR	85% of 1 RM	3-4	4-6	≥ 180 s	34	1.ST: 19 2.CG: 15	1.ST: 18.3(SD: 2.7) 2.CG: 18.3(SD: 2.4)	1.ST: 167 (±6) 2.CG: 168 (±5)	1.ST: 61.67(SD: 5.40) 2.CG: 62.92(SD: 10.48)	BMI: 1.ST: 22.1 (±2) 2.CG: 22.3 (±3)	Football	5 m, 10 m, 15 m sprint (time, s); CMJ (height, cm)

Data are presented as mean ± SD. ST: Strength training; PT: Plyometric training; CG: Control group; Dur.: durations; Freq.: frequency; Rep.: repetitions; BF: Body fat; BMI: Body mass index; 1 RM: One repetition maximum; SJ: Squat jump; VJ: Vertical jump; CMJ: Countermovement jump; NR: Non-reported; N: Total population; L: Low; M: Moderate; H: high.

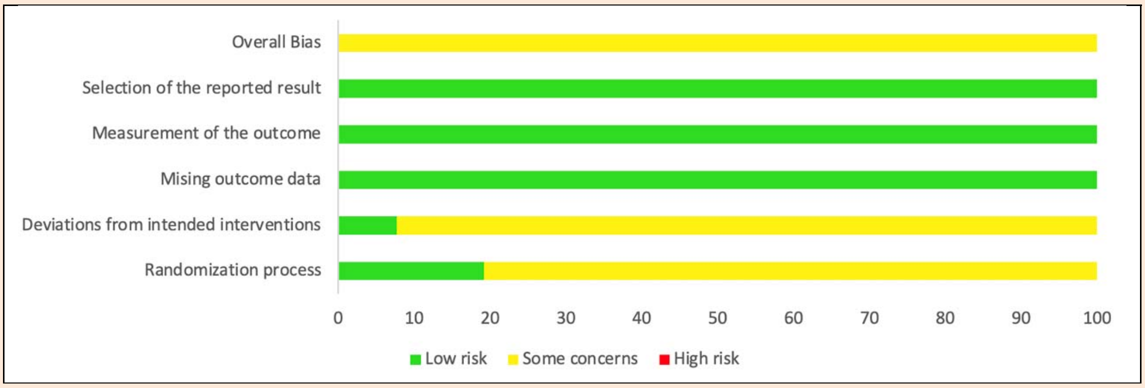

Figure 2. **Risk of bias graph.**

Risk of bias and certainty of evidence

The risk of bias in the included studies was assessed at the study level using the Cochrane risk-of-bias tool for randomized trials (ROB-2). Five studies (Attene et al., 2015; Haghighi et al., 2024; I, 2020; Pedersen et al., 2019; Turgut et al., 2016) were rated as low risk in the randomization process domain, while the remaining 21 studies raised some concerns mainly due to insufficient detail on randomization. Regarding deviations from intended interventions, two studies (Gaamouri et al., 2023b; Hammami et al., 2019) were rated as low risk, with the rest having some concerns in this domain. For the other domains, including missing outcome data, measurement of the outcome, and selection of the reported result, all studies were rated as low risk. Detailed results for domain-specific and overall risk-of-bias assessments are presented in Figure 2 and Figure 3.

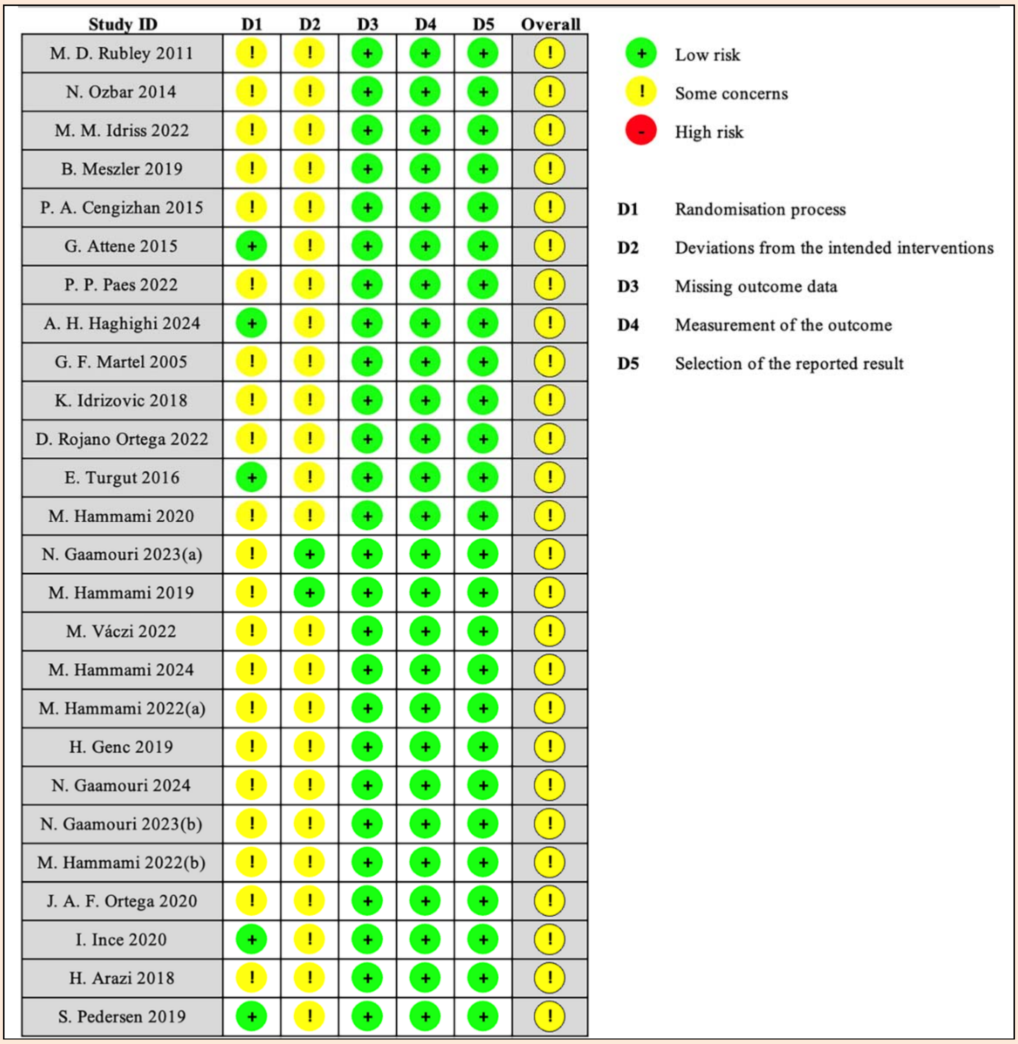

Figure 3. **Risk of bias summary.**

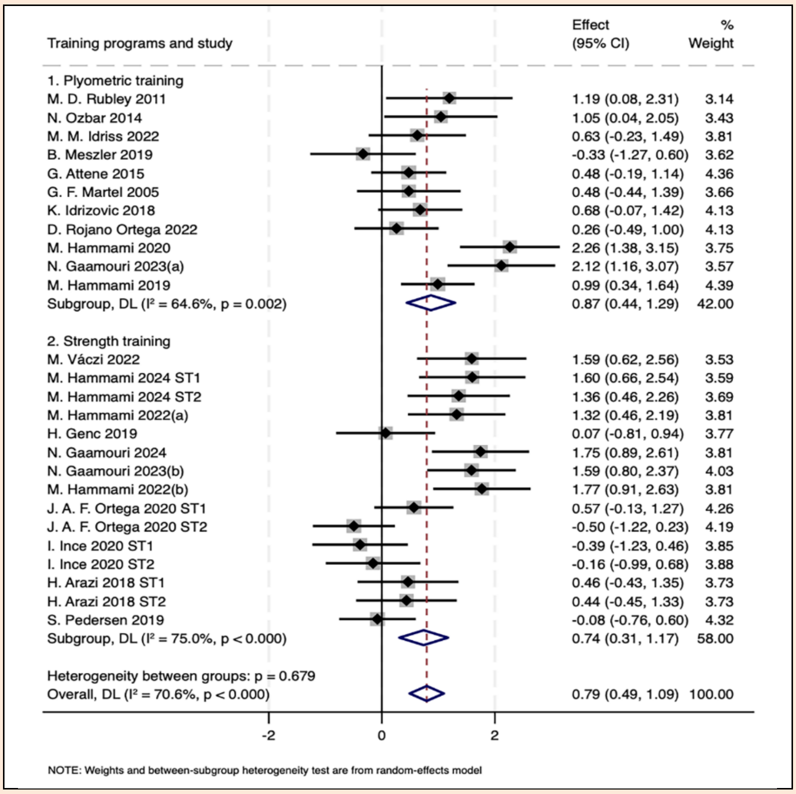

Figure 4. **Forest plot of the effects of strength and plyometric training on vertical jump in female adolescent team sport athletes.**

According to the GRADE assessment, the certainty of evidence was rated as high for most outcomes, including the effects of PT on vertical jump, and both ST and PT on linear sprint and change-of-direction performance. For ST on vertical jump, the certainty was moderate due to inconsistency and imprecision. Large effect sizes and dose–response trends supported upgrading, while heterogeneity and limited sample size led to some downgrading.

Main effect

Vertical jump

Twenty-two studies evaluated the effects of ST (11 studies) and PT (11 studies) on VJ in female adolescent team sport athletes. The between-group heterogeneity test showed no significant difference between ST and PT in the effect on VJ (p = 0.679). Significant and moderate positive effects were observed for both ST (p = 0.001, ES: 0.74, 95% CI: 0.31, 1.17) and PT (p < 0.001, ES: 0.87, 95% CI: 0.44, 1.29). The study results of ST (I^2 = 75%, p<0.000) and PT (I^2 = 64.6%, p = 0.002) had significant heterogeneity within groups (Figure 4). The pooled results of ST and PT were robust as verified by sensitivity analyses (Figure S1 and S2, Supplementary Materials 2). Egger's tests revealed no potential publication bias in the main pooled ES for both ST (p = 0.06) and PT (p = 0.435), as shown in the funnel plot (p > 0.05) (Figure S3 and S4, Supplementary Materials 2).

Linear sprint speed

Sixteen studies evaluated the effects of ST (8 studies) and PT (8 studies) on LS speed in female adolescent team sport athletes. The between-group heterogeneity test showed no significant difference between ST and PT in the effect on LS speed (p = 0.955). Significant and large positive effects were observed for both ST (p = 0.002, ES: -1.26, 95% CI: -2.07, -0.45) and PT (p = 0.008, ES: -1.23, 95% CI: -2.13, -0.32). The study results of ST (I^2 = 89.3%, p < 0.000) and PT (I^2 = 86.6%, p < 0.000) had significant heterogeneity within groups (Figure 5). The pooled results of ST and PT were robust as verified by sensitivity analyses (Figure S5 and S6, Supplementary Materials 2). Publication bias was not assessed since fewer than 10 studies were included for each intervention.

Change-of-direction speed

The effects of ST (8 studies) and PT (8 studies) on the CODS in female adolescent team sport athletes were evaluated in sixteen studies. The between-group heterogeneity test showed no significant difference between ST and PT in the effect on CODS (p = 0.933). Significant and moderate positive effects were observed for both ST (p < 0.001, ES: -1.16, 95% CI: -1.77, -0.55) and PT (p = 0.007, ES: -1.20, 95% CI: -2.08, -0.32). The study results of ST (I^2 = 80.2%, p < 0.000) and PT (I^2 = 8.6%, p < 0.000) had significant heterogeneity within groups (Figure 6). The pooled results of ST and PT were robust as verified by sensitivity analyses (Figure S7 and S8, Supplementary Materials 2). Publication bias was not assessed since fewer than 10 studies were included for each intervention.

Subgroup analyses

Subgroup analyses were conducted on ST and PT based on the variables of training programs (training duration, frequency, and total sessions) and participant characteristics (age, height, weight, and type of sports). The results are detailed in Supplementary Material 3.

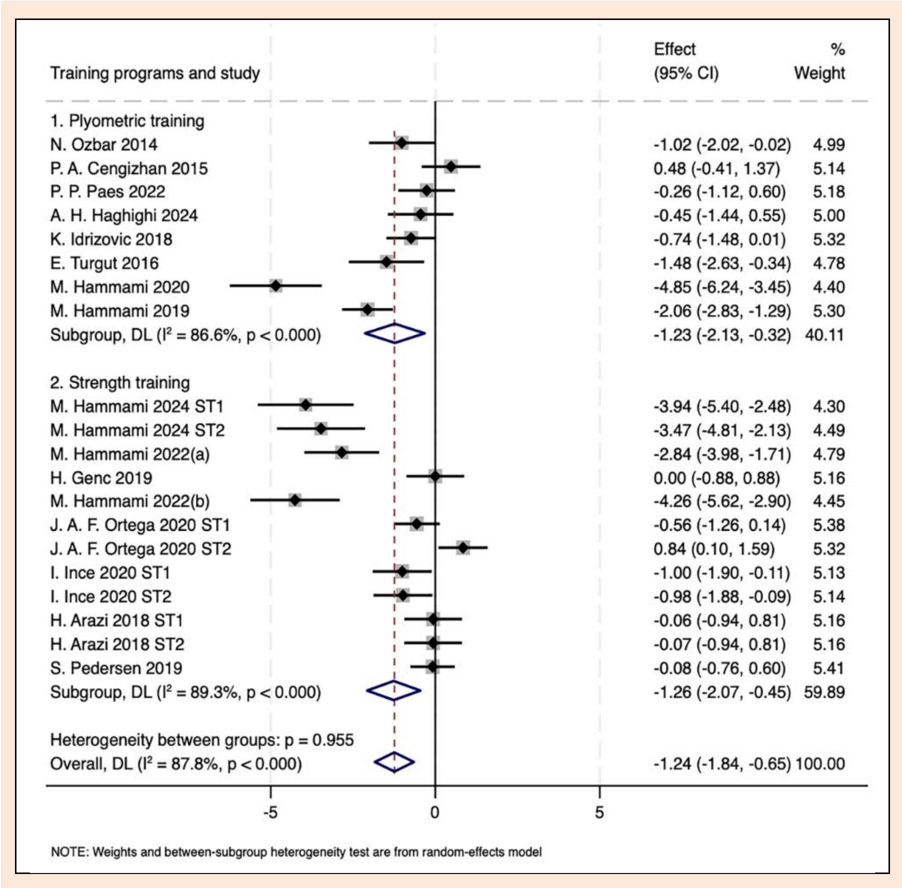

Figure 5. **Forest plot of the effects of strength and plyometric training on linear sprint speed in female adolescent team sport athletes.**

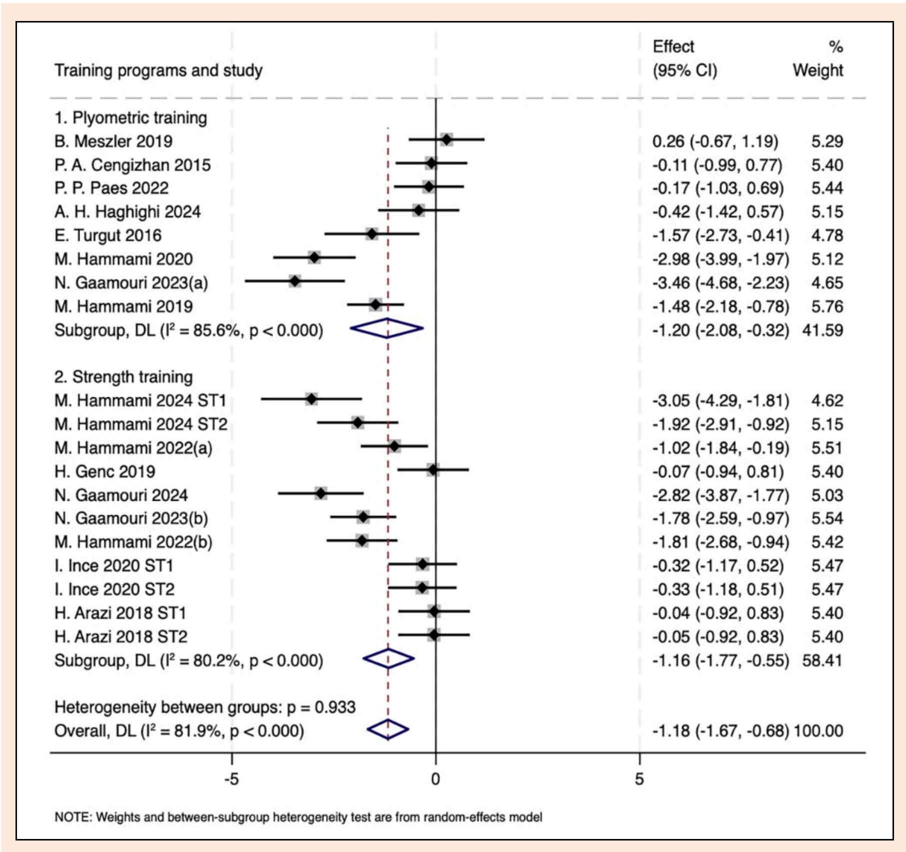

Figure 6. **Forest plot of the effects of strength and plyometric training on change-of-direction speed in female adolescent team sport athletes.**

Strength training

For VJ, great between-group heterogeneity was present in training duration, frequency, total sessions, weight, and type of sports, with statistical significance ($p < 0.05$). Specifically, ST with a longer duration (≥ 10 weeks, ES: 1.20), lower frequency (≤ 2 sessions/week, ES: 1.02), or fewer total sessions (≤ 20 sessions, ES: 1.02) was significantly more effective in improving VJ than that with a shorter duration (< 10 weeks, ES: 0.03), higher frequency (> 2 sessions/week, ES: 0.19), or more total sessions (> 20 sessions, ES: 0.19). Following ST, heavier participants (≥ 62 kg, ES: 1.30) had significantly better improvement in VJ than lighter ones (< 62 kg, ES: 0.23). VJ in handball players (ES: 1.38) benefitted much more from ST than in volleyball (ES: 0.07) and football players (ES: 0.00).

For LS speed, great between-group heterogeneity was present in training duration, frequency, total sessions, age, height, weight, and type of sports, with statistical significance ($p < 0.05$). Specifically, ST with a longer duration (≥ 10 weeks, ES: -2.31), lower frequency (≤ 2 sessions/week, ES: -2.29), or fewer total sessions (≤ 20 sessions, ES: -2.29) was significantly more effective in improving LS speed than that with a shorter duration (< 10 weeks, ES: -0.34), higher frequency (> 2 sessions/week, ES: 0.03), or more total sessions (> 20 sessions, ES: 0.03). Following ST, older (> 15 years, ES: -1.57), taller (≥ 163 cm, ES: -1.99), and heavier (≥ 62 kg, ES: -2.87) participants had significantly better improvement in LS speed than younger (< 15 years, ES: 0.13), shorter (< 163 cm, ES: 0.05), and lighter participants (< 62 kg, ES: -0.25). LS speed in handball players (ES: -2.86) benefitted much more from ST than in volleyball (ES: -0.52) and football players (ES: 0.06).

For CODS, great between-group heterogeneity was present in training duration, frequency, total sessions, height, weight, and type of sports, with statistical significance ($p < 0.05$). Specifically, ST with a longer duration (≥ 10 weeks, ES: -1.98), lower frequency (≤ 2 sessions/week, ES: -1.58), or fewer total sessions (≤ 20 sessions, ES: -1.58) was significantly more effective in improving CODS than that with a shorter duration (< 10 weeks, ES: -0.17), higher frequency (> 2 sessions/week, ES: -0.05), or more total sessions (> 20 sessions, ES: -0.05). Following ST, taller (≥ 163 cm, ES: -1.41) and heavier (≥ 63 kg, ES: -1.98) participants had significantly better improvement in CODS than shorter (< 163 cm, ES: -0.05) and lighter participants (< 63 kg, ES: -0.17). CODS in handball players (ES: -1.73) benefitted much more from ST than in volleyball players (ES: -0.19).

Plyometric training

For VJ, there was great between-group heterogeneity in training duration, total sessions, and type of sports, displaying statistical significance ($p < 0.05$). Specifically, PT with a longer duration (> 9 weeks, ES: 1.36) or more total sessions (> 14 sessions, ES: 1.30) greatly outperformed that with a shorter duration (≤ 9 weeks, ES: 0.51) or fewer total sessions (≤ 14 sessions, ES: 0.46) in improving VJ. VJ in handball players (ES: 1.74) benefitted much more from PT than in football (ES: 0.90), volleyball (ES: 0.47), and basketball players (ES: 0.14).

For LS speed, there was great between-group heterogeneity in training duration and type of sports, displaying statistical significance ($p < 0.05$). Specifically, PT with a longer duration (≥ 9 weeks, ES: -2.20) greatly outperformed that with a shorter duration (< 9 weeks, ES: -0.28) in improving LS speed. LS speed in handball players (ES: -3.39) benefitted much more from PT than in football (ES: -1.02), volleyball (ES: -0.98), and basketball players (ES: -0.06).

For CODS, there was great between-group heterogeneity in training duration, total sessions, and type of sports, displaying statistical significance ($p < 0.05$). Specifically, PT with a longer duration (≥ 9 weeks, ES: -2.32) or more total sessions (≥ 18 sessions, ES: -1.88) greatly outperformed that with a shorter duration (< 9 weeks, ES: -0.10) or fewer total sessions (< 18 sessions, ES: -0.10) in improving CODS. CODS in handball players (ES: -2.57) benefitted much more from PT than in volleyball (ES: -1.57), and basketball players (ES: -0.10).

Discussion

This meta-analysis intends to examine the effects of ST and PT on the physical fitness in female adolescent team sport athletes compared with controls. This meta-analysis included 26 studies. In total, 705 female adolescent team sport athletes were randomly assigned to ST (197 athletes), PT (183 athletes), or an active control group (325 athletes). It was found that ST and PT exhibited significant and moderate to large effects on VJ, LS speed, and CODS ($p < 0.05$).

Vertical jump

Compared with controls, significant moderate improvement was made in VJ in female adolescent team sport athletes after ST ($p = 0.001$, ES: 0.74). One possible explanation is that ST may enhance the ability of muscles to quickly generate force by increasing maximal muscle strength and explosiveness (Suchomel et al., 2016). In particular, ST involving the lower extremities (e.g., squats, Nordic hamstring exercise) can enhance lower limb muscle strength, which plays a crucial role in VJ performance (Suchomel et al., 2016). The efficacy of ST in enhancing muscle strength in female adolescents was also verified in a previous meta-analysis (Moran et al., 2018), which focused on a broader population of healthy adolescent females. In contrast, our study specifically targeted female adolescent team sport athletes, thereby offering sport-specific insights into the effects of ST. In addition, subgroup analyses revealed that ST with a longer duration (≥ 10 weeks), lower frequency (≤ 2 sessions/week), or fewer total sessions (≤ 20 sessions) was more effective in improving VJ compared to ST with a shorter duration, higher frequency, or more total sessions. However, these variables were analyzed independently, and their combined effects were not examined, meaning that potential synergy among them remains uncertain. With a longer duration or lower frequency, the body may have more adequate recovery time, thereby promoting effective gains in neuromuscular adaptations and muscle strength. Adequate recovery facilitates the resolution of exercise-induced muscle damage, replenishment of energy stores, and optimal supercompensation, which in turn enhance motor unit recruitment, neuromuscular coordination, and overall muscle strength (Şahin et al., 2022). Following ST, heavier athletes exhibited more pronounced improvements in VJ, which may be partially attributed to their greater likelihood of having progressed further in the maturation process, leading to increased muscle mass. Greater muscle mass may enhance force production, improve the rate of force development, and contribute to superior neuromuscular efficiency. This suggests that maturity thresholds may modulate the response to ST (Barker et al., 2014). These findings are consistent with the results of a previous meta-analysis on ST in female adolescents (Moran et al., 2018). In addition, the improvement in VJ was greater in handball players than in volleyball and football players after ST, likely because handball players frequently perform jumps followed by rapid deceleration and re-acceleration, making ST more effective in enhancing lower-limb power and explosiveness.

In addition, significant moderate improvement was also made in VJ in female adolescent team sport athletes after PT ($p < 0.001$, ES: 0.87) compared with controls, consistent with a previous meta-analysis on PT in female adolescents that PT greatly improves VJ performance in female adolescents (Moran et al., 2019). Such improvements can be attributed to various adaptive mechanisms such as enhanced motor unit recruitment, improved intermuscular coordination, increased neural drive to agonist muscles, and increased efficiency of SSC (Markovic and Mikulic, 2010; Taube et al., 2012). Informally, PT can more effectively increase lower extremity explosiveness by improving the rapid explosive contraction of the muscles, thereby making jump performance better (Markovic and Mikulic, 2010). Besides, subgroup analyses revealed that PT with a longer duration (> 9 weeks) or more total sessions (> 14 sessions) performed better in improving VJ. Similarly, a previous meta-analysis noted that longer duration or more total sessions of PT contribute to the effectiveness of the training cycle among female adolescents (Moran et al., 2019). Slimani et al. also argued that 20 sessions or 10 weeks of training programs are required to maximize the chances of adaptation (Slimani et al., 2016). The effective utilization of muscle elastic potential energy and neuromuscular adaptations may be facilitated by longer training cycles and adequate stimuli (Stojanović et al., 2017). In addition, the improvement in VJ was greater in handball players than in basketball, volleyball, and football players after PT, possibly due to their greater reliance on explosive jumps during gameplay. In contrast, basketball and volleyball players may have already developed high jumping ability, leading to comparatively smaller improvements.

To be specific, PT focuses more on optimizing the efficiency of SSC in lower extremity muscles, whereas ST enhances the jump ability primarily by increasing maximal muscle strength. The dynamic characteristics and explosive exercises of PT are closer to the actual jump movements than ST, which are especially suitable for the development of neuromuscular adaptations in female adolescents. In practice, PT can be prioritized as an effective method to enhance VJ performance in female adolescent team sport athletes, while ST provides a foundational strength base that supports PT adaptations and contributes to overall athletic development.

Linear sprint speed

LS with SSC movements involves a combination of eccentric, isometric (or amortization), and concentric muscle contractions (Komi, 1986). SSC-based movements tend to contribute to greater concentric force output when elastic energy is quickly and efficiently stored and transferred from the eccentric phase to the concentric phase (Bosco et al., 1982a; Bosco et al., 1982b; Cavagna et al., 1968; Cormie et al., 2010). Elasticity and contraction (e.g., increased muscle activation time, preload effects, muscle-tendon interactions, stretch reflexes) components affect maximum power output (Avela et al., 2006; Cavagna et al., 1968; Ettema et al., 1990; Lichtwark and Wilson, 2005). Since LS speed is largely influenced by lower extremity power output, a high ratio of muscle strength is one of the main contributors to optimal sprint performance (Aagaard et al., 2002; Cormie et al., 2007; Cronin and Sleivert, 2005). ST contributes to LS speed primarily by increasing lower extremity muscle strength, particularly in the hip, knee, and ankle joints (Suchomel et al., 2016). It enhances sprint performance by increasing maximal force production, improving neuromuscular efficiency, and enabling greater force application during ground contact. Therefore, this study revealed that ST ($p = 0.002$, ES: -1.26) exhibited a significant and greater benefit compared with controls, consistent with a previous meta-analysis that ST can to a greater extent improve LS speed in female adolescent team sport athletes (Hughes et al., 2023). However, that study did not isolate the effects of ST alone and included both adolescents and adults, whereas our analysis specifically focused on the independent effects of ST in female adolescent team sport athletes. Furthermore, subgroup analyses found that ST with a longer duration (≥ 10 weeks), lower frequency (≤ 2 sessions/week), or fewer total sessions (≤ 20 sessions) was more effective in improving LS speed compared to that with a shorter duration, higher frequency, or more total sessions. The reason is that long-term ST can more effectively enhance lower extremity muscle strength, thus improving LS speed. Following ST, older (> 15 years), taller (≥ 163 cm), and heavier (≥ 62 kg) participants showed significantly greater improvements in LS speed. This enhancement may be attributed to maturation-related increases in muscle mass, suggesting that maturity thresholds could influence the response to ST (Barker et al., 2014). Additionally, taller participants may benefit from a longer stride length, while increased body mass, when associated with greater lean muscle, can contribute to higher ground reaction forces, further supporting sprint performance. In addition, the improvement in LS speed was also greater in handball players than in volleyball and football players after ST, as handball involves repeated short sprints, making lower-limb strength gains more impactful for acceleration.

PT ($p = 0.008$, ES: -1.23) also achieved positive effects on improving LS speed in female adolescent team sport athletes, which may be due to an increase in the number of motor units activated and/or firing rates, as well as altered recruitment patterns of motor units (primarily fast muscle fibers) (Hakkinen, 1985). Accordingly, these adaptations may raise the maximal muscle strength and power capacity, allowing athletes to take longer strides during sprints (Bishop and Girard, 2013; Morin et al., 2012). In addition, neuro-mechanical adaptations induced by lower extremity PT, such as enhanced neural drive to agonist muscles and optimized muscle-tendon stiffness (Markovic and Mikulic, 2010), may enhance the efficiency of SSC. Since the efficiency of SSC in lower extremity musculature is improved, greater force may be generated in the concentric phase following rapid eccentric movements of the muscle (Markovic and Mikulic, 2010; Radnor et al., 2018; Tomalka et al., 2020), which is a key requirement for better sprint performance (Bishop and Girard, 2013). Furthermore, subgroup analyses revealed that a longer duration (≥ 9 weeks) of PT was more effective than a shorter duration, and analysis suggested that a longer adaptation process is required in PT to greatly improve sprint speed. LS speed in handball players benefited more than football, volleyball, and basketball players. Since PT enhance explosive power and neuromuscular coordination, handball players, who rely heavily on short bursts of speed, may experience greater improvements compared to athletes in sports with less sprinting demand.

This study found that ST and PT had comparable effects on improving linear sprint speed. However, a previous meta-analysis on adolescent athletes suggested that ST may provide a greater advantage in enhancing sprint performance (Behm et al., 2017). ST directly enhances the athletes' sprint performance by increasing the maximal strength and explosiveness of the lower extremity muscles. In contrast, PT relies more on improvements in neuromuscular coordination and reaction time, and it works indirectly despite its effects on improving LS speed. Therefore, ST may be the preferred training program to improve LS speed in female adolescent team sport athletes, especially during sprints.

Change-of-direction speed

When changing the direction of movements, rapid and systematic coordination of forces and impulses during the braking (eccentric), stabilizing (isometric), and accelerating (concentric) phases is required (Spiteri et al., 2015). Since the eccentric strength is an important determinant of the deceleration capacity during CODS (Chaabene et al., 2018), greater eccentric strength can enhance the athletes' braking efficiency during CODS, and allow them to more quickly complete CODS and transit to the accelerating phase, thereby increasing the use of propulsive forces (Glaister et al., 2008; Spiteri et al., 2013). Additionally, isometric strength is decisive for optimizing triple extension during CODS, which allows the athlete to control the displacement of the body and successfully transfer the force to a new direction, achieving faster CODS (Spiteri et al., 2015). Research suggests that CODS performance can often be ameliorated by increasing the athletes' lower extremity strength or, more specifically, lean muscle mass (Spiteri et al., 2013; Spiteri et al., 2014). ST possesses positive effects on improving eccentric strength, concentric strength, and isometric strength. Therefore, this study revealed that ST made a significant moderate improvement ($p < 0.001$, ES: -1.16) in CODS in female adolescent team sport athletes. Furthermore, subgroup analyses showed that ST with a longer duration (≥ 10 weeks), lower frequency (≤ 2 sessions/week), or fewer total sessions (≤ 20 sessions) was more effective in improving CODS, and CODS in taller (≥ 163 cm) and heavier (≥ 63 kg) athletes benefitted more from ST. Handball players had significantly better improvement in CODS than volleyball players after ST. This could be because handball requires frequent high-speed directional changes, whereas volleyball players primarily engage in lateral movements and vertical jumps, making ST less influential for agility.

Besides, PT ($p = 0.007$, ES: -1.20) also achieved positive effects on enhancing CODS in female adolescent team sport athletes, which may result from the interaction of multiple neuromuscular adaptations, including improved neural drive to agonist muscles, neuromuscular patterns capable of rapidly switching between decelerated and accelerated movements (i.e., higher SSC efficiency), and muscle activation strategies that enhance inter- and intramuscular coordination (Häkkukinen et al., 1985; Markovic and Mikulic, 2010). In addition, PT can increase muscle power output and movement efficiency to reduce ground reaction time, thereby positively affecting CODS (Granacher et al., 2015). Moreover, subgroup analyses revealed that PT with a longer duration (≥ 9 weeks) or more total sessions (≥ 18 sessions) was more effective than that with a shorter duration or fewer sessions. The reason is that a longer duration of PT helps enhance the lower extremity explosiveness and quick power transfer, thus improving CODS. Handball players had significantly better improvement in CODS than volleyball and basketball players after PT. This may be due to the frequent multi-directional movements in handball, which align well with the benefits of PT in enhancing rapid force production and movement transitions.

To sum up, the two have different emphases due to their respective mechanisms. ST directly enhances deceleration, stability, and reacceleration capacity primarily by increasing eccentric, isometric, and concentric strength, thereby improving CODS performance. PT relies more on optimizing neuromuscular coordination and SSC efficiency, which focuses on better speed and fluidity of overall movements. Considering the training needs and goals, therefore, it is recommended to combine ST and PT to achieve an overall improvement in CODS. ST can serve as the basis for improving lower extremity strength and explosiveness, while PT can enhance both neuromuscular coordination and quick reaction capability, thus maximizing the training effect.

Limitations

Although this meta-analysis fully explored the effects of ST and PT on female adolescent team sport athletes, some limitations are worth noting and need to be taken into account during the interpretation of results. First, due to the limited number of studies on the effects of training programs on physical fitness in female adolescents, this study focused solely on the three most representative indicators of athletic performance without including other potential indicators. To obtain more comprehensive results, more indicators (e.g., balance, reactive strength, and muscle endurance) for the effects of ST and PT on the overall performance of female adolescent team sport athletes should be included in the future. Second, most of the studies were assessed as having some concerns in the randomization process and deviations from intended interventions, possibly due to the difficulty of conducting studies with blinding of participants and/or therapists. As a result, some RoB was present due to inadequate randomization during study design and execution and interventions. Nonetheless, as these issues were consistent across studies and were unlikely to have a substantial impact on the pooled estimates, they were not considered serious enough to reduce the level of certainty of evidence. Accordingly, the overall level of certainty of evidence was rated as moderate to high, which should be considered when interpreting the results. Future studies should adopt better relevant study designs, such as implementing concealed allocation, evaluating outcomes by independent assessors, and applying single- or double-blind designs where feasible. Third, the training programs included lacked uniformity in variables such as training duration, frequency, and total sessions, which might affect the comparison and summary of training effects, so the findings should be interpreted with caution. Moreover, the subgroup sample sizes were small, especially in specific sports (e.g., basketball, volleyball, and football), so the findings remain to be validated by larger samples and more diverse types of sports. Fourth, although some physiological mechanisms have been empirically validated in adolescent females, others are extrapolated from studies on broader populations. Future research is needed to confirm these proposed mechanisms in female adolescents to strengthen the evidence base for training prescriptions. Finally, this study focused on female adolescent team sport athletes, including handball, basketball, football, and volleyball players, so the findings may only apply to this specific group. In conclusion, this study systematically examined the effects of ST and PT on physical fitness in female adolescent team sport athletes, but further refinement is required in the uniformity of training programs, sample sizes, and generalizability of results.

Practical implications

Based on the current findings, both ST and PT significantly improve vertical jump, linear sprint, and change-of-direction speed in female adolescent team sport athletes. To enhance athletic performance, coaches are advised to use a periodized training approach that strategically combines ST and PT. ST is preferred in the early preparatory phase to establish maximal strength and neuromuscular coordination. PT can then be gradually added into the pre-competition phase to improve explosive power and sport-specific speed. Alternatively, coaches could concurrently incorporate one to two sessions of ST and PT per week. This concurrent training method may also be effective for maintaining neuromuscular coordination while minimizing the risk of overtraining or injury. Training loads should be individually tailored according to athletes' maturity level and sport requirements. Moreover, the duration and volume of each training program should be appropriate. ST appears to be effective even with fewer weekly sessions. In contrast, as for PT, longer training duration and sessions are needed for improving athletic performance.

Conclusion

Both ST and PT can enhance physical fitness (VJ, LS, and CODS) in female adolescent team sport athletes. Specifically, longer duration, lower frequency, or fewer sessions of ST produce better effects. Older, taller, or heavier athletes are better adapted to ST. In addition, longer duration or more sessions of PT are more effective in enhancing physical fitness. Notably, the effects of PT are not affected by the athletes' age and biological maturity. Handball players seem more adaptive/sensitive to both ST and PT than athletes of other sports.

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Key points

- Strength and plyometric training are effective in improving vertical jump, linear sprint, and change-of-direction speed in female adolescent team sport athletes.
- Participants exhibited comparable improvements in vertical jump, linear sprint, and change-of-direction speed following strength and plyometric training, with no significant differences observed between the two training programs.
- Strength and plyometric training should be tailored to specific training protocols and athlete characteristics to maximize effectiveness. For strength training, extending training duration, reducing session frequency, or limiting total sessions may enhance outcomes. Adaptations to strength training appear more pronounced in older, taller, and heavier athletes. For plyometric training, longer training durations or higher total session counts yield greater improvements.

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College of Sport and Art, Shenzhen Technology University, China

Supplementary Materials

Supplementary Material 1. Detailed search strategies.

PubMed

No.	Query	Search Details	Results
7	(#1 OR #2 OR #3) AND (#4 OR #5) AND #6	("resistance training"[MeSH Terms] OR "plyometric exercise"[MeSH Terms] OR ("strength training"[Title/Abstract] OR "weight training"[Title/Abstract] OR "resistance training"[Title/Abstract] OR "eccentric training"[Title/Abstract] OR "strength exercise*"[Title/Abstract] OR "weight exercise*"[Title/Abstract] OR "resistance exercise*"[Title/Abstract] OR "power exercise*"[Title/Abstract] OR "eccentric exercise*"[Title/Abstract] OR "isokinetic exercise*"[Title/Abstract] OR "heavy load*"[Title/Abstract] OR "bodybuilding"[Title/Abstract] OR "olympic lift*"[Title/Abstract] OR "muscular endurance"[Title/Abstract] OR "crossfit"[Title/Abstract] OR "calisthenics"[Title/Abstract] OR "free weight*"[Title/Abstract] OR "machine exercise*"[Title/Abstract] OR "machine weight*"[Title/Abstract] OR "elastic bands"[Title/Abstract] OR "weight vest"[Title/Abstract] OR "medicine ball*"[Title/Abstract] OR "kettlebell*"[Title/Abstract] OR "resisted sprint*"[Title/Abstract] OR "resisted run*"[Title/Abstract] OR "sled towing"[Title/Abstract] OR "resisted sled"[Title/Abstract] OR "uphill run*"[Title/Abstract] OR "muscle strength"[Title/Abstract] OR "plyometric training"[Title/Abstract] OR "plyometrics"[Title/Abstract] OR "plyometric*"[Title/Abstract] OR "plyometric exercise"[Title/Abstract] OR "plyometric drills"[Title/Abstract] OR "plyometric intervention"[Title/Abstract] OR "plyometric program"[Title/Abstract] OR "jump training"[Title/Abstract] OR "explosive training"[Title/Abstract] OR "ballistic training"[Title/Abstract] OR "reactive strength training"[Title/Abstract] OR "power training"[Title/Abstract] OR "vertical jump training"[Title/Abstract] OR "bounding exercises"[Title/Abstract] OR "depth jumps"[Title/Abstract] OR "box jumps"[Title/Abstract] OR "drop jumps"[Title/Abstract] OR "countermovement jumps"[Title/Abstract] OR "squat jumps"[Title/Abstract] OR "rebound jumps"[Title/Abstract] OR "shock training"[Title/Abstract] OR "eccentric-concentric training"[Title/Abstract] OR "stretch-shortening cycle exercises"[Title/Abstract] OR "explosive strength training"[Title/Abstract] OR "explosive power training"[Title/Abstract] OR "high-impact training"[Title/Abstract] OR "high-velocity training"[Title/Abstract])) AND ("team sports"[MeSH Terms] OR ("football"[Title/Abstract] OR "soccer"[Title/Abstract] OR "futsal"[Title/Abstract] OR "basketball"[Title/Abstract] OR "handball"[Title/Abstract] OR "volleyball"[Title/Abstract] OR "rugby"[Title/Abstract] OR "hockey"[Title/Abstract] OR "baseball"[Title/Abstract] OR "softball"[Title/Abstract] OR "team sport*"[Title/Abstract])) AND ("randomized controlled trial"[Title/Abstract] OR "controlled clinical trial"[Title/Abstract] OR "randomized"[Title/Abstract] OR "randomised"[Title/Abstract] OR "placebo"[Title/Abstract] OR "randomly"[Title/Abstract] OR "trial"[Title/Abstract] OR "groups"[Title/Abstract])	1,411
6	"randomized controlled trial"[Title/Abstract] OR "controlled clinical trial"[Title/Abstract] OR "randomized"[Title/Abstract] OR "randomised"[Title/Abstract] OR "placebo"[Title/Abstract] OR "randomly"[Title/Abstract] OR "trial"[Title/Abstract] OR "groups"[Title/Abstract]	"randomized controlled trial"[Title/Abstract] OR "controlled clinical trial"[Title/Abstract] OR "randomized"[Title/Abstract] OR "randomised"[Title/Abstract] OR "placebo"[Title/Abstract] OR "randomly"[Title/Abstract] OR "trial"[Title/Abstract] OR "groups"[Title/Abstract]	3,898,138
5	"football"[Title/Abstract] OR "soccer"[Title/Abstract] OR "futsal"[Title/Abstract] OR "basketball"[Title/Abstract] OR "handball"[Title/Abstract] OR "volleyball"[Title/Abstract] OR "rugby"[Title/Abstract] OR "hockey"[Title/Abstract] OR "baseball"[Title/Abstract] OR "softball"[Title/Abstract] OR "team sport*"[Title/Abstract]	"football"[Title/Abstract] OR "soccer"[Title/Abstract] OR "futsal"[Title/Abstract] OR "basketball"[Title/Abstract] OR "handball"[Title/Abstract] OR "volleyball"[Title/Abstract] OR "rugby"[Title/Abstract] OR "hockey"[Title/Abstract] OR "baseball"[Title/Abstract] OR "softball"[Title/Abstract] OR "team sport*"[Title/Abstract]	43,083
4	team sports[MeSH Terms]	"team sports"[MeSH Terms]	429

3	"strength training"[Title/Abstract] OR "weight training"[Title/Abstract] OR "resistance training"[Title/Abstract] OR "eccentric training"[Title/Abstract] OR "strength exercise*"[Title/Abstract] OR "weight exercise*"[Title/Abstract] OR "resistance exercise*"[Title/Abstract] OR "power exercise*"[Title/Abstract] OR "eccentric exercise*"[Title/Abstract] OR "isokinetic exercise*"[Title/Abstract] OR "heavy load*"[Title/Abstract] OR "bodybuilding"[Title/Abstract] OR "Olympic lift*"[Title/Abstract] OR "muscular endurance"[Title/Abstract] OR "crossfit"[Title/Abstract] OR "calisthenics"[Title/Abstract] OR "free weight*"[Title/Abstract] OR "machine exercise*"[Title/Abstract] OR "machine weight*"[Title/Abstract] OR "elastic bands"[Title/Abstract] OR "weight vest"[Title/Abstract] OR "weights belts"[Title/Abstract] OR "medicine ball*"[Title/Abstract] OR "kettlebell*"[Title/Abstract] OR "resisted speed"[Title/Abstract] OR "resisted sprint*"[Title/Abstract] OR "resisted run*"[Title/Abstract] OR "sled towing"[Title/Abstract] OR "resisted sled"[Title/Abstract] OR "uphill run*"[Title/Abstract] OR "muscle strength"[Title/Abstract] OR "plyometric training"[Title/Abstract] OR "plyometrics"[Title/Abstract] OR "plyometric*"[Title/Abstract] OR "plyometric exercise"[Title/Abstract] OR "plyometric drills"[Title/Abstract] OR "plyometric intervention"[Title/Abstract] OR "plyometric program"[Title/Abstract] OR "jump training"[Title/Abstract] OR "explosive training"[Title/Abstract] OR "ballistic training"[Title/Abstract] OR "reactive strength training"[Title/Abstract] OR "power training"[Title/Abstract] OR "vertical jump training"[Title/Abstract] OR "bounding exercises"[Title/Abstract] OR "depth jumps"[Title/Abstract] OR "box jumps"[Title/Abstract] OR "drop jumps"[Title/Abstract] OR "countermovement jumps"[Title/Abstract] OR "squat jumps"[Title/Abstract] OR "rebound jumps"[Title/Abstract] OR "shock training"[Title/Abstract] OR "eccentric-concentric training"[Title/Abstract] OR "stretch-shortening cycle exercises"[Title/Abstract] OR "explosive strength training"[Title/Abstract] OR "explosive power training"[Title/Abstract] OR "high-impact training"[Title/Abstract] OR "high-velocity training"[Title/Abstract]	"strength training"[Title/Abstract] OR "weight training"[Title/Abstract] OR "resistance training"[Title/Abstract] OR "eccentric training"[Title/Abstract] OR "strength exercise*"[Title/Abstract] OR "weight exercise*"[Title/Abstract] OR "resistance exercise*"[Title/Abstract] OR "power exercise*"[Title/Abstract] OR "eccentric exercise*"[Title/Abstract] OR "isokinetic exercise*"[Title/Abstract] OR "heavy load*"[Title/Abstract] OR "bodybuilding"[Title/Abstract] OR "olympic lift*"[Title/Abstract] OR "muscular endurance"[Title/Abstract] OR "crossfit"[Title/Abstract] OR "calisthenics"[Title/Abstract] OR "free weight*"[Title/Abstract] OR "machine exercise*"[Title/Abstract] OR "machine weight*"[Title/Abstract] OR "elastic bands"[Title/Abstract] OR "weight vest"[Title/Abstract] OR "medicine ball*"[Title/Abstract] OR "kettlebell*"[Title/Abstract] OR "resisted sprint*"[Title/Abstract] OR "resisted run*"[Title/Abstract] OR "sled towing"[Title/Abstract] OR "resisted sled"[Title/Abstract] OR "uphill run*"[Title/Abstract] OR "muscle strength"[Title/Abstract] OR "plyometric training"[Title/Abstract] OR "plyometrics"[Title/Abstract] OR "plyometric*"[Title/Abstract] OR "plyometric exercise"[Title/Abstract] OR "plyometric drills"[Title/Abstract] OR "plyometric intervention"[Title/Abstract] OR "plyometric program"[Title/Abstract] OR "jump training"[Title/Abstract] OR "explosive training"[Title/Abstract] OR "ballistic training"[Title/Abstract] OR "reactive strength training"[Title/Abstract] OR "power training"[Title/Abstract] OR "vertical jump training"[Title/Abstract] OR "bounding exercises"[Title/Abstract] OR "depth jumps"[Title/Abstract] OR "box jumps"[Title/Abstract] OR "drop jumps"[Title/Abstract] OR "countermovement jumps"[Title/Abstract] OR "squat jumps"[Title/Abstract] OR "rebound jumps"[Title/Abstract] OR "shock training"[Title/Abstract] OR "eccentric-concentric training"[Title/Abstract] OR "stretch-shortening cycle exercises"[Title/Abstract] OR "explosive strength training"[Title/Abstract] OR "explosive power training"[Title/Abstract] OR "high-impact training"[Title/Abstract] OR "high-velocity training"[Title/Abstract]	64,360
2	plyometric exercise[MeSH Terms]	"plyometric exercise"[MeSH Terms]	887
1	resistance training[MeSH Terms]	"resistance training"[MeSH Terms]	13,300

EMBASE

No.	**Query**	**Results**
#7	(#1 OR #2 OR #3) AND (#4 OR #5) AND #6	1,542
#6	'randomized controlled trial':ti,ab,kw OR 'controlled clinical trial':ti,ab,kw OR 'randomized':ti,ab,kw OR 'randomised':ti,ab,kw OR 'placebo':ti,ab,kw OR 'randomly':ti,ab,kw OR 'trial':ti,ab,kw OR 'groups':ti,ab,kw	5,473,571
#5	'football':ti,ab,kw OR 'soccer':ti,ab,kw OR 'futsal':ti,ab,kw OR 'basketball':ti,ab,kw OR 'hand-ball':ti,ab,kw OR 'volleyball':ti,ab,kw OR 'rugby':ti,ab,kw OR 'hockey':ti,ab,kw OR 'baseball':ti,ab,kw OR 'softball':ti,ab,kw OR 'team sport*':ti,ab,kw	49,497
#4	'team sport'/exp	1,758
#3	'strength training':ti,ab,kw OR 'weight training':ti,ab,kw OR 'resistance training':ti,ab,kw OR 'eccen-tric training':ti,ab,kw OR 'strength exercise*':ti,ab,kw OR 'weight exercise*':ti,ab,kw OR 'resistance exercise*':ti,ab,kw OR 'power exercise*':ti,ab,kw OR 'eccentric exercise*':ti,ab,kw OR 'isokinetic ex-ercise*':ti,ab,kw OR 'heavy load*':ti,ab,kw OR 'bodybuilding':ti,ab,kw OR 'olympic lift*':ti,ab,kw OR 'muscular endurance':ti,ab,kw OR 'crossfit':ti,ab,kw OR 'calisthenics':ti,ab,kw OR 'free weight*':ti,ab,kw OR 'machine exercise*':ti,ab,kw OR 'machine weight*':ti,ab,kw OR 'elastic bands':ti,ab,kw OR 'weight vest':ti,ab,kw OR 'weights belts':ti,ab,kw OR 'medicine ball*':ti,ab,kw OR 'kettlebell*':ti,ab,kw OR 'resisted speed':ti,ab,kw OR 'resisted sprint*':ti,ab,kw OR 'resisted run*':ti,ab,kw OR 'sled towing':ti,ab,kw OR 'resisted sled':ti,ab,kw OR 'uphill run*':ti,ab,kw OR 'mus-cle strength':ti,ab,kw OR 'plyometric training':ti,ab,kw OR 'plyometrics':ti,ab,kw OR 'plyome-tric*':ti,ab,kw OR 'plyometric exercise':ti,ab,kw OR 'plyometric drills':ti,ab,kw OR 'plyometric inter-vention':ti,ab,kw OR 'plyometric program':ti,ab,kw OR 'jump training':ti,ab,kw OR 'explosive train-ing':ti,ab,kw OR 'ballistic training':ti,ab,kw OR 'reactive strength training':ti,ab,kw OR 'power train-ing':ti,ab,kw OR 'vertical jump training':ti,ab,kw OR 'bounding exercises':ti,ab,kw OR 'depth jumps':ti,ab,kw OR 'box jumps':ti,ab,kw OR 'drop jumps':ti,ab,kw OR 'countermovement jumps':ti,ab,kw OR 'squat jumps':ti,ab,kw OR 'rebound jumps':ti,ab,kw OR 'shock training':ti,ab,kw OR 'eccentric-concentric training':ti,ab,kw OR 'stretch-shortening cycle exercises':ti,ab,kw OR 'explo-sive strength training':ti,ab,kw OR 'explosive power training':ti,ab,kw OR 'high-impact train-ing':ti,ab,kw OR 'high-velocity training':ti,ab,kw	84,770
#2	'plyometrics'/exp	1,400
#1	'resistance training'/exp	30,785

Web of Science

No.	Search Query	Results
#1	TS=("strength training" OR "weight training" OR "resistance training" OR "eccentric training" OR "strength exercise*" OR "weight exercise*" OR "resistance exercise*" OR "power exercise*" OR "eccentric exercise*" OR "isokinetic exercise*" OR "heavy load*" OR "bodybuilding" OR "Olympic lift*" OR "muscular endurance" OR "crossfit" OR "calisthenics" OR "free weight*" OR "machine exercise*" OR "machine weight*" OR "elastic bands" OR "weight vest" OR "weights belts" OR "medicine ball*" OR "kettlebell*" OR "resisted speed" OR "resisted sprint*" OR "resisted run*" OR "sled towing" OR "resisted sled" OR "uphill run*" OR "muscle strength" OR "plyometric training" OR "plyometrics" OR "plyometric*" OR "plyometric exercise" OR "plyometric drills" OR "plyome-tric intervention" OR "plyometric program" OR "jump training" OR "explosive training" OR "ballis-tic training" OR "reactive strength training" OR "power training" OR "vertical jump training" OR "bounding exercises" OR "depth jumps" OR "box jumps" OR "drop jumps" OR "countermovement jumps" OR "squat jumps" OR "rebound jumps" OR "shock training" OR "eccentric-concentric train-ing" OR "stretch-shortening cycle exercises" OR "explosive strength training" OR "explosive power training" OR "high-impact training" OR "high-velocity training")	95,161
#2	TS=("football" OR "soccer" OR "futsal" OR "basketball" OR "handball" OR "volleyball" OR "rugby" OR "hockey" OR "baseball" OR "softball" OR "team sport*")	99,021
#3	TS=("randomized controlled trial" OR "controlled clinical trial" OR "randomized" OR "randomised" OR "placebo" OR "randomly" OR "trial" OR "groups")	5,528,765
#4	#1 AND #2 AND #3	2,321

Cochrane library

No.	Search	Hits
#1	MeSH descriptor: [Resistance Training] explode all trees	5,775
#2	MeSH descriptor: [Plyometric Exercise] explode all trees	333
#3	(‘strength training’ OR ‘weight training’ OR ‘resistance training’ OR ‘eccentric training’ OR ‘strength exercise*’ OR ‘weight exercise*’ OR ‘resistance exercise*’ OR ‘power exercise*’ OR ‘eccentric exercise*’ OR ‘isokinetic exercise*’ OR ‘heavy load*’ OR ‘bodybuilding’ OR ‘Olympic lift*’ OR ‘muscular endurance’ OR ‘crossfit’ OR ‘calisthenics’ OR ‘free weight*’ OR ‘machine exercise*’ OR ‘machine weight*’ OR ‘elastic bands’ OR ‘weight vest’ OR ‘weights belts’ OR ‘medicine ball*’ OR ‘kettlebell*’ OR ‘resisted speed’ OR ‘resisted sprint*’ OR ‘resisted run*’ OR ‘sled towing’ OR ‘resisted sled’ OR ‘uphill run*’ OR ‘muscle strength’ OR ‘plyometric training’ OR ‘plyometrics’ OR ‘plyometric*’ OR ‘plyometric exercise’ OR ‘plyometric drills’ OR ‘plyometric intervention’ OR ‘plyometric program’ OR ‘jump training’ OR ‘explosive training’ OR ‘ballistic training’ OR ‘reactive strength training’ OR ‘power training’ OR ‘vertical jump training’ OR ‘bounding exercises’ OR ‘depth jumps’ OR ‘box jumps’ OR ‘drop jumps’ OR ‘countermovement jumps’ OR ‘squat jumps’ OR ‘rebound jumps’ OR ‘shock training’ OR ‘eccentric-concentric training’ OR ‘stretch-shortening cycle exercises’ OR ‘explosive strength training’ OR ‘explosive power training’ OR ‘high-impact training’ OR ‘high-velocity training’):ti,ab,kw	91,452
#4	MeSH descriptor: [Team Sports] explode all trees	23
#5	(‘football’ OR ‘soccer’ OR ‘futsal’ OR ‘basketball’ OR ‘handball’ OR ‘volleyball’ OR ‘rugby’ OR ‘hockey’ OR ‘baseball’ OR ‘softball’ OR ‘team sport*’):ti,ab,kw	6,096
#6	(‘randomized controlled trial’ OR ‘controlled clinical trial’ OR ‘randomized’ OR ‘randomised’ OR ‘placebo’ OR ‘randomly’ OR ‘trial’ OR ‘groups’):ti,ab,kw	1,616,225
#7	(#1 OR #2 OR #3) AND (#4 OR #5) AND #6	2,298

SPORTDiscus

No.	Search Query	Results
S1	SU (“strength training” OR “weight training” OR “resistance training” OR “eccentric training” OR “strength exercise*” OR “weight exercise*” OR “resistance exercise*” OR “power exercise*” OR “eccentric exercise*” OR “isokinetic exercise*” OR “heavy load*” OR “bodybuilding” OR “Olympic lift*” OR “muscular endurance” OR “crossfit” OR “calisthenics” OR “free weight*” OR “machine exercise*” OR “machine weight*” OR “elastic bands” OR “weight vest” OR “weights belts” OR “medicine ball*” OR “kettlebell*” OR “resisted speed” OR “resisted sprint*” OR “resisted run*” OR “sled towing” OR “resisted sled” OR “uphill run*” OR “muscle strength” OR “plyometric training” OR “plyometrics” OR “plyometric*” OR “plyometric exercise” OR “plyometric drills” OR “plyometric intervention” OR “plyometric program” OR “jump training” OR “explosive training” OR “ballistic training” OR “reactive strength training” OR “power training” OR “vertical jump training” OR “bounding exercises” OR “depth jumps” OR “box jumps” OR “drop jumps” OR “countermovement jumps” OR “squat jumps” OR “rebound jumps” OR “shock training” OR “eccentric-concentric training” OR “stretch-shortening cycle exercises” OR “explosive strength training” OR “explosive power training” OR “high-impact training” OR “high-velocity training”)	55,265
S2	SU (“football” OR “soccer” OR “futsal” OR “basketball” OR “handball” OR “volleyball” OR “rugby” OR “hockey” OR “baseball” OR “softball” OR “team sport*”)	379,813
S3	SU (“randomized controlled trial” OR “controlled clinical trial” OR “randomized” OR “randomised” OR “placebo” OR “randomly” OR “trial” OR “groups”)	33,042
S4	S1 AND S2 AND S3	353

Supplementary Material 2. **Sensitivity analyses and funnel plots.**

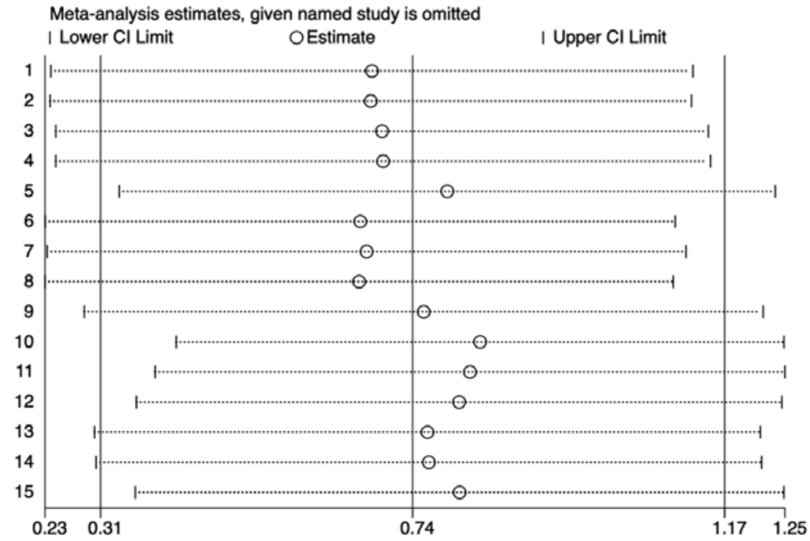

Figure S1. **Sensitivity analysis of the effect of strength training on vertical jump in female adolescent team sport athletes.**

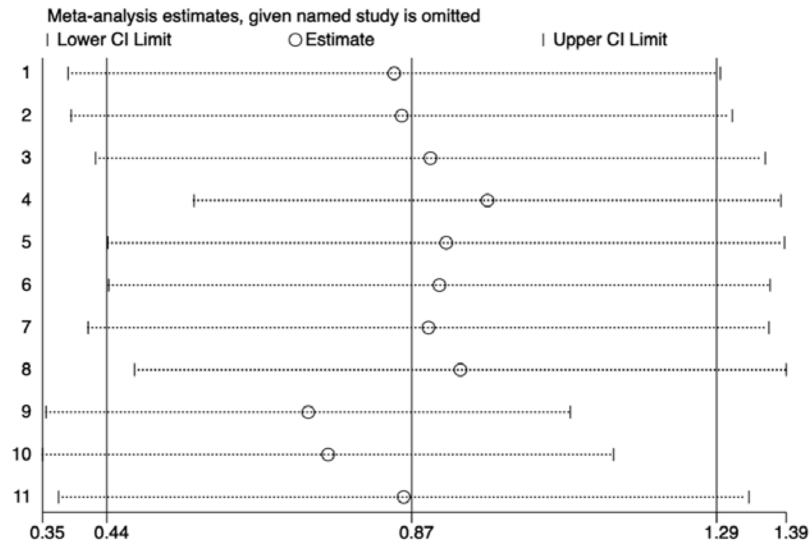

Figure S2. **Sensitivity analysis of the effect of plyometric training on vertical jump in female adolescent team sport athletes.**

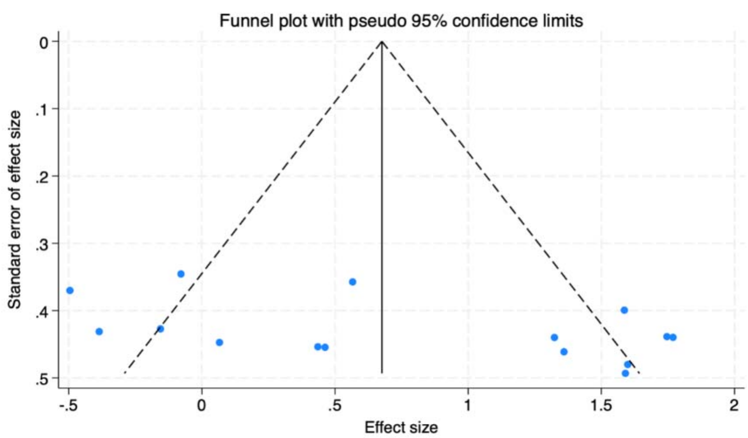

Figure S3. **Funnel plot of the effect of strength training on vertical jump in female adolescent team sport athletes.**

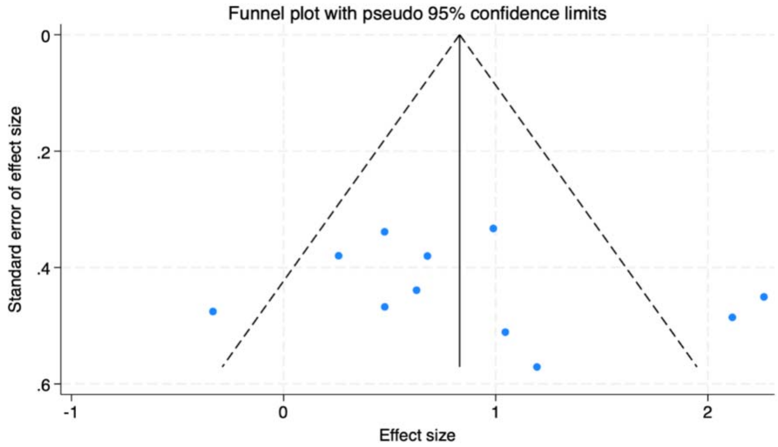

Figure S4. **Funnel plot of the effect of plyometric training on vertical jump in female adolescent team sport athletes.**

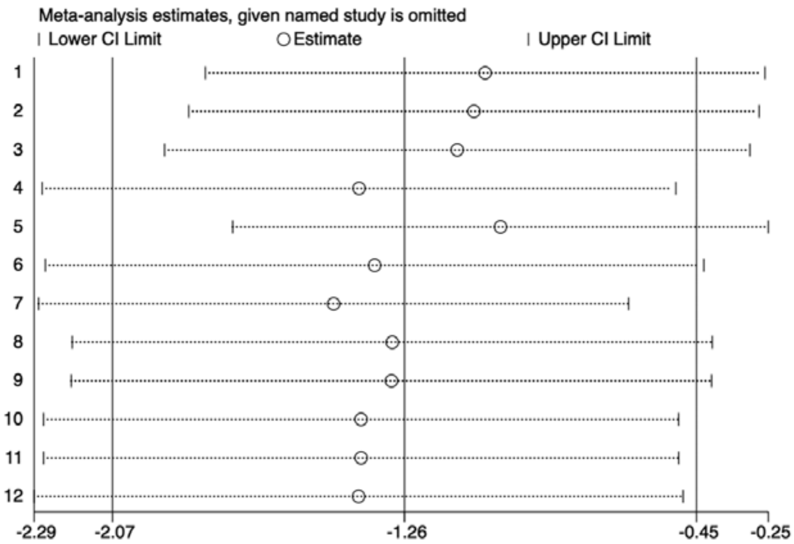

Figure S5. **Sensitivity analysis of the effect of strength training on linear sprint speed in female adolescent team sport athletes.**

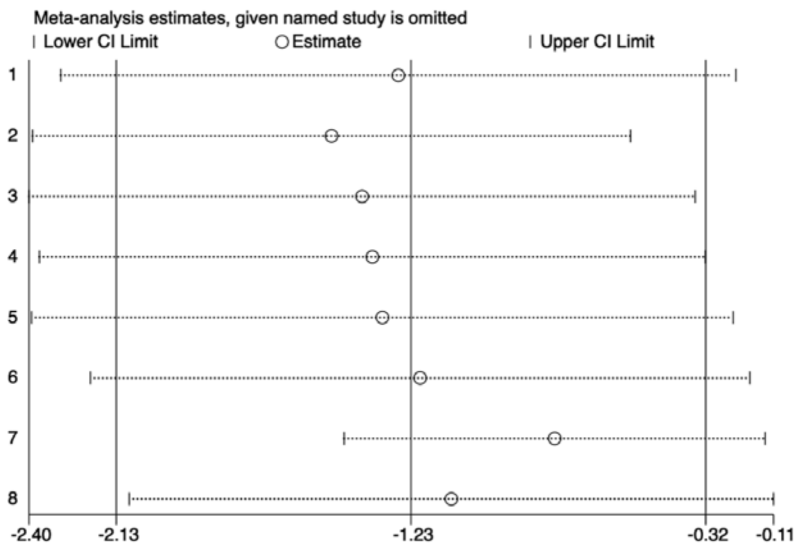

Figure S6. Sensitivity analysis of the effect of plyometric training on linear sprint speed in female adolescent team sport athletes.

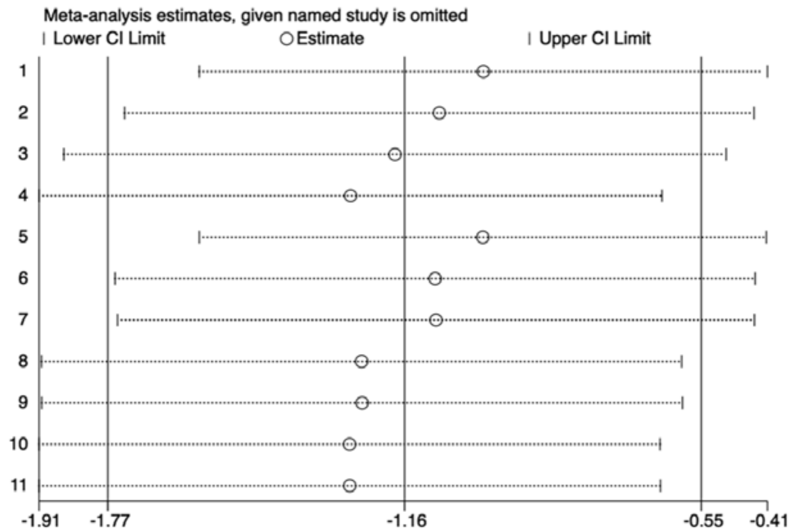

Figure S7. **Sensitivity analysis of the effect of strength training on change-of-direction speed in female adolescent team sport athletes.**

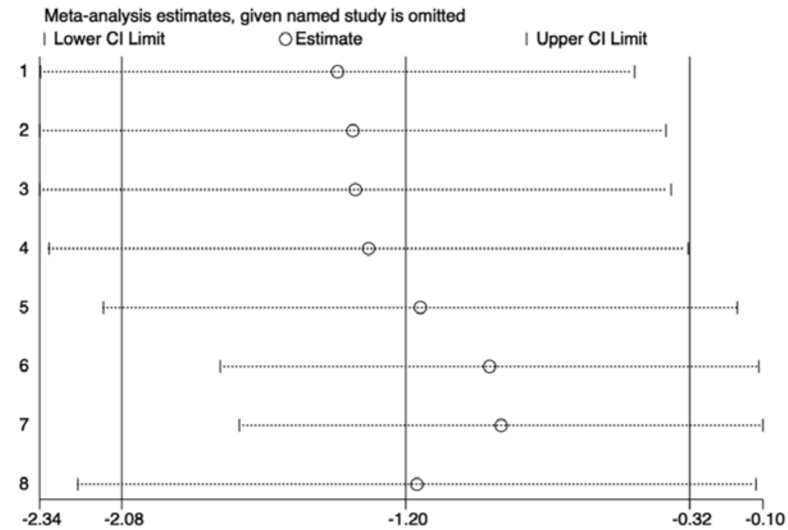

Figure S8. **Sensitivity analysis of the effect of plyometric training on change-of-direction speed in female adolescent team sport athletes**

Supplementary Material 3. Subgroup analyses.

1. VJ
1.1 PT
1.1.1 Training duration
Significant subgroup differences were found in VJ performance between PT duration >9 weeks (ES: 1.36, 95% CI: 0.65, 2.07) and ≤9 weeks (ES: 0.51, 95% CI: 0.13, 0.89) **(*p*=0.039)**.

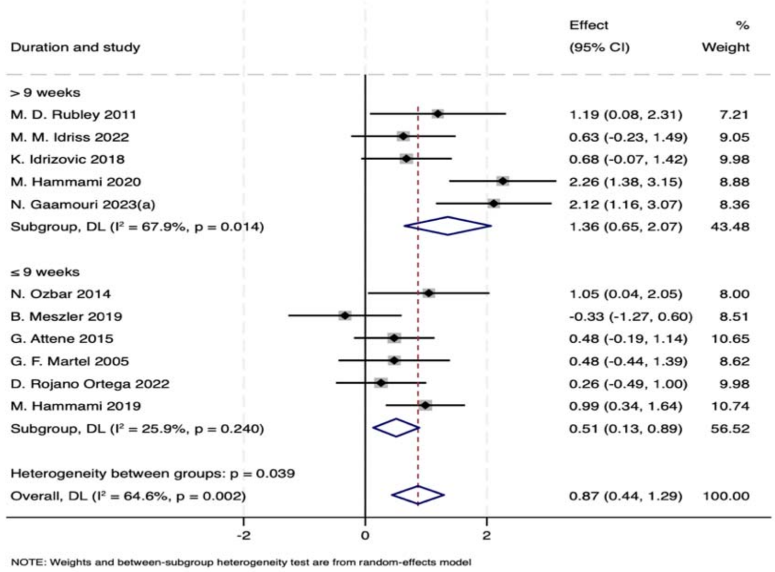

Figure 3.1 Forest plot of the effect of PT duration on VJ performance in female adolescent team sport athletes

1.1.2 Training frequency
No significant subgroup differences were found in VJ performance between PT frequency <2 sessions/week (ES: 1.11, 95% CI: 0.37, 1.86) and ≥2 sessions/week (ES: 0.83, 95% CI: 0.33, 1.32) (*p*=0.531).

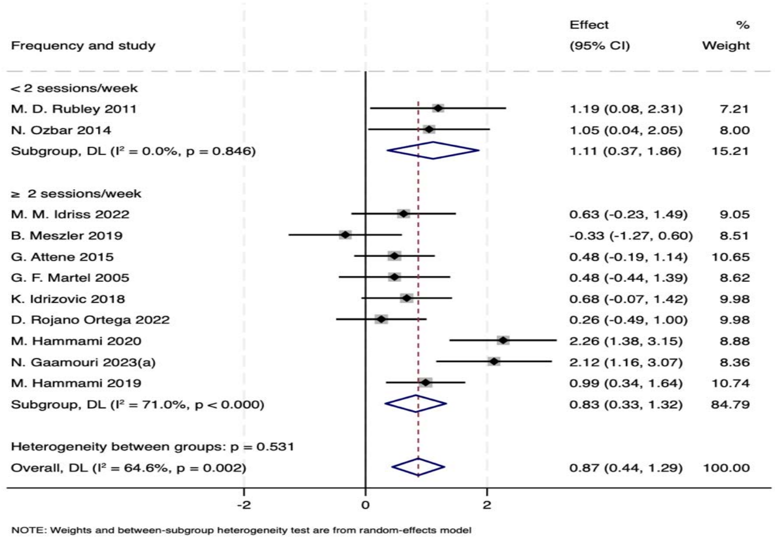

Figure 3.2 Forest plot of the effect of PT frequency on VJ performance in female adolescent team sport athletes

1.1.3 Total sessions

VJ performance exhibited significant subgroup differences between total PT sessions ≤14 sessions (ES: 0.46, 95% CI: 0.07, 0.85) and >14 sessions (ES: 1.30, 95% CI: 0.64, 1.95) **(*p*=0.031)**.

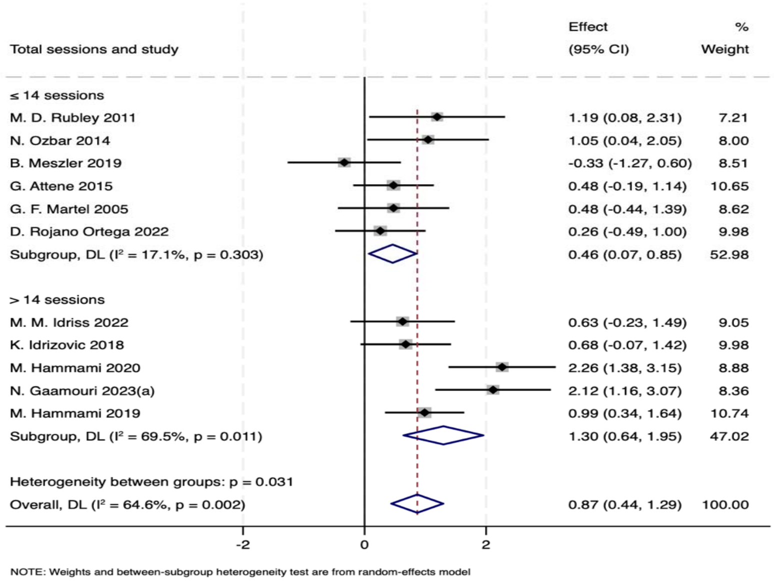

Figure 3.3 **Forest plot of the effect of total PT sessions on VJ performance in female adolescent team sport athletes**

1.1.4 Age

VJ performance exhibited no significant subgroup differences between PT participants aged <15 years (ES: 0.75, 95% CI: 0.36, 1.13) and >15 years (ES: 0.94, 95% CI: 0.26, 1.62) (*p*=0.629).

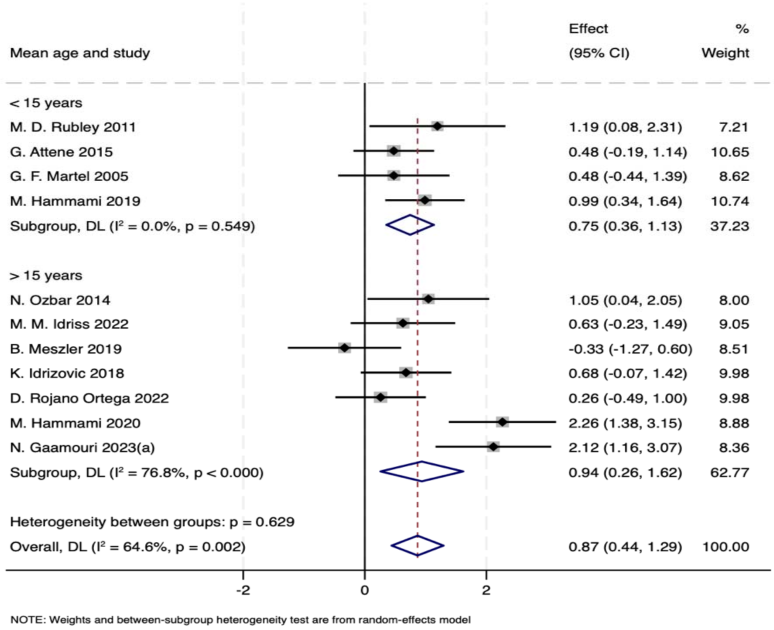

Figure 3.4 **Forest plot of the effect of PT participants' age on VJ performance in female adolescent team sport athletes**

1.1.5 Height

PT participants <163 cm (ES: 0.94, 95% CI: 0.51, 1.37) and ≥163 cm (ES: 0.83, 95% CI: 0.17, 1.49) had no significant subgroup differences in VJ performance (*p*=0.788).

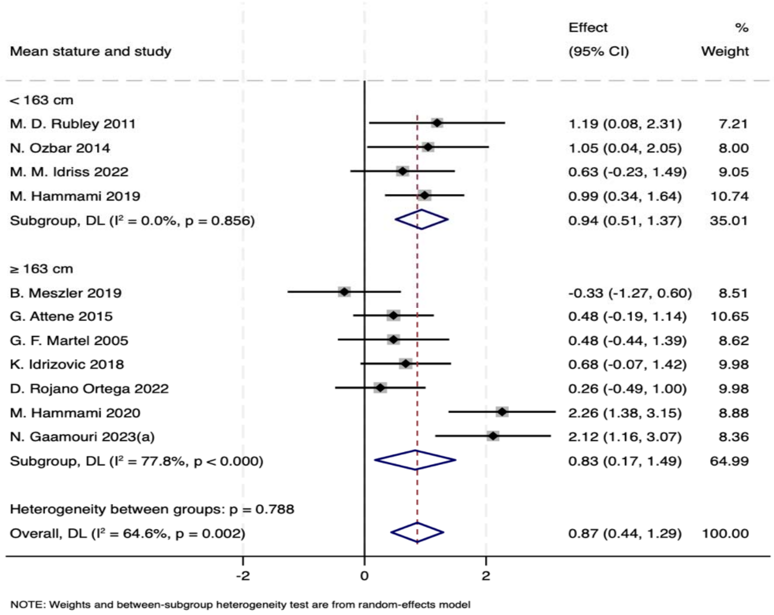

Figure 3.5 **Forest plot of the effect of PT participants' height on VJ performance in female adolescent team sport athletes**

1.1.6 Weight

PT participants <59 kg (ES: 0.80, 95% CI: 0.45, 1.16) and ≥59 kg (ES: 0.90, 95% CI: 0.10, 1.70) had no significant subgroup differences in VJ performance (*p*=0.829).

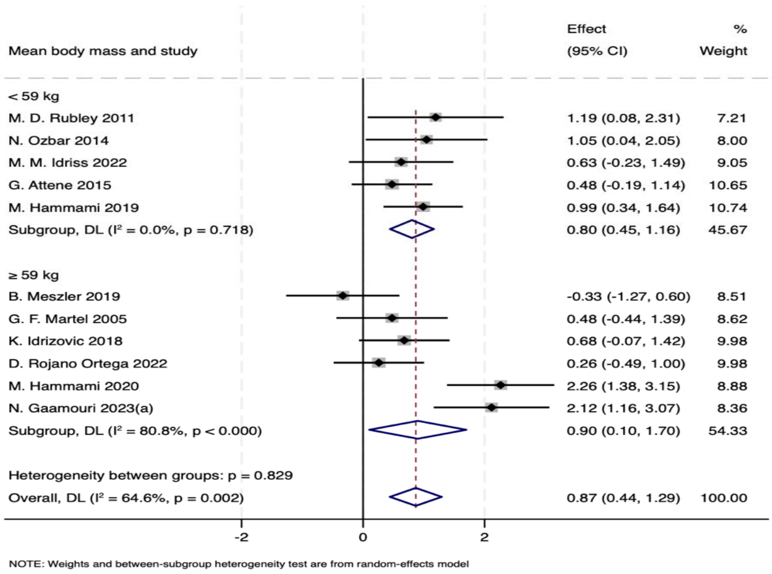

Figure 3.6 **Forest plot of the effect of PT participants' weight on VJ performance in female adolescent team sport athletes**

1.1.7 Type of sports

Following PT, handball players (ES: 1.74, 95% CI: 0.87, 2.61) had significant subgroup differences in VJ performance from football (ES: 0.90, 95% CI: 0.34, 1.47), basketball (ES: 0.14, 95% CI: -0.64, 0.92), and volleyball players (ES: 0.47, 95% CI: 0.01, 0.93) **(*p*=0.030)**.

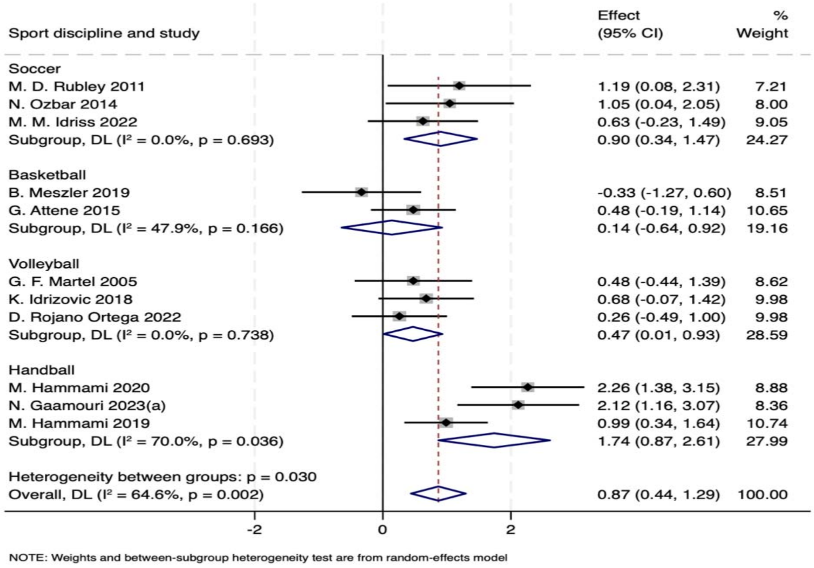

Figure 3.7 Forest plot of the effect of type of sports on VJ performance in female adolescent team sport athletes following PT

1.2 ST

1.2.1 Training duration

Significant subgroup differences were found in VJ performance between ST duration ≥10 weeks (ES: 1.20, 95% CI: 0.66, 1.73) and <10 weeks (ES: 0.03, 95% CI: -0.30, 0.37) **(*p*=0.000)**.

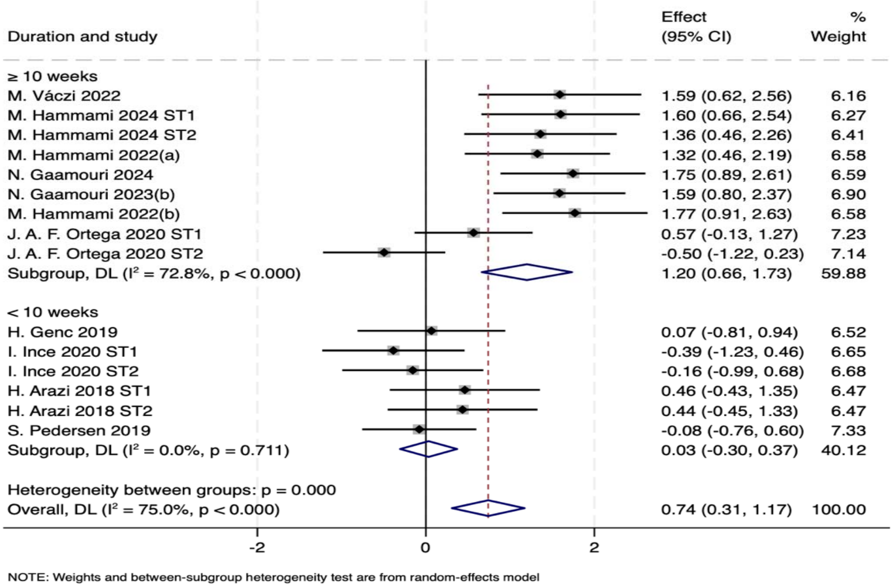

Figure 3.8 Forest plot of the effect of ST duration on VJ performance in female adolescent team sport athletes

1.2.2 Training frequency

Significant subgroup differences were found in VJ performance between ST frequency ≤2 sessions/week (ES: 1.02, 95% CI: 0.46, 1.58) and >2 sessions/week (ES: 0.19, 95% CI: -0.22, 0.60) **(p=0.020)**.

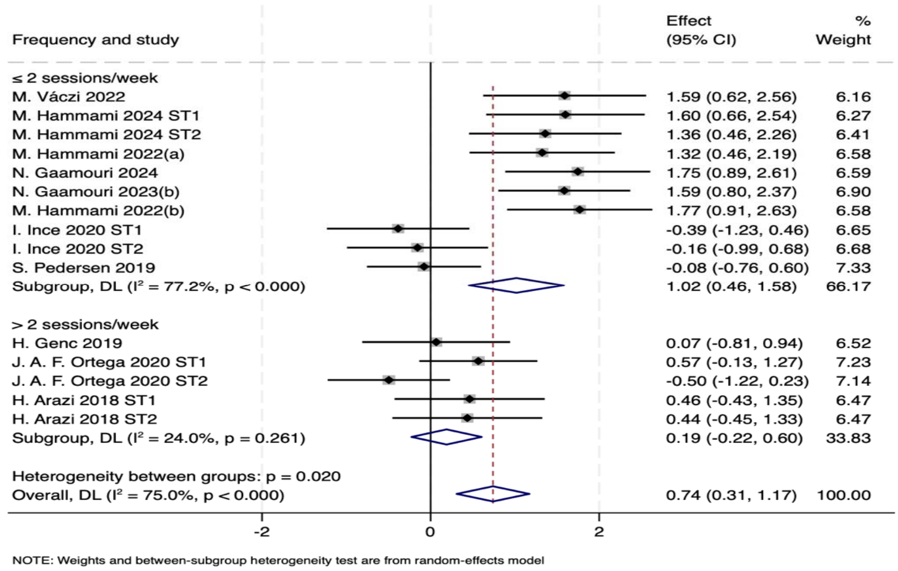

Figure 3.9 Forest plot of the effect of ST frequency on VJ performance in female adolescent team sport athletes

1.2.3 Total sessions

VJ performance exhibited significant subgroup differences between total ST sessions ≤20 sessions (ES: 1.02, 95% CI: 0.46, 1.58) and >20 sessions (ES: 0.19, 95% CI: -0.22, 0.60) **(p=0.020)**.

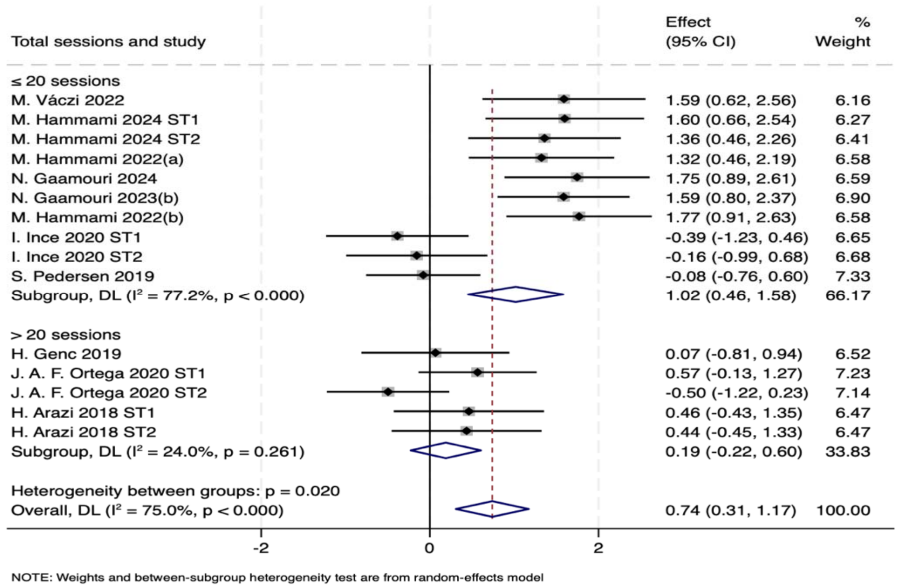

Figure 3.10 Forest plot of the effect of total ST sessions on VJ performance in female adolescent team sport athletes

1.2.4 Age

VJ performance exhibited no significant subgroup differences between ST participants aged <15 years (ES: 0.52, 95% CI: -0.59, 1.63) and >15 years (ES: 0.80, 95% CI: 0.32, 1.28) (p=0.646).

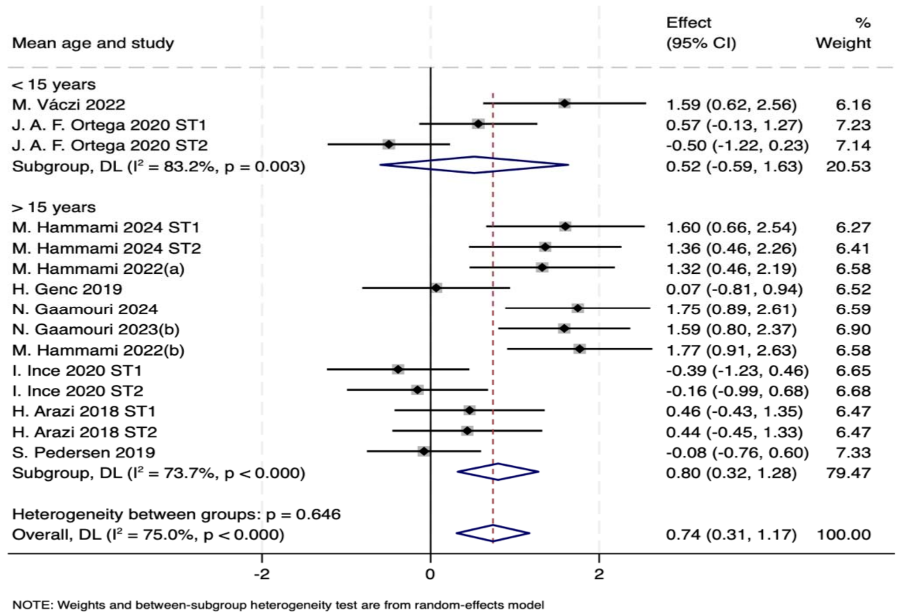

Figure 3.11 Forest plot of the effect of ST participants' age on VJ performance in female adolescent team sport athletes

1.2.5 Height

ST participants <163 cm (ES: 0.40, 95% CI: -0.24, 1.05) and ≥163 cm (ES: 0.91, 95% CI: 0.36, 1.46) had no significant subgroup differences in VJ performance (p=0.245).

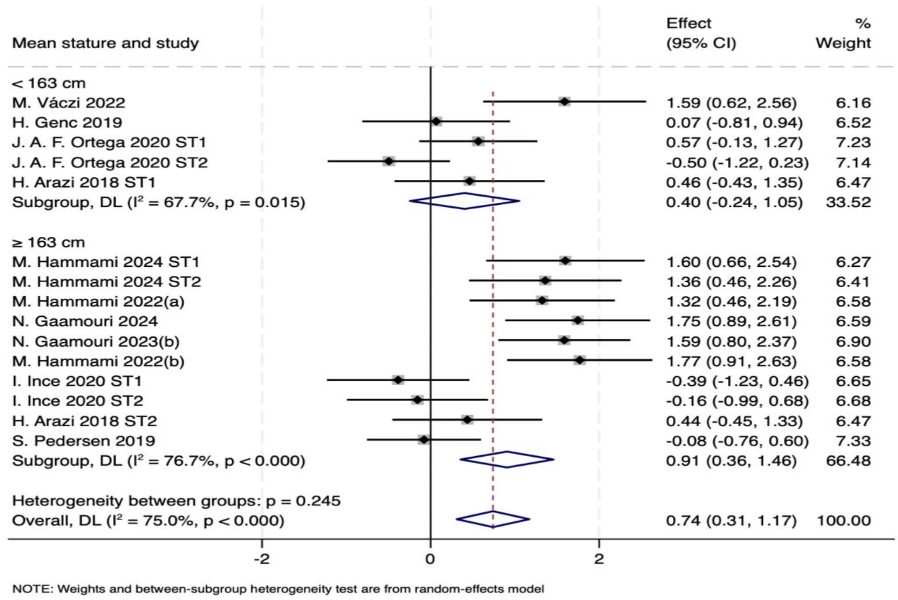

Figure 3.12 Forest plot of the effect of ST participants' height on VJ performance in female adolescent team sport athletes

1.2.6 Weight

ST participants <62 kg (ES: 0.23, 95% CI: -0.21, 0.67) and ≥62 kg (ES: 1.30, 95% CI: 0.74, 1.86) had significant subgroup differences in VJ performance **(*p*=0.003)**.

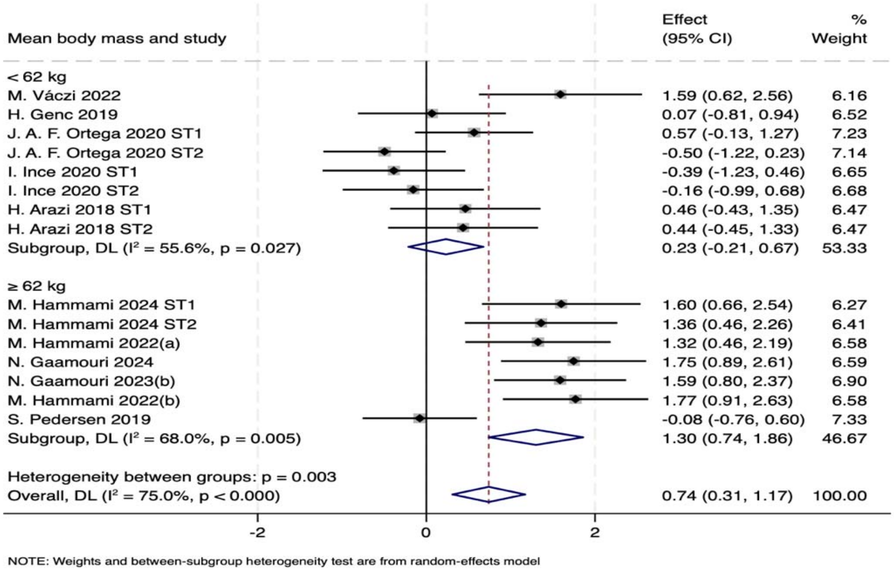

Figure 3.13 Forest plot of the effect of ST participants' weight on VJ performance in female adolescent team sport athletes

1.2.7 Type of sports

Following ST, handball players (ES: 1.38, 95% CI: 0.99, 1.77) had significant subgroup differences in VJ performance from football (ES: 0.00, 95% CI: -0.59, 0.60) and volleyball players (ES: 0.07, 95% CI: -0.36, 0.50) **(*p*=0.000)**.

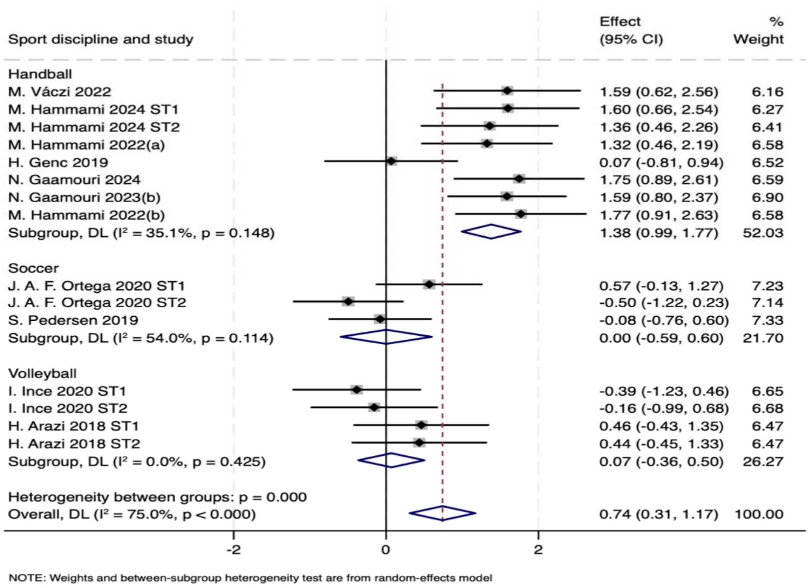

Figure 3.14 Forest plot of the effect of type of sports on VJ performance in female adolescent team sport athletes following ST

2 LS speed
2.1 PT
2.1.1 Training duration
Significant subgroup differences were found in LS speed between PT duration <9 weeks (ES: -0.28, 95% CI: -0.88, 0.32) and ≥9 weeks (ES: -2.20, 95% CI: -3.63, -0.76) **(*p*=0.016)**.

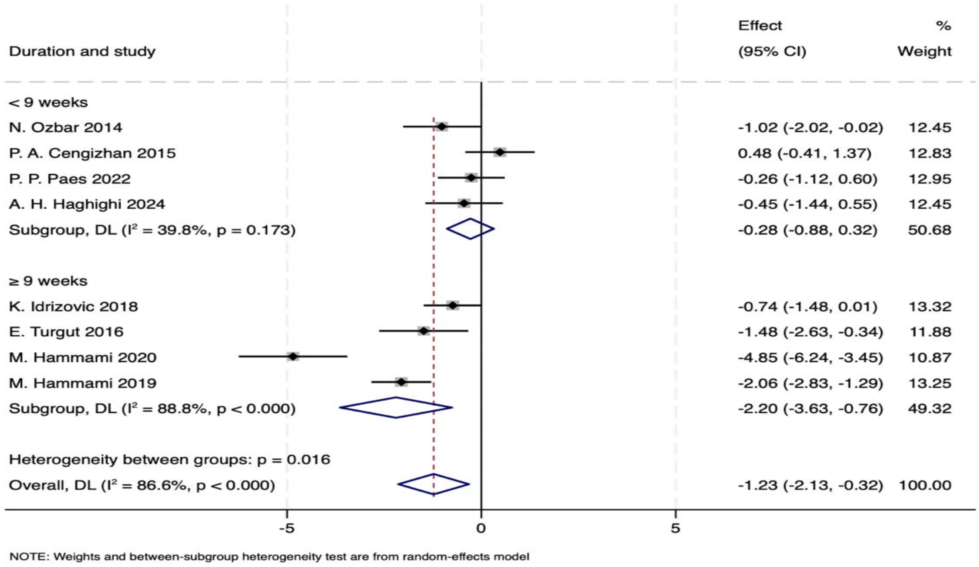

Figure 3.15 Forest plot of the effect of PT duration on LS speed in female adolescent team sport athletes

2.1.2 Training frequency
No significant subgroup differences were found in LS speed between PT frequency ≤2 sessions/week (ES: -1.48, 95% CI: -2.54, -0.42) and >2 sessions/week (ES: -0.47, 95% CI: -2.39, 1.45) (*p*=0.365).

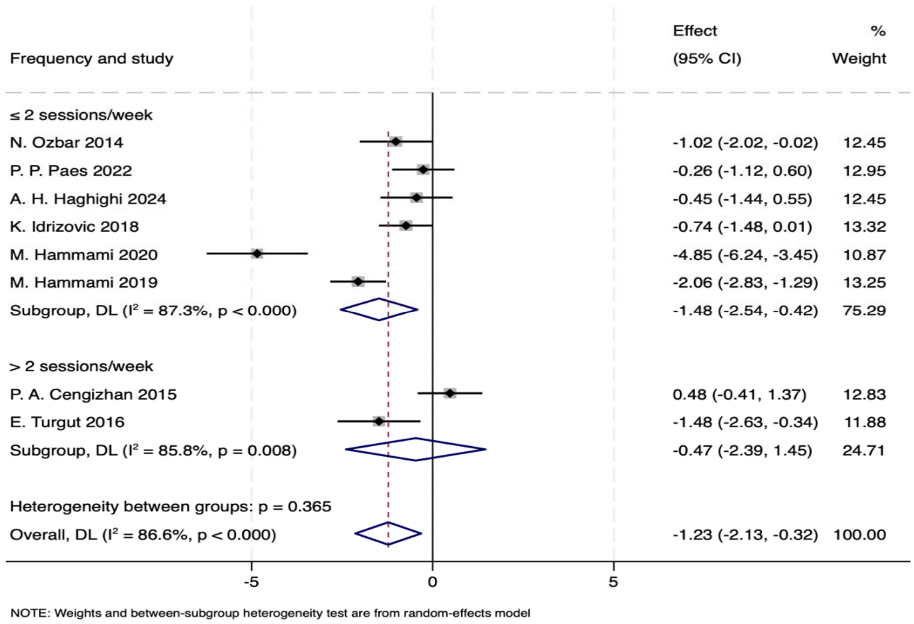

Figure 3.16 Forest plot of the effect of PT frequency on LS speed in female adolescent team sport athletes

2.1.3 Total sessions

LS speed exhibited no significant subgroup differences between total PT sessions <18 sessions (ES: -0.54, 95% CI: -1.09, 0.00) and ≥18 sessions (ES: -1.66, 95% CI: -3.09, -0.24) (p=0.151).

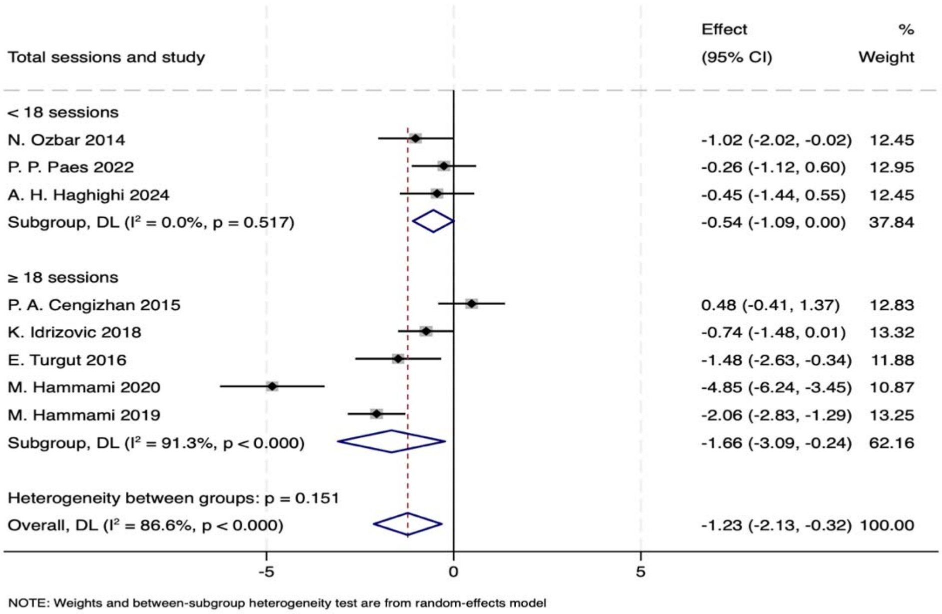

Figure 3.17 Forest plot of the effect of total PT sessions on LS speed in female adolescent team sport athletes

2.1.4 Age

LS speed exhibited no significant subgroup differences between PT participants aged >15 years (ES: -2.13, 95% CI: -4.28, 0.03) and <15 years (ES: -0.75, 95% CI: -1.71, 0.20) (p=0.253).

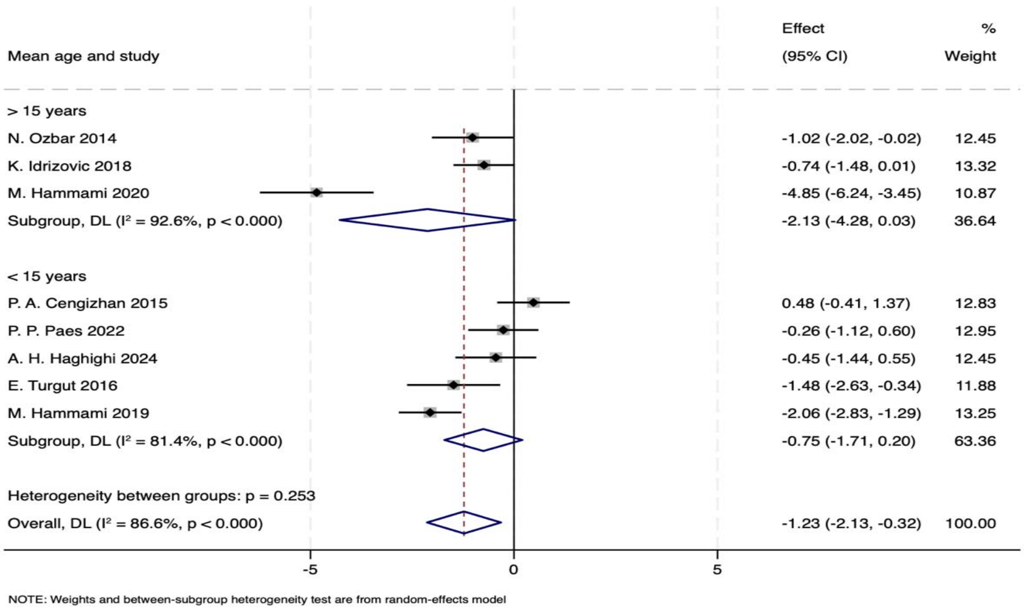

Figure 3.18 Forest plot of the effect of PT participants' age on LS speed in female adolescent team sport athletes

2.1.5 Height

PT participants <163 cm (ES: -0.72, 95% CI: -1.85, 0.40) and ≥163 cm (ES: -1.80, 95% CI: -3.44, -0.17) had no significant subgroup differences in LS speed (*p*=0.286).

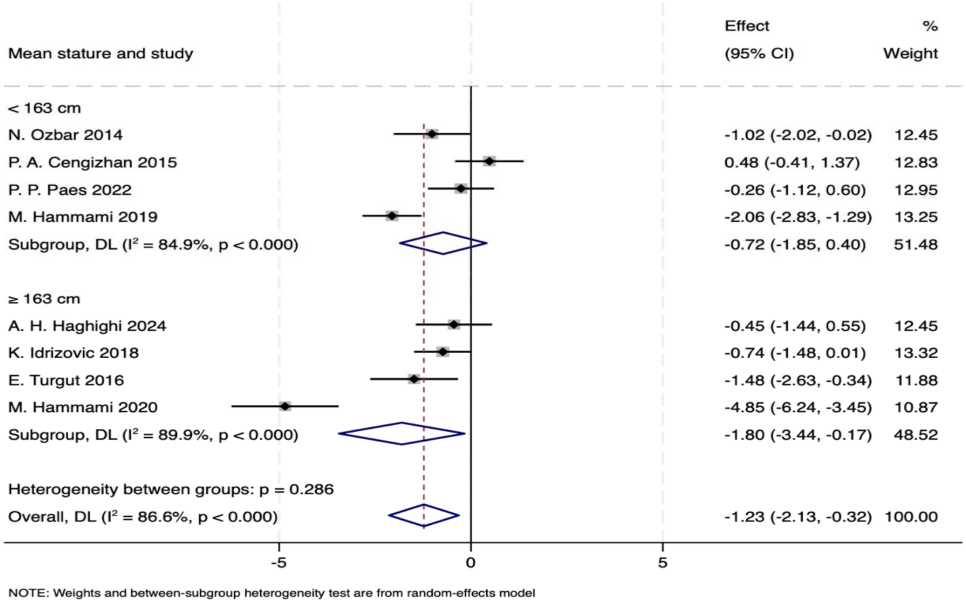

Figure 3.19 **Forest plot of the effect of PT participants' height on LS speed in female adolescent team sport athletes**

2.1.6 Weight

PT participants <57 kg (ES: -1.21, 95% CI: -2.05, -0.37) and ≥57 kg (ES: -1.31, 95% CI: -3.09, 0.47) had no significant subgroup differences in LS speed (*p*=0.919).

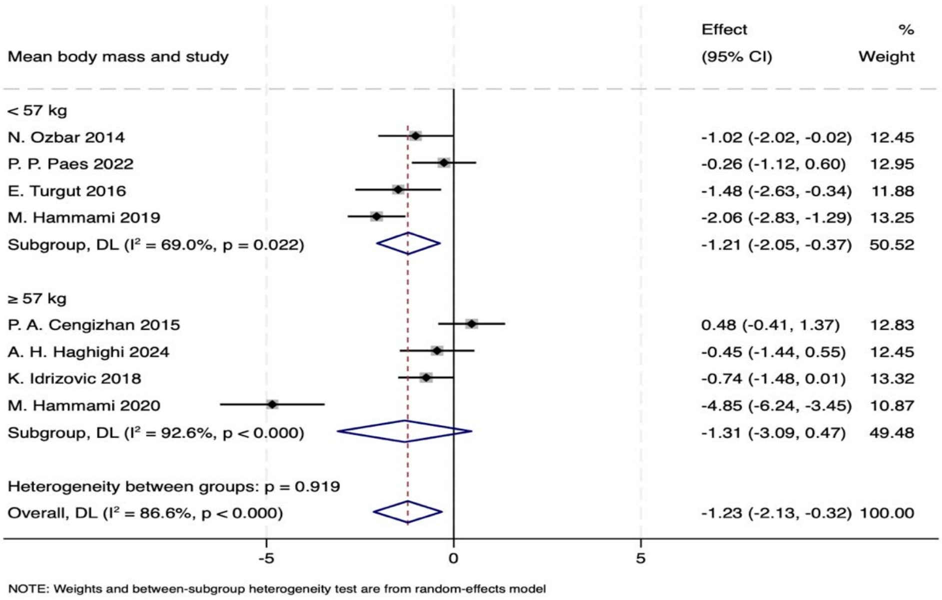

Figure 3.20 **Forest plot of the effect of PT participants' weight on LS speed in female adolescent team sport athletes**

2.1.7 Type of sports

Following PT, handball players (ES: -3.39, 95% CI: -6.12, -0.66) had significant subgroup differences in LS speed from football (ES: -1.02, 95% CI: -2.02, -0.02), basketball (ES: -0.06, 95% CI: -0.61, 0.49), and volleyball players (ES: -0.98, 95% CI: -1.67, -0.29) (***p*=0.022**).

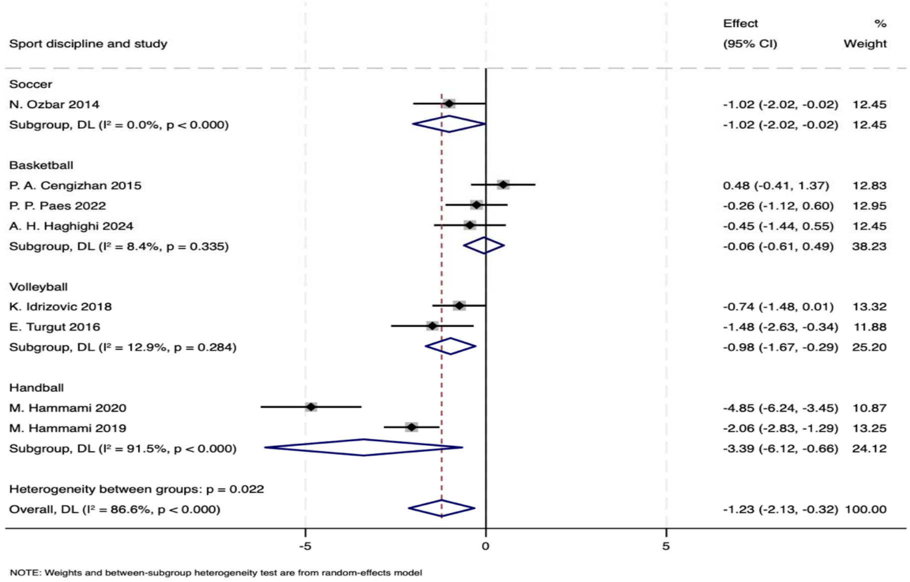

Figure 3.21 Forest plot of the effect of type of sports on LS speed in female adolescent team sport athletes following PT

2.2 ST

2.2.1 Training duration

Significant subgroup differences were found in LS speed between ST duration ≥10 weeks (ES: -2.31, 95% CI: -4.04, -0.58) and <10 weeks (ES: -0.34, 95% CI: -0.71, 0.04) (***p*=0.029**).

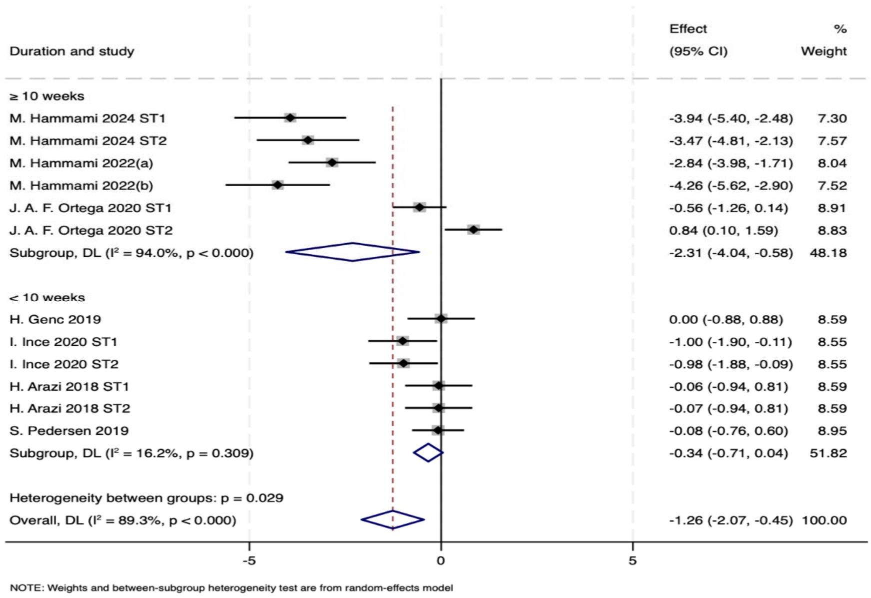

Figure 3.22 Forest plot of the effect of ST duration on LS speed in female adolescent team sport athletes

2.2.2 Training frequency

Significant subgroup differences were found in LS speed between ST frequency ≤2 sessions/week (ES: -2.29, 95% CI: -3.52, -1.05) and >2 sessions/week (ES: 0.03, 95% CI: -0.46, 0.52) **(*p*=0.001)**.

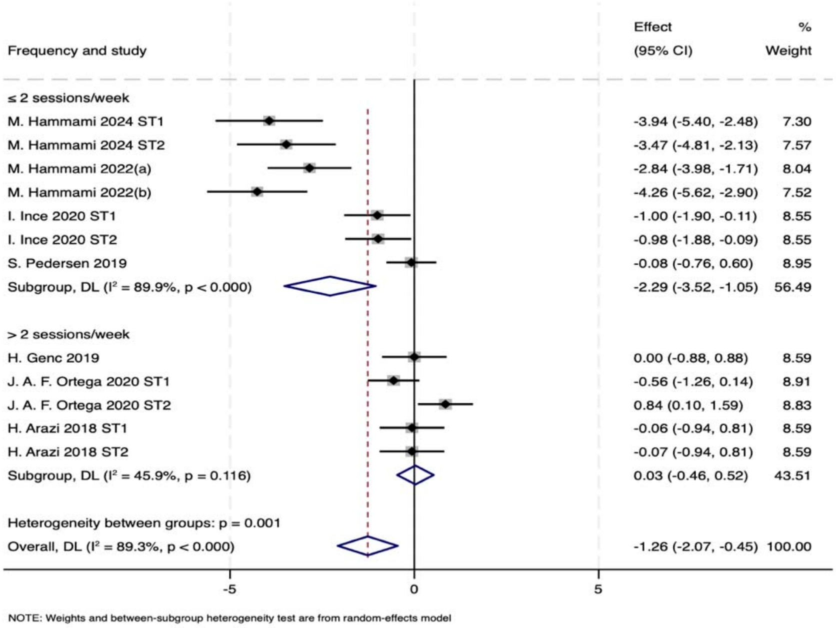

Figure 3.23 Forest plot of the effect of ST frequency on LS speed in female adolescent team sport athletes

2.2.3 Total sessions

LS speed exhibited significant subgroup differences between total ST sessions ≤20 sessions (ES: -2.29, 95% CI: -3.52, -1.05) and >20 sessions (ES: 0.03, 95% CI: -0.46, 0.52) **(*p*=0.001)**.

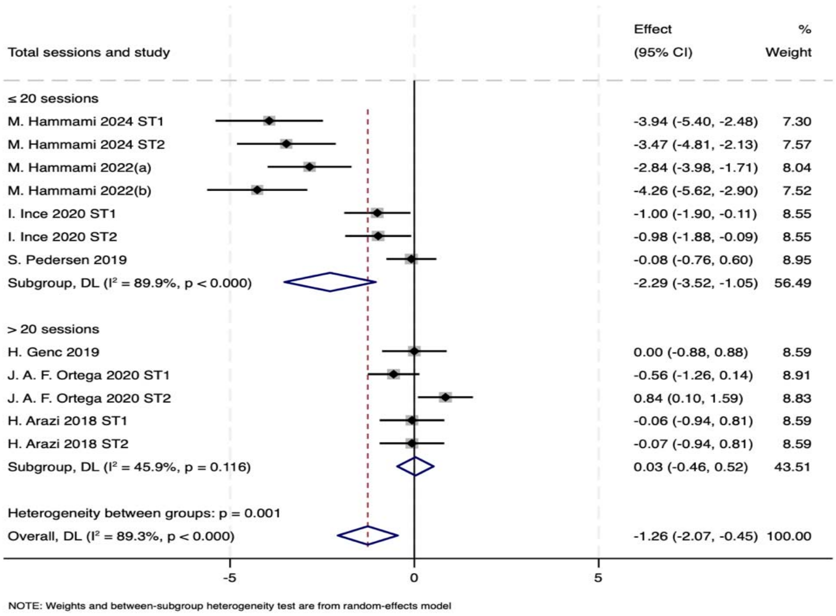

Figure 3.24 Forest plot of the effect of total ST sessions on LS speed in female adolescent team sport athletes

2.2.4 Age

LS speed exhibited significant subgroup differences between ST participants aged >15 years (ES: -1.57, 95% CI: -2.51, -0.64) and <15 years (ES: 0.13, 95% CI: -1.24, 1.51) (***p*=0.044**).

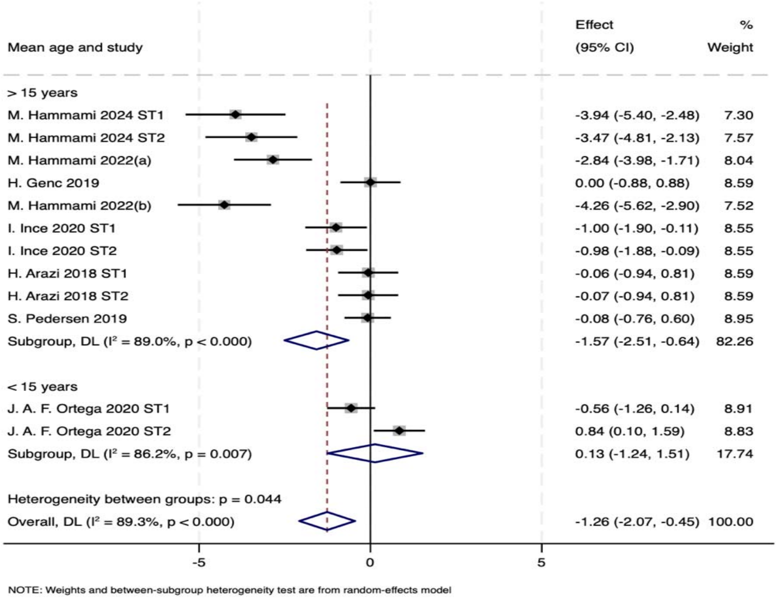

Figure 3.25 **Forest plot of the effect of ST participants' age on LS speed in female adolescent team sport athletes**

2.2.5 Height

ST participants ≥163 cm (ES: -1.99, 95% CI: -3.11, -0.87) and <163 cm (ES: 0.05, 95% CI: -0.57, 0.67) had significant subgroup differences in LS speed (***p*=0.002**).

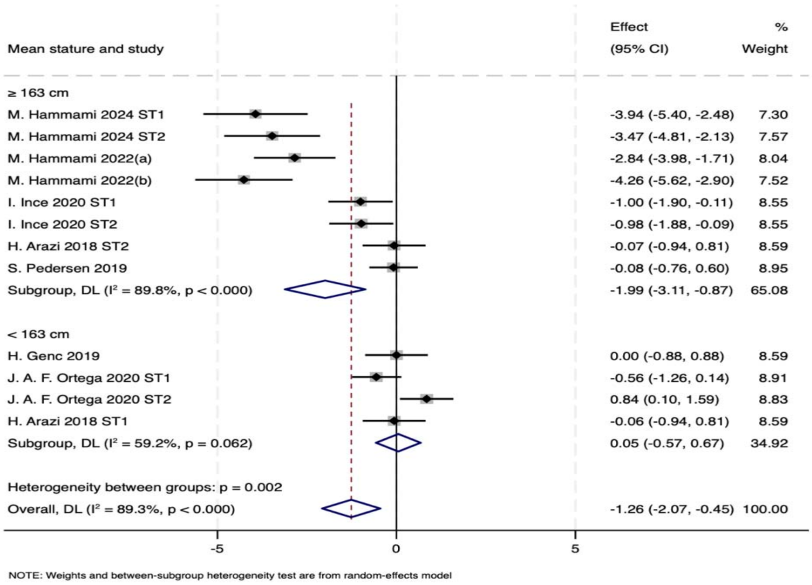

Figure 3.26 **Forest plot of the effect of ST participants' height on LS speed in female adolescent team sport athletes**

2.2.6 Weight

ST participants ≥62 kg (ES: -2.87, 95% CI: -4.74, -1.00) and <62 kg (ES: -0.25, 95% CI: -0.74, 0.25) had significant subgroup differences in LS speed **(*p*=0.008)**.

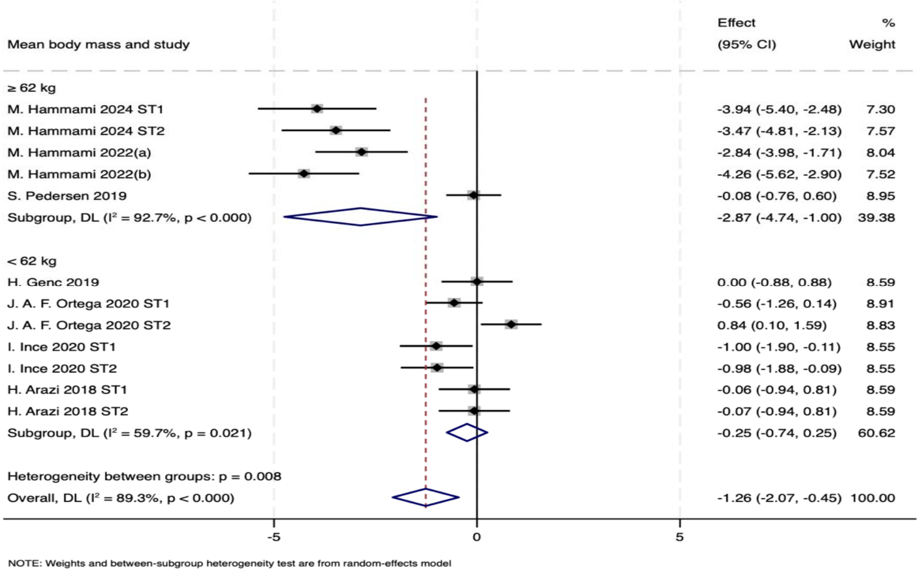

Figure 3.27 Forest plot of the effect of ST participants' weight on LS speed in female adolescent team sport athletes

2.2.7 Type of sports

Following ST, handball players (ES: -2.86, 95% CI: -4.62, -1.09) had significant subgroup differences in LS speed from football (ES: 0.06, 95% CI: -0.73, 0.84) and volleyball players (ES: -0.52, 95% CI: -1.05, 0.00) **(*p*=0.012)**.

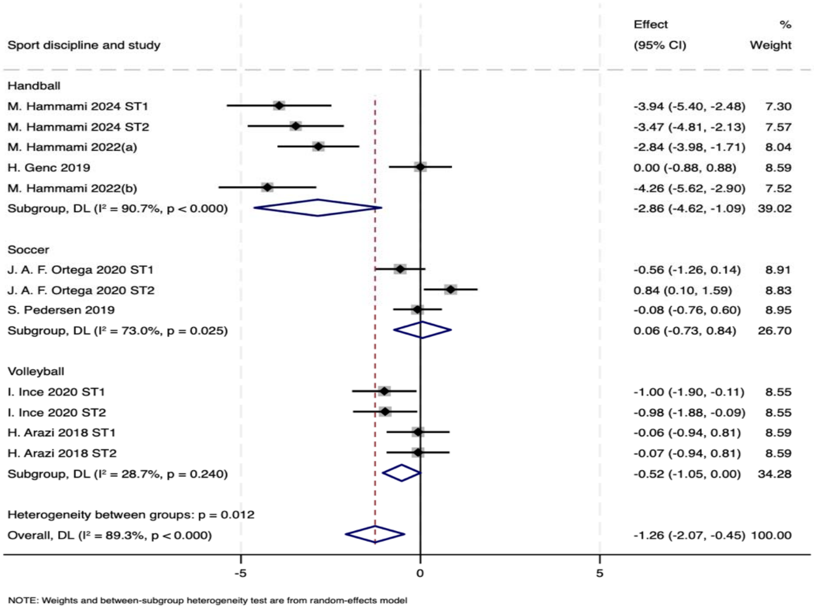

Figure 3.28 Forest plot of the effect of type of sports on LS speed in female adolescent team sport athletes following ST

3 COD speed
3.1 PT
3.1.1 Training duration
Significant subgroup differences were found in COD speed between PT duration <9 weeks (ES: -0.10, 95% CI: -0.56, 0.35) and ≥9 weeks (ES: -2.32, 95% CI: -3.30, -1.34) **(*p*=0.000)**.

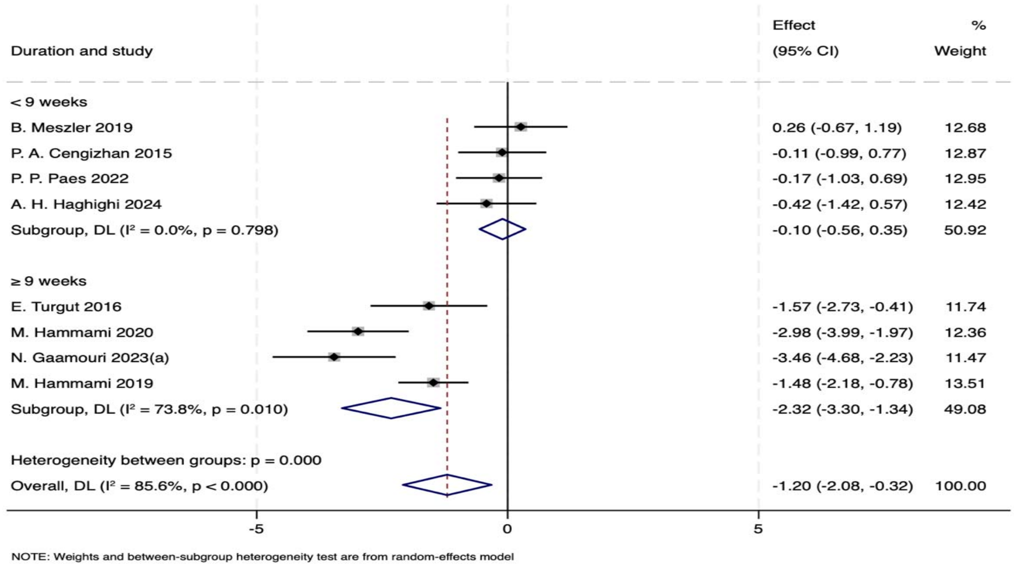

Figure 3.29 Forest plot of the effect of PT duration on COD speed in female adolescent team sport athletes

3.1.2 Training frequency
No significant subgroup differences were found in COD speed between PT frequency ≤2 sessions/week (ES: -1.34, 95% CI: -2.45, -0.23) and >2 sessions/week (ES: -0.79, 95% CI: -2.21, 0.64) (*p*=0.548).

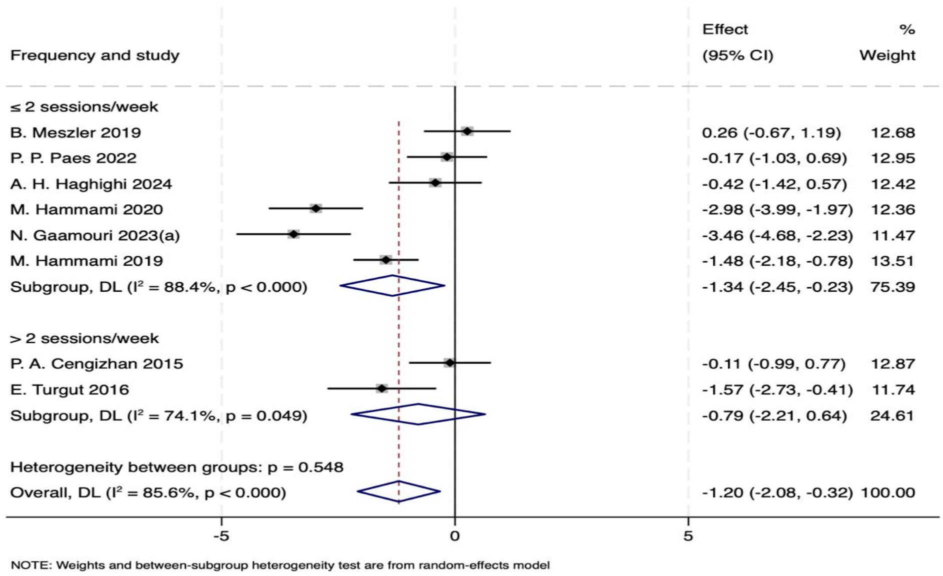

Figure 3.30 Forest plot of the effect of PT frequency on COD speed in female adolescent team sport athletes

3.1.3 Total sessions

COD speed exhibited significant subgroup differences between total PT sessions <18 sessions (ES: -0.10, 95% CI: -0.63, 0.43) and ≥18 sessions (ES: -1.88, 95% CI: -3.00, -0.75) (***p*=0.005**).

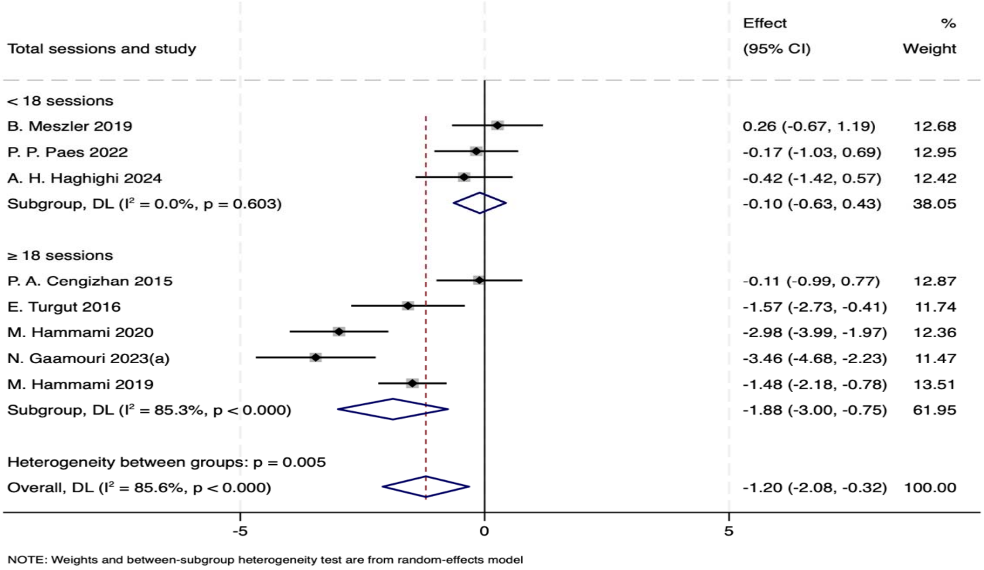

Figure 3.31 Forest plot of the effect of total PT sessions on COD speed in female adolescent team sport athletes

3.1.4 Age

COD speed exhibited no significant subgroup differences between PT participants aged >15 years (ES: -2.04, 95% CI: -4.43, 0.35) and <15 years (ES: -0.74, 95% CI: -1.39, -0.10) (*p*=0.304).

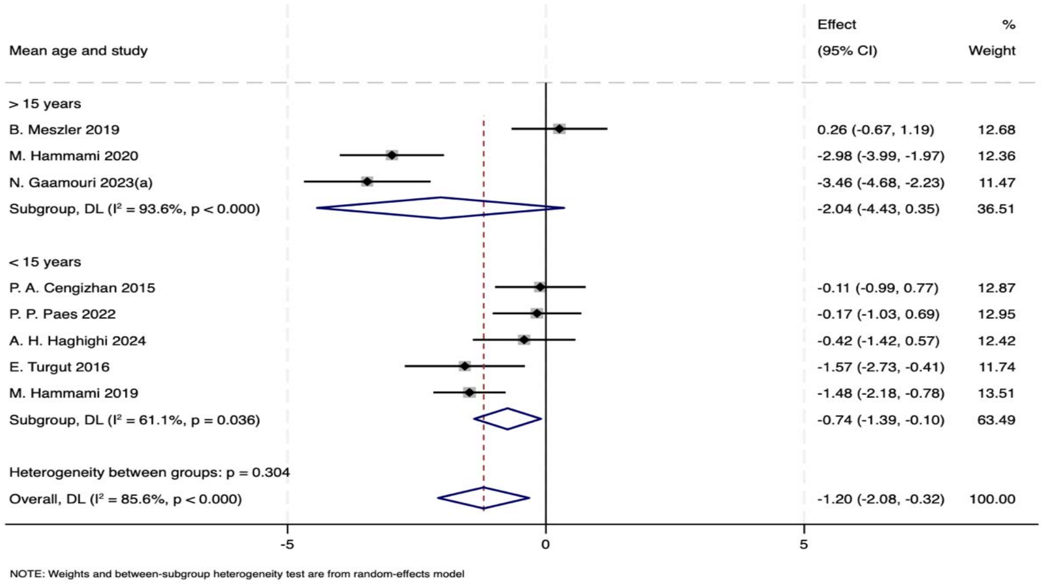

Figure 3.32 Forest plot of the effect of PT participants' age on COD speed in female adolescent team sport athletes

3.1.5 Height

PT participants ≥163 cm (ES: -1.61, 95% CI: -3.03, -0.19) and <163 cm (ES: -0.62, 95% CI: -1.55, 0.31) had no significant subgroup differences in COD speed (p=0.253).

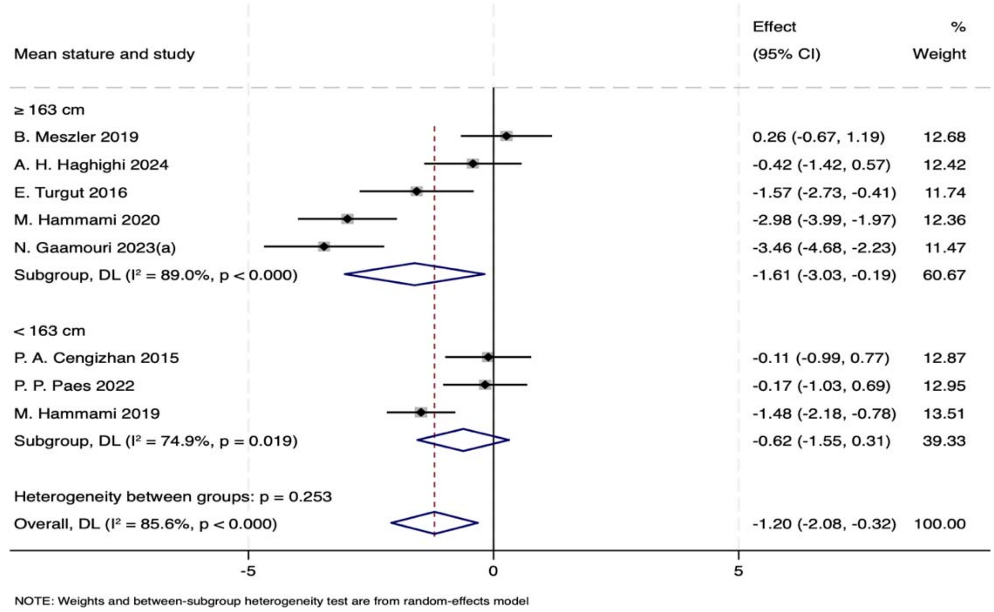

Figure 3.33 Forest plot of the effect of PT participants' height on COD speed in female adolescent team sport athletes

3.1.6 Weight

PT participants ≥59 kg (ES: -1.63, 95% CI: -3.42, 0.17) and <59 kg (ES: -0.82, 95% CI: -1.61, -0.02) had no significant subgroup differences in COD speed (p=0.418).

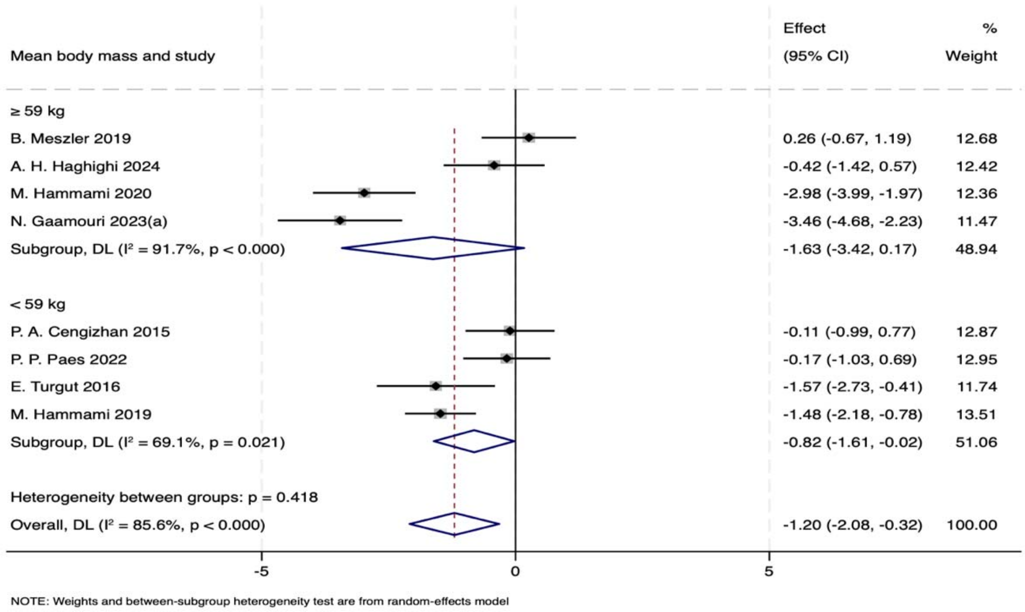

Figure 3.34 Forest plot of the effect of PT participants' weight on COD speed in female adolescent team sport athletes

3.1.7 Type of sports

Following PT, handball players (ES: -2.57, 95% CI: -3.84, -1.30) had significant subgroup differences in COD speed from basketball (ES: -0.10, 95% CI: -0.56, 0.35) and volleyball players (ES: -1.57, 95% CI: -2.73, -0.41) **(*p*=0.000)**.

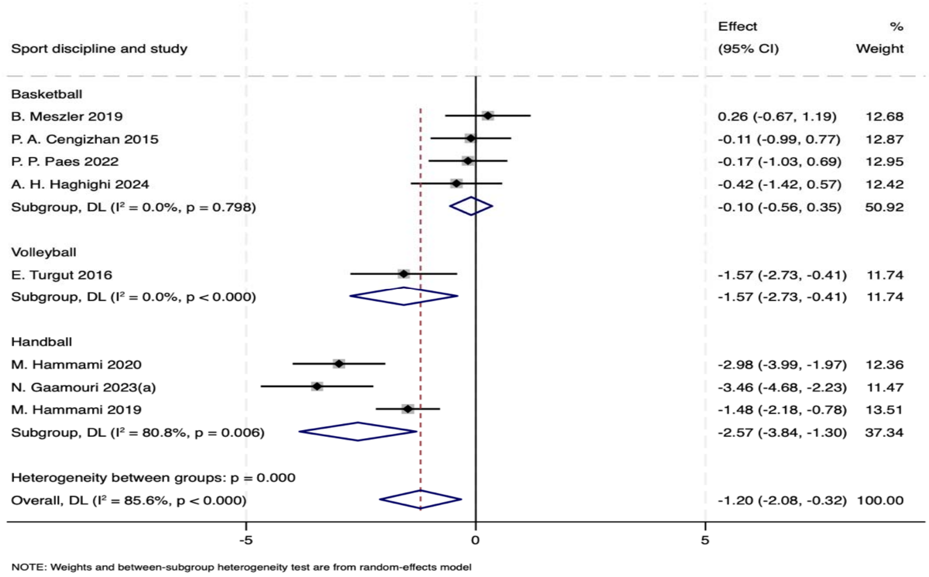

Figure 3.35 **Forest plot of the effect of type of sports on COD speed in female adolescent team sport athletes following PT**

3.2 ST

3.2.1 Training duration

Significant subgroup differences were found in COD speed between ST duration ≥10 weeks (ES: -1.98, 95% CI: -2.55, -1.41) and <10 weeks (ES: -0.17, 95% CI: -0.55, 0.22) **(*p*=0.000)**.

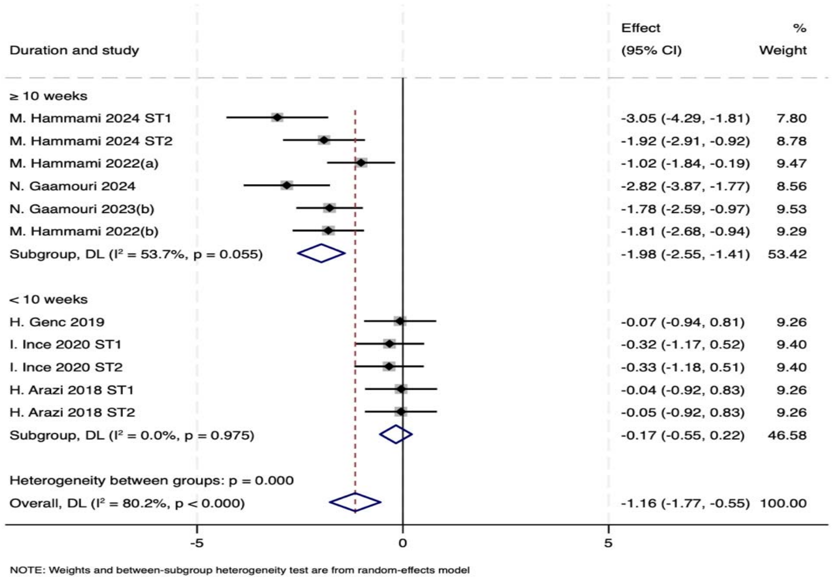

Figure 3.36 **Forest plot of the effect of ST duration on COD speed in female adolescent team sport athletes**

3.2.2 Training frequency

Significant subgroup differences were found in COD speed between ST frequency ≤2 sessions/week (ES: -1.58, 95% CI: -2.24, -0.91) and >2 sessions/week (ES: -0.05, 95% CI: -0.56, 0.45) **(*p*=0.000)**.

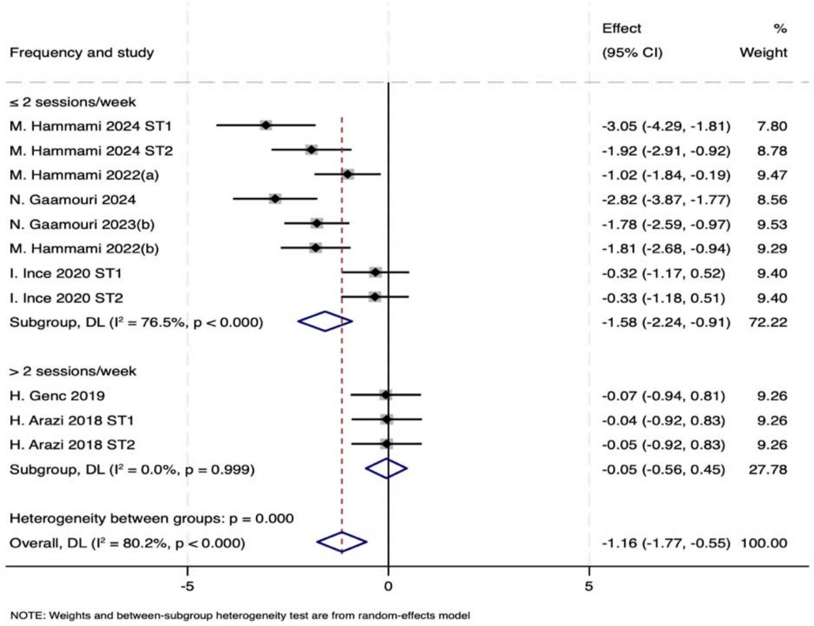

Figure 3.37 Forest plot of the effect of ST frequency on COD speed in female adolescent team sport athletes

3.2.3 Total sessions

COD speed exhibited significant subgroup differences between total ST sessions ≤20 sessions (ES: -1.58, 95% CI: -2.24, -0.91) and >20 sessions (ES: -0.05, 95% CI: -0.56, 0.45) **(*p*=0.000)**.

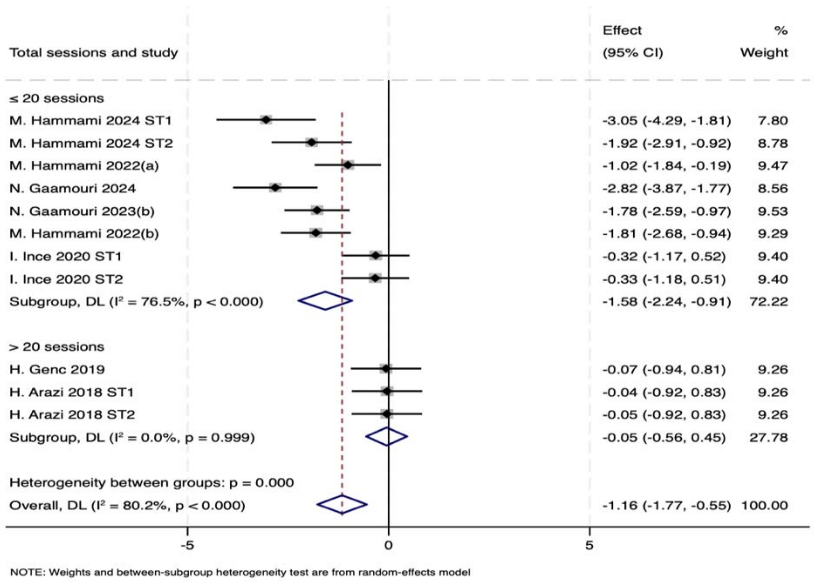

Figure 3.38 Forest plot of the effect of total ST sessions on COD speed in female adolescent team sport athletes

3.2.4 Age (>15 years, no grouping)

3.2.5 Height

ST participants ≥163 cm (ES: -1.41, 95% CI: -2.07, -0.74) and <163 cm (ES: -0.05, 95% CI: -0.67, 0.57) had significant subgroup differences in COD speed **(*p*=0.004)**.

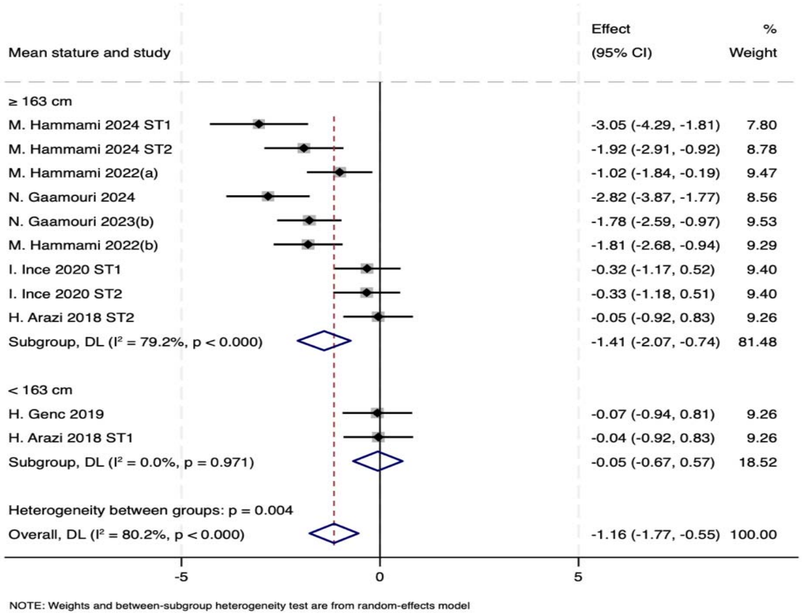

Figure 3.39 **Forest plot of the effect of ST participants' height on COD speed in female adolescent team sport athletes**

3.2.6 Weight

ST participants ≥63 kg (ES: -1.98, 95% CI: -2.55, -1.41) and <63 kg (ES: -0.17, 95% CI: -0.55, 0.22) had significant subgroup differences in COD speed **(*p*=0.000)**.

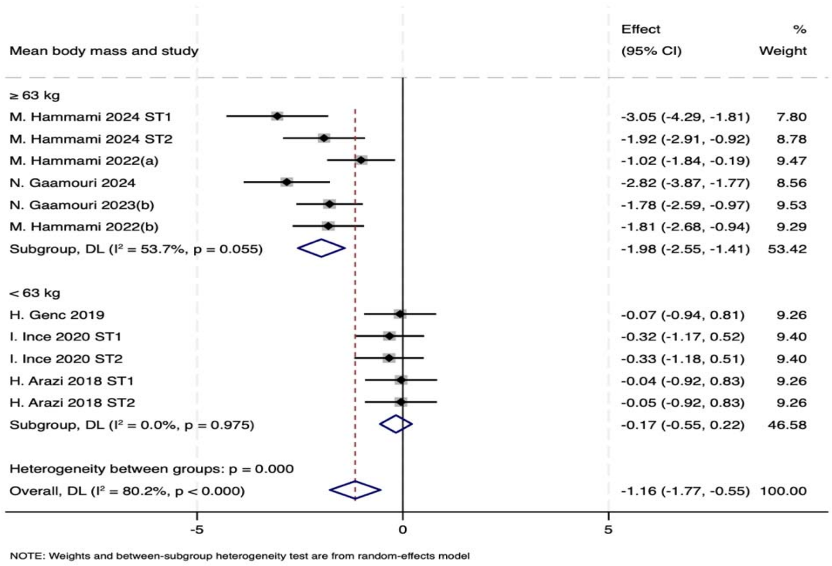

Figure 3.40 **Forest plot of the effect of ST participants' weight on COD speed in female adolescent team sport athletes**

3.2.7 Type of sports

Following ST, handball players (ES: -1.73, 95% CI: -2.45, -1.01) had significant subgroup differences in COD speed from volleyball players (ES: -0.19, 95% CI: -0.62, 0.24) (***p*=0.000**).

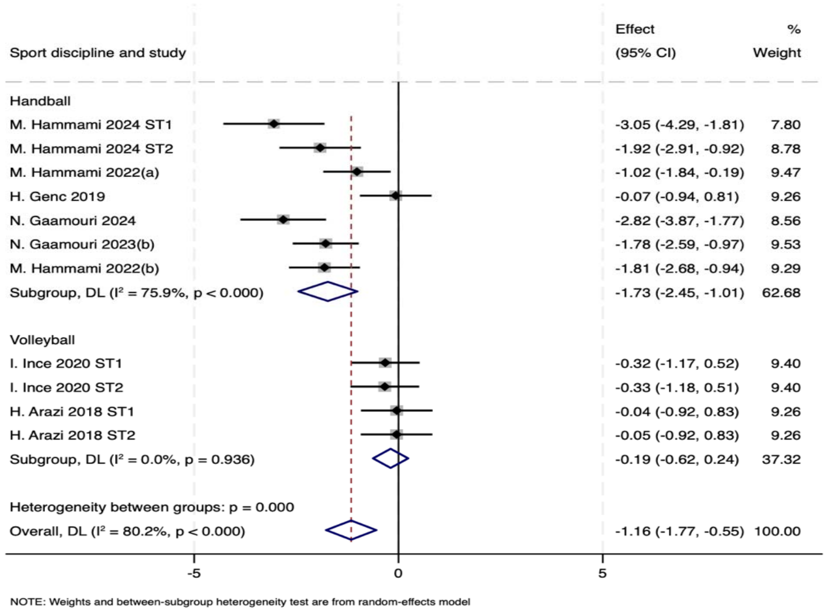

Figure 3.41 Forest plot of the effect of type of sports on COD speed in female adolescent team sport athletes following ST