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Review article

Effects of Plyometric Training on Physical Fitness Attributes in Handball Players: A Systematic Review and Meta-Analysis

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Abstract

This meta-analysis aimed to examine the effects of plyometric training on physical fitness attributes in handball players. A systematic literature search across PubMed, SCOPUS, SPORTDiscus, and Web of Science identified 20 studies with 563 players. Plyometric training showed significant medium-to-large effects on various attributes: countermovement jump with arms (ES = 1.84), countermovement jump (ES = 1.33), squat jump (ES = 1.17), and horizontal jump (ES = 0.83), ≤ 10-m linear sprint time (ES = -1.12), > 10-m linear sprint time (ES = -1.46), repeated sprint ability with change-of-direction time (ES = -1.53), agility (ES = -1.60), maximal strength (ES = 0.52), and force–velocity (muscle power) (ES = 1.13). No significant impact on balance was found. Subgroup analysis indicated more pronounced agility improvements in players ≤ 66.6 kg compared to > 66.6 kg (ES = -1.93 vs. -0.23, p = 0.014). Additionally, greater improvements were observed in linear sprint and repeat sprint ability when comparing training durations of > 8 weeks with those ≤ 8 weeks (ES = -2.30 to -2.89 vs. ES = -0.92 to -0.97). In conclusion, plyometric training effectively improves various physical fitness attributes, including jump performance, linear sprint ability, maximal strength, muscle power and agility.

Key words: Plyometric training, jumping training, physical fitness, performance, handball.

Introduction

Handball is classified as an intermittent, high-intensity competitive sport (Chelly et al., 2011). During the fast-paced offence and defence of the game, athletes are required to effectively and repeatedly perform numerous high-threshold actions, such as acceleration, sprinting, jumping, changing direction, and engaging in vigorous physical contact (Luteberget and Spencer, 2017, Ferrari et al., 2019, Pereira et al., 2018). These decisive actions demand athletes' high levels of power and strength, as well as agility and balance (Bayios et al., 2001, Ortega-Becerra et al., 2018). Therefore, it is very important to develop effective training methods aimed at improving these physical fitness attributes of handball players to optimize their athletic performance.

Several training methods, such as traditional resistance training (Bragazzi et al., 2020), complex training (Chaabene et al., 2021b, Hammami et al., 2019a), and weightlifting training (Hermassi et al., 2019b, Hermassi et al., 2019a), have been proven effective in improving the physical fitness of handball players. However, the application of plyometric training methods seems to be particularly common (Wagner et al., 2014), and its effectiveness in improving the physical fitness of handball players appears to be equal to that of other training methods, such as strength training or eccentric-overload training (Falch et al., 2022; Saez de Villareal et al., 2023), or even more effective than traditional resistance training (Murugavel and Balaji, 2020). This is attributed to the fact that the plyometric training method utilizes the stretch-shortening cycle (SSC), wherein muscles are rapidly stretched before a rapid concentric contraction, aligning more closely with the actual movement patterns (e.g., sprint and jump) in competitive sports (Taube et al., 2012, Ramirez-Campillo et al., 2018). The SSC training pattern offers more benefits in comparison to non-SSC training patterns, which can result in a wide range of structural adaptations (e.g., fiber type composition and musculotendinous stiffness) and neuromuscular adaptations (e.g., motor unit recruitment, co-contraction, and reflex control) (Radnor et al., 2018, Taube et al., 2012). These adaptations can ultimately contribute to enhance physical fitness and improve athletic performance. Several reviews have confirmed the effectiveness of plyometric training in improving the physical fitness attributes of athletes from different disciplines, including basketball (Cherni et al., 2019; 2021; Ramirez-Campillo et al., 2022), soccer (Bedoya et al., 2015, Ramirez-Campillo et al., 2020), and volleyball (Markovic, 2007, Ramirez-Campillo et al., 2021). Meanwhile, there is a growing body of studies focusing on the effects of plyometric training on the physical fitness of handball players (Aloui et al., 2021, Chelly et al., 2014, Hammami et al., 2019c). However, there is a lack of a comprehensive summary of this study evidence.

To our knowledge, there is just one meta-analysis examining the effects of plyometric training on physical fitness in handball athletes (Ramirez-Campillo et al., 2020). However, the analysis solely focuses on the effects of plyometric training on countermovement jump performance, while other physical fitness attributes, such as linear sprint, agility, balance, and change-of-direction were neglected, and no moderator analysis (e.g, gender, age, and

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training factors) was conducted to detect the potential impact on the training effectiveness. Furthermore, only five studies (n = 129 participants) were included in the meta-analysis, which means that its findings are rather preliminary. Due to the lack of comprehensive analysis of the effects of plyometric training on the physical fitness attributes in handball players, the purpose of this meta-analysis was to examine the effects of plyometric training on various physical fitness attributes (i.e., jump performance, sprint performance, muscle strength, agility, and balance) in handball players and provide practical training recommendations for coaches and athletes.

Methods

Experimental approach to the problem

This systematic review was conducted following the guidelines for Systematic Reviews and Meta-analyses provided in the PRISMA statement (Page et al., 2021) (Prospero registration number: CRD42023468986).

Search strategy and study selection

Articles published by September 17, 2023, were located using the electronic databases PubMed, SCOPUS, SPORTDiscus, and Web of Science. The search strategy was conducted using the Boolean operators AND and OR in combination with the following keywords: "plyometric", "stretch-shortening cycle", "jump", "power", "explosive", "complex", "compound", "combined", "ballistic", "training", "intervention", "handball". The detailed search string is shown in Appendix A. After excluding duplicate articles, a review of retrieved article titles was conducted. Subsequently, an examination of article abstracts and full articles followed (Figure 1). Furthermore, examinations were also conducted on cited articles from the included studies, reference lists from prior review studies, and the personal libraries of the lead authors. Two assessors (N.J.M.N. and D.D.) independently retrieved articles and extracted the data from the included studies. Any discrepancies were resolved by the consensus of the third author (X.W.)

Eligibility criteria

Determined using the PICOS approach (Liberati et al., 2009), the inclusion/exclusion criteria were as follows: (1) population: healthy handball players without any restrictions on age, gender, or expertise level; (2) intervention: a plyometric training program lasting a minimum of 3 weeks, incorporating jump, bound and hop actions utilizing the stretch-shortening cycle (Chu and Meyer, 2013, Wang et al., 2023a); (3) comparator: active healthy handball players without involvement in a plyometric training program; (4) outcome: at least one measure of physical fitness indicators (e.g., jump, sprint, agility, balance and strength). (5) design: controlled trials.

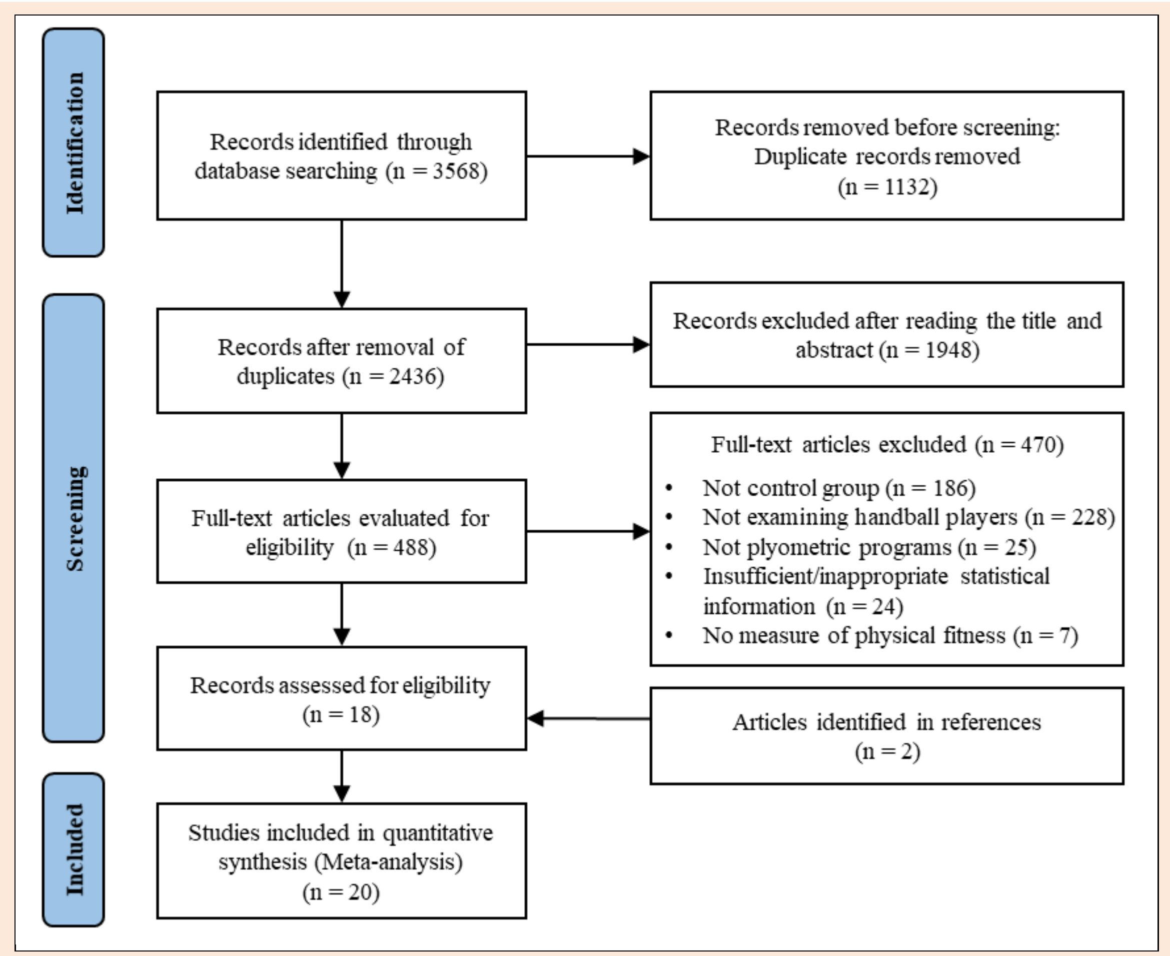

Figure 1. PRISMA flow diagram.

The excluded criteria were as follows: (1) not availability in English; (2) non-human intervention; (3) case reports, review articles, or cross-sectional studies; (3) lack of baseline and/or follow-up data on physical fitness; (4) observational studies that did not focus on the effects of the plyometric training program.

Methodological quality assessment

The quality assessment of the included studies was assessed using the Physiotherapy Evidence Database (PEDro) scale (Maher et al., 2003), which comprises 11 items (e.g., randomization, blinding, and outcome measures) with a total possible score of 10 points (item 1 is not rated). As in the previous meta-analysis review [33], the literature quality was categorized as "low quality" (≤ 3 points), "medium quality" (4–5 points), or "high quality" (6–10 points). The quality assessment was independently conducted by two reviewers (N.J.M.N. and D.D.), and any discrepancies were resolved by the consensus of the third author (X.W.).

Data extraction

Various physical fitness indicators were extracted from the included studies, including jumping, sprinting, strength, agility, and balance. Jumping actions primarily included countermovement jump, countermovement jump with arms, squat jump, and horizontal jump. Sprinting actions mainly consisted of ≤ 10-meter linear sprint, >10-meter linear sprint time, and repeated sprint ability with change-of-direction. Strength indicators encompass maximal strength and force-velocity. Agility actions were primarily assessed using the agility T-test time. Balance variables included both dynamic balance and static balance.

The extracted data also included the population characteristics and the plyometric training protocol. Regarding population characteristics, data encompassed age (years), gender, body mass (kg), height (m), previous experience with plyometric training (yes/no), and expertise level (professional or amateur). Additionally, the plyometric training protocol details were recorded, including the frequency (days/week), duration (weeks), training intensity, box height (cm), total number of jumping contacts, type of plyometric drill, and the rest time between sets or repetitions (s). The specific characteristics of the participants and plyometric training protocol were presented in Table 1 and Table 2, respectively.

Statistical analyses

Effect sizes were calculated for each study using the mean and standard deviation of changes compared to baseline, due to potential baseline differences in some included studies (Higgins et al., 2019). The mean changes were computed by subtracting the mean score after the intervention from the mean score prior to the intervention, while the standard deviation of the change was determined using the following equation (correlation coefficient, Corr = 0.5)

$$SD_{change} = \sqrt{{SD_{pre}}^2 + {SD_{post}}^2 - (2 \times Corr \times SD_{pre} \times SD_{post})}$$

The R packages (R version 4.3.0 with R Studio version 2023.06.1+524) were applied for meta-analysis. A total of 12 meta-analyses be conducted, encompassing physical fitness variables from different categories: jumping variables (1) countermovement jump with arms height, (2) countermovement jump height, (3) squat jump height, (4) horizontal jump distance; sprint variables (5) ≤ 10-m linear sprint time, (6) >10-m linear sprint time, (7) repeated sprint ability with change-of-direction time; strength variables (8) maximal strength, (9) force–velocity test; balance variables (10) dynamic balance, (11) static balance; and (12) Agility test time. Meta-analysis was not performed when the number of included studies is less than 3 (Moran et al., 2018, Wang et al., 2023b). Hedge's g was used to calculate the effect size, with categorization as follows: < 0.2 as trivial, 0.2–0.5 as small, 0.5–0.8 as moderate, and > 0.8 as large (Cohen, 2013). The random-effects model was utilized for meta-analysis because it assigns weights based on the standard errors of each study and facilitates analysis in the presence of heterogeneity among studies.

Table 1. Characteristics of included participants.

Study	RCT	N	Gender	Age (year)	Body mass (kg)	Height (m)	PLT experience	Fitness level
Aloui et al. (2020)	Yes	29	M	17.9 ± 0.5	75.3 ± 13.9	1.83 ± 0.06	NR	High
Chaabene et al. (2021)	NR	21	F	15.0/16.0	63.3 ± 7.1	1.65 ± 0.1	NR	High
Chelly et al. (2014)	Yes	23	M	17.2 ± 0.4	79.9 ± 11.5	1.79 ± 0.04	NR	High
De Villarreal et al. (2022)	Yes	24	M	23.7 ± 4.9	80.2 ± 8.3	1.81 ± 0.06	No	Moderate
De Villarreal et al. (2022)	Yes	24	M	20.2 ± 2.2	80.2 ± 8.3	1.79 ± 0.04	No	Moderate
Ethiraj and Kamatchi (2020)	Yes	40	M	20.8 ± 1.6	NR	NR	NR	Low
Gaamouri et al. (2023a)	Yes	28	M	16.6 ± 0.4	72.1 ± 7.6	1.80 ± 0.03	NR	High
Gaamouri et al. (2023b)	No	28	F	15.8 ± 0.2	63.3 ± 4.1	1.67 ± 0.03	3	High
Gaamouri et al. (2023c)	No	34	F	15.8 ± 0.2	63.2 ± 3.8	1.68 ± 0.04	NR	High
Hammami et al. (2019a)	Yes	28	M	14.0/15.0	66.6 ± 4.7	1.75 ± 0.07	NR	High
Hammami et al. (2019b)	Yes	41	F	13.4 ± 0.3	42.5 ± 4.2	1.43 ± 0.4	NR	Moderate
Hammami et al. (2020a)	Yes	20	M	16.5 ± 0.5	70.1 ± 6.9	1.79 ± 0.07	NR	High
Hammami et al. (2020b)	Yes	34	F	15.8 ± 0.2	63.6 ± 3.8	1.67 ± 0.04	3	High
Hammami et al. (2021)	Yes	32	M	16.6 ± 0.8	69.0 ± 5.4	1.77 ± 0.07	NR	High
Hermassi et al. (2014)	Yes	24	M	20.1 ± 0.3	87.5 ± 3.1	1.89 ± 0.07	NR	High
Karadenizli (2016)	Yes	26	F	14.0/15.0	NR	1.57/1.70	NR	Moderate
Mazurek et al. (2018)	Yes	26	M	20.2 ± 2.2	86.0 ± 9.9	1.83 ± 0.05	NR	Moderate
Noutsos et al. (2021)	Yes	33	NR	12.4 ± 2.1	48.3 ± 3.9	1.55 ± 0.02	NR	Low
Pancar et al. (2020)	Yes	28	F	13.1 ± 0.8	NR	1.59 ± 0.07	NR	Low
Spieszny and Zubik (2018)	Yes	20	NR	22.1 ± 3.1	87.24/88.86	1.83 ± 0.06	NR	Moderate-high

F, female; M, male; NR, not reported, PLT experience, plyometric training experience (years); RCT, randomized controlled trial.

Table 2. Characteristics of the plyometric jump training (PJT) programmes implemented in the included studies

Study	Frequency (sessions/ week)	Duration (week)	Intensity	Type	Box height (cm)	Total contacts	Comb	RBS (s)	RBR (s)	PO	TP	Repl
Aloui et al. (2020)	2	8	NR	V-jump	NA	1056	Elastic	NR	NR	V, I	NR	Yes
Chaabene et al. (2021)	2	8	Max	V-jump	NA	800	No	90	NR	V	IS	NR
Chelly et al. (2014)	2	8	Max	V-jump	40	430	No	NR	5	T, V	IS	Yes
De Villarreal et al. (2022)	2	9	NR	Mix	NA	NR	Sprint	NR	NR	NR	IS	Yes
De Villarreal et al. (2022)	3	5	NR	Mix	NA	NR	No	NR	NR	NR	OS	Yes
Ethiraj and Kamatchi (2020)	3	12	NR	Mix	NR	NR	RT	NR	NR	NR	NR	NR
Gaamouri et al. (2023a)	2	10	NR	Mix	25-40	1440	Elastic	30	NR	V	IS	Yes
Gaamouri et al. (2023b)	2	10	NR	Mix	25-40	1440	No	30	NR	V	IS	Yes
Gaamouri et al. (2023c)	2	8	Max	Mix	30-40	3072	Sprint	10	NR	No	IS	Yes
Hammami et al. (2019a)	2	8	Max	Mix	30-40	768	Sprint	NR	NR	V	NR	NR
Hammami et al. (2019b)	2	9	NR	Mix	25-30	630	No	90	NR	T, V	IS	NR
Hammami et al. (2020a)	2	8	Max	Mix	30-40	594	Sprint	NR	NR	V	NR	NR
Hammami et al. (2020b)	2	10	NR	Mix	25-40	720	Sprint	30	NR	V	IS	Yes
Hammami et al. (2021)	2	8	NR	Mix	30-40	3072	Sprint	180-300	10	No	IS	Yes
Hermassi et al. (2014)	2	8	Max	V-jump	40	470	No	180	5	T, V	IS	NR
Karadenizli (2016)	2	10	Moderate	Mix	40	2100	Sprint	60	NR	T, V	IS	NR
Mazurek et al. (2018)	3	5	Max	Mix	20-76	1168	No	120	NR	T, V	NR	NR
Noutsos et al. (2021)	2	6	Max	Mix	NA	2304	No	60	NR	No	IS	Yes
Pancar et al. (2020)	3	8	Low-High	Mix	NA	1502	No	60-120	NR	T, V, I	IS	NR
Spieszny and Zubik (2018)	NR	16	NR	Mix	NR	NR	NR	NR	NR	NR	IS	No

Comb, combined; NA, not applicable; NR, not reported; PO, progressive overload, in the form of intensity (I), volume (V) and type of drills (T); RBR, rest between repetitions (seconds); RBS, rest between sets (seconds); Repl, replace, indicating if athletes substituted regular training drills with plyometric training drills; TP, training period of the season, in the form of in the season (IS) and off the season (OS); V-jump, vertical jump.

Heterogeneity among the included studies was assessed using both chi-squared and Higgins I^2 tests. I^2 values of ≤ 25%, 25%–75%, and ≥ 75% indicate low, medium, and high heterogeneity, respectively (Higgins et al., 2003). In addition, Egger's test was used to identify the potential risk of bias in the included studies.

Additional analyses

In consideration of potential sources of heterogeneity that might impact training effects, age, and gender were initially designated as a priori factors for subgroup analysis, subsequently, body mass and height were regarded as posteriori factors for subgroup analysis. Additionally, subgroup analyses were conducted for individual training factors, including training duration and frequency. Variables for subgroup analysis were divided by using the median split technique. The median values were computed based on studies that provided data pertaining to the specific outcome under analysis, rather than deriving a global median value across all included studies. If one study included two or more experimental groups with the same information, they were treated as a single group to avoid median calculation bias.

In addition, the multivariate meta-regression was performed to determine if training variables, such as frequency and duration, could serve as predictors for the effects of plyometric training on physical fitness. In order to conduct a multivariate meta-regression analysis, a minimum of 10 studies for each covariate was necessary (Higgins and Green, 2008).

Results

Study selection

After the initial database search, a total of 3568 studies were identified. Following the removal of 1132 duplicates, 2436 studies were retained for screening based on their titles and abstracts. After this screening, 1948 studies were excluded, leaving 488 studies for full-text review. During the full-text screening, 470 studies were further eliminated. Through the identification of additional studies in the references of articles, two more studies were included. In total, 20 studies were eventually included in the meta-analysis. The search process is shown in Figure 1. The characteristics of the participants and plyometric training program are presented in Table 1 and Table 2. The means and standard deviations of the physical fitness variables before and after the experiment for both the control and experimental groups are presented in Appendix B.

Methodological quality assessment

Among the included studies, 10 studies achieved moderate study quality (4–5 points), and 10 studies achieved high study quality (6–8 points), with a median PEDro scale score of 5.5 out of 10 points. Overall, the literature exhibited moderate to high quality, ensuring high credibility. The specific details regarding the PEDro scale scores for the included studies are presented in Appendix C.

Meta-analysis results

The overall effects of plyometric training on physical fitness are shown in Table 3, and the forest plots are displayed in Appendix D. Significant large effects of plyometric training were observed on various parameters, including countermovement jump with arms (ES = 1.84), countermovement jump (ES = 1.33), squat jump (ES = 1.17), and horizontal jump (ES = 0.83) (refer to Appendix D Figure 1–4). Additionally, significant large effects of plyometric training were noted on sprint variables, such as ≤ 10-m linear sprint time (ES = -1.12), > 10-m linear sprint time (ES = -1.46), and repeated sprint ability with change-of-direction time (ES = -1.53) (see Appendix D Figure 5–7). There were significant moderate-to-large effects of plyometric training on maximal strength (ES = 0.52) and force–velocity (muscle power) (ES = 1.13) (see Appendix D Figure 8–9). Plyometric training did not have significant effects on dynamic and static balance, but it did demonstrate a significant large effect on agility (ES = -1.60) (see Appendix D Figure 10–12). Through Egger's test for risk of bias, seven out of the 12 meta-analyses did not display significant bias risk, while the remaining five studies exhibited the risk of bias. After applying the trim and fill method for adjustment, the significance of the results in these five meta-analyses remained unchanged, indicating that publication bias did not significantly impact the effect sizes.

Additional analyses

Subgroup analyses were considered when there were at least three studies available for each moderator. A total of 37 subgroup analyses were performed for: ≤ 10-m linear sprint time (sex, age, body mass, height and duration), > 10-m linear sprint time (sex, age, body mass, height and duration), repeated sprint ability with change-of-direction time (sex, age, body mass, height and duration), Countermovement jump height (sex, age, body mass, height and duration), squat jump height (sex, age, body mass, height and duration), horizontal jump distance (sex, age, body mass, height and duration), agility test time (sex, age, body mass, height and duration), and static balance (height and duration). Significant differences in agility test times were observed between participants with a body mass ≤ 66.6 kg and participants with a body mass > 66.6 kg (ES = -1.93 vs. -0.23, p = 0.014). Additionally, significant differences in sprint variables were observed when comparing training durations ≤ 8 weeks with those > 8 weeks, for ≤ 10-m linear sprint time (ES = -0.92 vs. -2.54, p = 0.009), > 10-m linear sprint time (ES = -0.92 vs. -2.30, p = 0.042), and repeated sprint ability with change-of-direction time (ES = -0.97 vs. -2.89, p < 0.001).

Multivariate meta-regression was conducted when there were at least 10 studies for each covariate. Initially, ≤ 10-m linear sprint time, > 10-m linear sprint time, repeated sprint ability with change-of-direction time, countermovement jump height, squat jump height, and agility test time were considered for multivariate meta-regression. However, multivariate regression analysis for > 10-m linear sprint time and repeated sprint ability with change-of-direction time was not conducted due to collinearity. Therefore, multivariate regression analysis was performed for ≤ 10-m linear sprint time, countermovement jump height, squat jump height, and agility test time, involving two training variables (i.e., duration and frequency) (see Table 4). The results of multivariate regression analysis indicated that training duration, training frequency, and the total number of contacts per week were all unable to predict the plyometric training benefits.

Discussion

This meta-analysis comprehensively investigated the effects of plyometric training on the physical fitness attributes of handball players in contrast to a control condition. The results showed large effects of plyometric training on jumping performance, sprinting performance, muscle power, maximal strength, and agility, while no significant effects were observed on balance. Subgroup analysis revealed significant differences in agility test times between participants with a body mass of ≤ 66.6 kg and those with a body mass of > 66.6 kg. Similarly, significant differences in sprinting performance were observed when comparing training durations of ≤ 8 weeks with those > 8 weeks. Additionally, meta-regression analysis demonstrated that none of the training variables (i.e., duration, frequency, and total number of contacts per week) predicted the effects of plyometric training on physical fitness attributes in handball players.

Table 3. Synthesized results of plyometric jump training effects on handball players' fitness attributes.

Fitness attribute	n[a]	ES (95%CI)	*p*	I^2 (%)	Egger's test (*p*)	RW (%)
		Jumping variables				
Countermovement jump with arms height	5, 5, 5, 157	1.84 (1.07 to 2.62)	< 0.001	77	0.193	19.2–21.1
Countermovement jump height	15, 15, 15, 421	1.33 (0.83 to 1.83)	< 0.001	78.5	0.004[b]	5.1–7.4
Squat jump height	14, 14, 14, 400	1.17 (0.79 to 1.55)	< 0.001	66.5	0.061	5.8–8.2
Horizontal jump distance	8, 8, 8, 239	0.83 (0.50 to 1.15)	< 0.001	23.8	0.363	9.3–15
		Sprint variables				
≤ 10-m linear sprint time	16, 16, 9, 470	-1.12 (-1.41 to -0.83)	< 0.001	52	0.012[b]	5.2–7.8
> 10-m linear sprint time	16, 16, 12, 523	-1.46 (-1.99 to -0.94)	< 0.001	80.1	0.001[b]	4.6–6.3
Repeated sprint ability with change-of-direction time	10, 10, 10, 278	-1.53 (-2.22 to -0.84)	< 0.001	82.7	0.004[b]	9.4–10.6
		Balance variables				
Dynamic balance	5, 5, 5, 149	0.04 (-0.28 to 0.37)	0.790	0	0.419	13.4–27.6
Static balance	6, 6, 6, 177	-0.24 (-0.53 to 0.06)	0.123	11	0.710	11.4–23.4
		Agility variables				
Agility test time	18, 18, 12, 523	-1.60 (-1.90 to -1.29)	< 0.001	67.7	0.016[b]	5.2–7.1
		Strength variables				
Maximal strength	4, 4, 4, 119	0.52 (0.08 to 0.95)	0.020	27.0	0.001[b]	24.6–25.5
Force–velocity test (muscle power)	5, 5, 5, 139	1.13 (0.76 to 1.49)	< 0.001	0	0.831	16.8–22.8

[a] n indicates the number of experimental groups, the number of control groups, the number of studies providing data and the total number of participants in the analysis. [b] The significance remained the same after the trim and fill method, suggesting that publication bias did not significantly impact the effect sizes.

Table 4. Multivariate meta-regression for training variables to predict plyometric jump training effects.

Covariate	Coefficient	95%CI	95%CI	T	*p*
Countermovement jump height (n = 14)					
Intercept	2.148	-2.982	7.277	0.933	0.373
Training duration	0.377	-1.080	1.835	0.577	0.577
Training frequency	-0.430	-2.361	1.501	-0.496	0.631
Total number of contacts per week	-0.002	-0.007	0.003	-0.862	0.409
Squat jump height (n = 13)					
Intercept	2.314	-1.439	6.069	1.395	0.197
Training duration	0.139	-0.888	1.167	0.307	0.766
Training frequency	-0.487	-1.880	0.907	-0.790	0.450
Total number of contacts per week	-0.001	-0.005	0.002	-0.787	0.451
≤ 10-m linear sprint time (n = 17)					
Intercept	-1.957	-5.544	1.631	-1.189	0.258
Training duration	0.148	-0.778	1.073	0.348	0.734
Training frequency	0.237	-1.021	1.494	0.410	0.689
Total number of contacts per week	0.001	-0.003	0.005	0.623	0.545
Agility t-test time (n = 18)					
Intercept	-2.465	-6.971	2.041	-1.192	0.256
Training duration	-0.170	-1.202	0.863	-0.358	0.863
Training frequency	0.414	-1.224	2.051	0.550	0.592
Total number of contacts per week	0.001	-0.003	0.005	0.742	0.473

Muscle power

There was a significant large effect of plyometric training on force–velocity of the lower limbs (muscle power) (ES = 1.13) compared to control groups. The increase in force–velocity indicates rapid generating greater force in a short period, implying an improvement in the rate of force development. Such ability is crucial for rapid starts, stops, and jumps in high-intensity handball matches. In addition, jumping ability is also considered a manifestation of muscle maximal power. Our findings demonstrated large effects of plyometric training on various jumping performances, including countermovement jump with arms height (ES = 1.84), countermovement jump height (ES = 1.33), squat jump height (ES = 1.17), and horizontal jump distance (ES = 0.83). These training benefits for muscle power may be attributed to structural and neuromuscular adaptations, such as an increase in the proportion of type IIx muscle fibers, enhanced tendon stiffness, improved motor unit recruitment, greater muscle coordination and enhanced reflex control (Taube et al., 2012, Radnor et al., 2018). It is noteworthy that plyometric training had notably superior effects on improving vertical jump performance in comparison to horizontal jump performance. This could be attributed to the specificity of the training, as plyometric training primarily focuses on vertical jumping, thus leading to more significant improvements in vertical jump performance. The research by Iacono et al. (2017) confirmed this specificity. Their research revealed that vertical-oriented plyometric training was more effective for vertical jumps, while horizontal-oriented plyometric training was more effective for sprinting and changing direction in the horizontal direction. In fact, 16 of the 20 included studies used a combination of horizontal and vertical jumping exercises in this meta-analysis, which is one of the reasons for the significant effect of horizontal jump performance. Therefore, for plyometric training, it is essential to consider incorporating elements of horizontal-oriented training to enhance the improvement of maximal power in the horizontal direction.

In addition, none of the single training variables (i.e., frequency and duration) predicted the effects of plyometric training on jumping performance. The range of training duration for the included studies was 5-16 weeks in this meta-analysis, suggesting that even a 5-week training duration can yield some training benefits. However, it is worth noting that the plyometric training effects observed in the 5-week (ES = 0; Mazurek et al., 2018) and 6-week (ES = 0.08; Noutsos et al., 2021) training periods are minimal in this review. Therefore, it is recommended to consider a plyometric training duration of 8 weeks or longer. Regarding training frequency, all 20 included studies utilized an intervention frequency of 2 or 3 times per week, and no significant differences in training effects for all physical fitness were observed between them. Therefore, it is recommended to keep the training frequency at 2 or 3 times per week, as excessive training can lead to fatigue and injuries, while a frequency that is too low may not achieve the desired training effect.

Linear sprinting

Our meta-analysis results showed that plyometric training had significant large effects on ≤ 10m sprint (ES = -1.12), > 10m sprint (ES =-1.46), and repeat sprint ability (ES = -1.53) compared to the control group. This aligns with findings from previous meta-analyses in other team sports, such as soccer, basketball and volleyball (Ramirez-Campillo et al., 2021; Ramirez-Campillo et al., 2022; Sánchez et al., 2020). Improvements in linear sprinting ability with plyometric training may be largely attributable to neurological adaptations, including improved motor unit recruitment, enhanced muscle coordination, and refined reflex control (Markovic and Mikulic, 2010). It is worth noting that plyometric training is less effective in improving linear sprinting ability for distances ≤ 10m compared to its effectiveness in improving sprinting ability for distances > 10m. This is due to the fact that horizontal forces predominantly take place during the initial acceleration phase of the sprint (≤ 10m) (Morin et al., 2012). As speed increases (> 10m), the influence of horizontal forces gradually diminishes, while the vertical forces application to the ground progressively strengthens

(Iacono et al., 2017). Plyometric training primarily emphasizes vertical performance, and the improvement of vertical force surpasses that of horizontal force. Consequently, the improvement in the initial acceleration phase (≤ 10m) is comparatively weaker, while it is notably stronger in the speed increase phase (> 10m) with plyometric training. To enhance linear sprinting ability, it may be beneficial to incorporate horizontal-oriented training, such as long jumps, within plyometric training, or to combine sprint-specific training to optimize training effectiveness. In addition, improvements in repeated sprint ability may be related to improvements in lactate buffering capacity and maximal oxygen uptake as a result of plyometric training (Mahulkar, 2021, Hammami et al., 2021). In practical terms, this implies that plyometric training can effectively boost an athlete's sprinting endurance by reducing the rate of lactic acid accumulation in the muscles, simultaneously enhancing the muscles' ability to utilize oxygen more efficiently. These adaptations support prolonged and repetitive sprint performance.

In the subgroup analysis, significant differences were observed in the improvement of sprint performance between plyometric training lasting > 8 weeks and plyometric training lasting ≤ 8 weeks (ES = -2.30 to -2.89 vs. ES = -0.92 to -0.97). These findings strongly imply that achieving significant physiological adaptation requires a substantial amount of time (Stojanović et al., 2017), making it evident that interventions of a duration less than 8 weeks in plyometric training may not offer sufficient time for the physiological mechanisms associated with improved sprinting ability to reach their optimal adaptive states. This aligns with previous review results (Slimani et al., 2016), which highlighted a plyometric training period of 6-7 weeks is insufficient for effectively enhancing physical fitness attributes such as sprinting ability. Therefore, it is recommended to implement plyometric training with a duration exceeding 8 weeks to effectively enhance sprinting performance.

Maximal strength

Increased muscle strength plays a crucial role in the execution of specific movements for handball athletes. The results of this meta-analysis showed a moderate effect of plyometric training on the improvement of maximal strength in handball players (ES = 0.52), which is consistent with previous meta-analyses in other team sports (De Villarreal et al., 2010; Ramirez-Campillo et al., 2022; Oxfeldt et al., 2019). Improvements in maximal strength with plyometric training may be largely attributed to neural adaptations (e.g., activation and recruitment of motor units) and muscle adaptations (e.g., muscle fiber types and hypertrophy) (Markovic and Mikulic, 2010, Grgic et al., 2021). It's worth noting that while plyometric training can improve maximal strength to some extent, it's not as effective as traditional resistance and compound training (Wang et al., 2023a, Whitehead et al., 2018, McKinlay et al., 2018). Plyometric training focuses primarily on improving maximal power and therefore may not be as effective in improving maximal strength as traditional resistance training or compound training (i.e., combining plyometric training with resistance training). However, the level of maximal power is not only affected by neuromuscular adaptations (Markovic and Mikulic, 2010), but is also closely related to the level of maximal strength (Taber et al., 2016). In other words, the level of maximal power is limited by the level of maximal strength. Therefore, in order to achieve long-term maximal power development, it is recommended to combine plyometric training with resistance training. This integrated approach can increase maximal strength levels and improve maximal power, enabling athletes to improve their overall physical fitness for better training benefits.

Agility (change-of-direction)

In handball, agility skills are crucial for rapidly altering speed and direction, enabling players to swiftly respond to unpredictable situations or stimuli (Sheppard and Young, 2006). The results of this meta-analysis demonstrated significant improvements in agility performance (ES = -1.60) compared to the control group. Furthermore, the enhancement in the change-of-direction ability with plyometric training (ES = -1.53) also reflected an increase in agility. These improvements in agility performance are consistent with previous meta-analyses examining athletes at different levels and stages of maturity (Chaabene et al., 2020, Asadi et al., 2017). Agility is primarily manifested through rapid change-of-direction, achieved by accelerating and decelerating in the lower limbs, in response to various situations or stimuli (Sheppard and Young, 2006). The deceleration phase mainly relies on the eccentric strength of the thigh muscles (Chaabene et al., 2018). In plyometric training, the higher inertia accumulated during the braking phase leads to a greater eccentric load, which may contribute to the enhancement of eccentric strength. The rapid switching between deceleration and acceleration primarily depends on neuromuscular adaptations, especially, improved neural drive to the agonist muscles and enhanced inter- and intra-muscular coordination (Markovic and Mikulic, 2010). The acceleration phase, an expression of maximal power, heavily relies on rapid force development and movement efficiency (Asadi et al., 2016). These factors also play a crucial role in reducing ground reaction time, ultimately leading to an improvement in change-of-direction speed (Granacher et al., 2015).

Interestingly, subgroup analysis revealed that plyometric training had a significantly more pronounced impact on the agility of athletes with less than 66.6 kg of body mass when compared to those with a body mass exceeding 66.6 kg (ES = -1.93 vs. ES = -0.23). This is consistent with the findings of several previous research studies (Sattler et al., 2015, Chaouachi et al., 2009, Popowczak et al., 2022), suggesting that as body mass index increases, agility or change-of-direction abilities gradually decline. The somatotype of athletes is one of the key factors for success in team sports (Bayios et al., 2006). Excessive body mass leads to increased fat storage, and an excess of fat has a detrimental impact on athletic performance, especially in agility or change-of-direction (Popowczak et al., 2022). Therefore, for handball players, they need to control their weight effectively in order to attain the desired competitive condition.

Balance

Balance improvement is crucial for enhancing physical performance and preventing sports injuries (Zech et al., 2010). However, our findings demonstrated no significant improvements in balance with plyometric training. This is consistent with the results of two previous meta-analyses (Deng et al., 2022, Clemente et al., 2022). It suggests that plyometric training may not be highly effective in improving dynamic and static balance. Several research studies have demonstrated that combining plyometric training with balance training can effectively improve balance and other physical performance (Bouteraa et al., 2020, Huang and Lin, 2010). Therefore, it is recommended to incorporate specialized balance training elements into the plyometric training program to enhance athletes' balance, overall physical performance, and reduce the risk of sports injuries.

Study limitations

There are some potential limitations of this meta-analysis that require the findings to be interpreted with caution. First, subgroup analyses were always possible due to limitations in the number of studies available. In terms of moderators, such as sex, age, body mass, height, training duration and frequency, there are some subgroups with fewer than three studies, leading to the inability to conduct subgroup analyses. This limitation was also evident regarding comprehensive regression analyses for training factors, as some of the regression analyses were not possible due to having fewer than 10 studies. Second, in half of the included studies, exercise intensity was not reported, while the remaining studies solely provided verbal descriptions of intensity levels, such as “jump as far as possible” or “keep minimum ground contact time”. Furthermore, out of the 20 studies, 8 did not report rest between sets, and 17 did not report rest between repetitions. These training rest intervals can also serve as indicators of exercise intensity. In order to better understand the impact of training intensity on plyometric training benefits, future research should provide clear reporting of training rest intervals and employ more precise methods for measuring exercise intensity, such as heart rate monitoring or the rating of perceived exertion. Thirdly, while none of the included studies reported any adverse effects of plyometric training, caution should be taken regarding the conclusion that plyometric training does not lead to adverse effects due to the lack of relevant reporting. Moreover, due to variations in body size among athletes, it is not possible to determine a specific body mass threshold for each athlete (in this review, the threshold is 66.6 kg). When this threshold is exceeded, the benefits of increased agility with plyometric training may be reduced. More research is needed to examine the impact of body mass on plyometric training benefits in improving agility.

Practical applications

Plyometric training can be recommended as a training method to improve various physical fitness in handball players. However, it does not significantly improve balance ability. Therefore, it is recommended to incorporate specialized balance training elements into the plyometric training program to enhance athletes' balance, and overall physical performance. Furthermore, plyometric training has limited impact on maximal strength compared to high-intensity resistance and compound training (Wang et al., 2023a, Whitehead et al., 2018, McKinlay et al., 2018). Since physical fitness attributes, especially maximal power, are related to maximal strength, it is recommended to combine plyometric training with resistance training for the long-term development of maximal power and overall physical fitness.

The plyometric training duration of the included studies in this review ranged 5–16 weeks, but training for less than 8 weeks was not very effective, especially for linear sprint and repeat sprint ability. Short-term training is not conducive to physiological mechanism adaptations (Stojanović et al., 2017), so the recommended duration of plyometric training is 8 weeks or more. The training frequency did not demonstrate a significant impact on the training benefits, mainly due to the fact that the training frequency of the included studies had a similar training frequency (all 2 or 3 times per week). It is recommended to incorporate moderate plyometric training, with a frequency of 2 to 3 times per week. This frequency can help to avoid insufficient training stimulus that may prevent achieving the desired training effects, while also preventing overtraining that could lead to excessive fatigue or exercise-related injuries. Furthermore, while the included studies did not report adverse effects, it is recommended to implement a progressive approach to plyometric training and consider the specific circumstances of the participants, particularly for less experienced athletes, to prevent exercise-related injuries. Additionally, body mass can impact the improvement of agility with plyometric training, with overweight players experiencing diminished gains in agility. Therefore, athletes should rigorously manage their body mass to maintain optimal competitive conditions. Maintaining an appropriate body mass can also help reduce the risk of sports-related injuries (Amoako et al., 2017).

Conclusion

Plyometric training is effective in improving various physical fitness attributes, including jump performance, linear sprint or repeat sprint ability, maximal strength, muscle power and agility, regardless of sex, age, body height and training frequency. However, the plyometric training program lasting more than 8 weeks appears to be more effective for improving physical fitness. Furthermore, it seems that body mass moderates the training benefits of plyometric training on agility, with athletes of normal body mass experiencing significantly greater gains in agility compared to their overweight counterparts.

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References

Aloui, G., Hermassi, S., Hammami, M., Cherni, Y., Gaamouri, N., Shephard, R. J., Van Den Tillaar, R. and Chelly, M. S. (2020) Effects of elastic band based plyometric exercise on explosive muscular performance and change of direction abilities of male team handball players. *Frontiers in Physiology* **11,** 604983. https://doi.org/10.3389/fphys.2020.604983

Aloui, G., Hermassi, S., Hayes, L. D., Shephard, R. J., Chelly, M. S. and Schwesig, R. (2021) Effects of elastic band plyometric training on physical performance of team handball players. *Applied Sciences* **11,** 1309. https://doi.org/10.3390/app11031309

Amoako, A. O., Nassim, A. and Keller, C. (2017) Body mass index as a predictor of injuries in athletics. *Current Sports Medicine Reports* **16,** 256-262. https://doi.org/10.1249/JSR.0000000000000383

Asadi, A., Arazi, H., Ramirez-Campillo, R., Moran, J. and Izquierdo, M. (2017) Influence of maturation stage on agility performance gains after plyometric training: a systematic review and meta-analysis. *The Journal of Strength & Conditioning Research* **31,** 2609-2617. https://doi.org/10.1519/JSC.0000000000001994

Asadi, A., Arazi, H., Young, W. B. and De Villarreal, E. S. (2016) The effects of plyometric training on change-of-direction ability: A meta-analysis. *International Journal of Sports Physiology and Performance* **11,** 563-573. https://doi.org/10.1123/ijspp.2015-0694

Bayios, I. A., Anastasopoulou, E., Sioudris, D. and Boudolos, K. D. (2001) Relationship between isokinetic strength of the internal and external shoulder rotators and ball velocity in team handball. *Journal of Sports Medicine and Physical Fitness,* **41,** 229-235.

Bayios, I. A., Bergeles, N. K., Apostolidis, N. G., Noutsos, K. S. and Koskolou, M. D. (2006) Anthropometric, body composition and somatotype differences of Greek elite female basketball, volleyball and handball players. *Journal of Sports Medicine and Physical Fitness* **46,** 271.

Bedoya, A. A., Miltenberger, M. R. and Lopez, R. M. (2015) Plyometric training effects on athletic performance in youth soccer athletes: a systematic review. *The Journal of Strength & Conditioning Research* **29,** 2351-2360. https://doi.org/10.1519/JSC.0000000000000877

Bouteraa, I., Negra, Y., Shephard, R. J. and Chelly, M. S. (2020) Effects of combined balance and plyometric training on athletic performance in female basketball players. *The Journal of Strength & Conditioning Research* **34,** 1967-1973. https://doi.org/10.1519/JSC.0000000000002546

Bragazzi, N. L., Rouissi, M., Hermassi, S. and Chamari, K. (2020) Resistance training and handball Players' isokinetic, isometric and maximal strength, muscle power and throwing ball velocity: a systematic review and meta-analysis. *International Journal of Environmental Research and Public Health* **17,** 2663. https://doi.org/10.3390/ijerph17082663

Chaabene, H., Negra, Y., Moran, J., Prieske, O., Sammoud, S., Ramirez-Campillo, R. and Granacher, U. (2021a) Plyometric training improves not only measures of linear speed, power, and change-of-direction speed but also repeated sprint ability in young female handball players. *The Journal of Strength & Conditioning Research* **35,** 2230-2235. https://doi.org/10.1519/JSC.0000000000003128

Chaabene, H., Negra, Y., Sammoud, S., Moran, J., Ramirez-Campillo, R., Granacher, U. and Prieske, O. (2021b) The effects of combined balance and complex training versus complex training only on measures of physical fitness in young female handball players. *International Journal of Sports Physiology and Performance* **16,** 1439-1446. https://doi.org/10.1123/ijspp.2020-0765

Chaabene, H., Prieske, O., Moran, J., Negra, Y., Attia, A. and Granacher, U. (2020) Effects of resistance training on change-of-direction speed in youth and young physically active and athletic adults: a systematic review with meta-analysis. *Sports Medicine* **50,** 1483-1499. https://doi.org/10.1007/s40279-020-01293-w

Chaabene, H., Prieske, O., Negra, Y. and Granacher, U. (2018) Change of direction speed: Toward a strength training approach with accentuated eccentric muscle actions. *Sports Medicine* **48,** 1773-1779. https://doi.org/10.1007/s40279-018-0907-3

Chaouachi, A., Brughelli, M., Chamari, K., Levin, G. T., Abdelkrim, N. B., Laurencelle, L. and Castagna, C. (2009) Lower limb maximal dynamic strength and agility determinants in elite basketball players. *The Journal of Strength & Conditioning Research* **23,** 1570-1577. https://doi.org/10.1519/JSC.0b013e3181a4e7f0

Chelly, M. S., Hermassi, S., Aouadi, R., Khalifa, R., Van Den Tillaar, R., Chamari, K. and Shephard, R. J. (2011) Match analysis of elite adolescent team handball players. *The Journal of Strength & Conditioning Research* **25,** 2410-2417. https://doi.org/10.1519/JSC.0b013e3182030e43

Chelly, M. S., Hermassi, S., Aouadi, R. and Shephard, R. J. (2014) Effects of 8-week in-season plyometric training on upper and lower limb performance of elite adolescent handball players. *The Journal of Strength & Conditioning Research* **28,** 1401-1410. https://doi.org/10.1519/JSC.0000000000000279

Cherni, Y., Hammami, M., Jelid, M. C., Aloui, G., Suzuki, K., Shephard, R. J. and Chelly, M. S. (2021) Neuromuscular adaptations and enhancement of physical performance in female basketball players after 8 weeks of plyometric training. *Frontiers in Physiology* **11**, 588787. https://doi.org/10.3389/fphys.2020.588787

Cherni, Y., Jlid, M. C., Mehrez, H., Shephard, R. J., Paillard, T., Chelly, M. S. and Hermassi, S. (2019) Eight weeks of plyometric training improves ability to change direction and dynamic postural control in female basketball players. *Frontiers in Physiology* **10**, 726. https://doi.org/10.3389/fphys.2019.00726

Chu, D. A. and Meyer, G. C. (2013) *Plyometrics*, Human kinetics. https://doi.org/10.5040/9781718225459

Clemente, F., Ramirez-Campillo, R., Castillo, D., Raya-González, J., Rico-González, M., Oliveira, R., Rosemann, T. and Knechtle, B. (2022) Effects of plyometric jump training on soccer player's balance: A systematic review and meta-analysis of randomized-controlled trials. *Biology of sport* **39,** 765-778. https://doi.org/10.5114/biolsport.2022.107484

Cohen, J. (2013) *Statistical power analysis for the behavioral sciences*, Academic press. https://doi.org/10.4324/9780203771587

De Villarreal, E. S.-S., Requena, B. and Newton, R. U. (2010) Does plyometric training improve strength performance? A meta-analysis. *Journal of Science and Medicine in Sport* **13,** 513-522. https://doi.org/10.1016/j.jsams.2009.08.005

De Villarreal, E. S., Byrne, P. J. and Ramirez-Campillo, R. (2022) Change of Direction Ability as a Sensitive Marker of Adaptation to Different Training Configurations, and Different Populations: Results from Four Experiments. *Journal of Human Kinetics* **85,** 63-73. https://doi.org/10.2478/hukin-2022-0110

Deng, N., Soh, K. G., Zaremohzzabieh, Z., Abdullah, B., Salleh, K. M. and Huang, D. (2022) Effects of Combined Upper and Lower Limb Plyometric Training Interventions on Physical Fitness in Athletes: A Systematic Review with Meta-Analysis. *International Journal of Environmental Research and Public Health* **20,** 482. https://doi.org/10.3390/ijerph20010482

Ethiraj, B. and Kamatchi, M. (2020) Impact of maximal power training with and without plyometric on speed endurance and upper body power of team handball players. *Physical Education of Students* **24,** 71-79. https://doi.org/10.15561/20755279.2020.0201

Falch, H. N., Haugen, M. E., Kristiansen, E. L. and Van Den Tillaar, R. (2022) Effect of strength vs. plyometric training upon change of direction performance in young female handball players. *International Journal of Environmental Research and Public Health* **19,** 6946. https://doi.org/10.3390/ijerph19116946

Ferrari, W. R., Sarmento, H. and Vaz, V. (2019) Match analysis in handball: a systematic review. *Montenegrin Journal of Sports Science & Medicine* **8**. https://doi.org/10.26773/mjssm.190909

Gaamouri, N., Hammami, M., Cherni, Y., Oranchuk, D. J., Bragazzi, N., Knechtle, B., Chelly, M. S. and Van Den Tillaar, R. (2023c) The effects of upper and lower limb elastic band training on the change of direction, jump, power, strength and repeated sprint ability performance in adolescent female handball players. *Frontiers in Sports and Active Living* **5,** 1021757. https://doi.org/10.3389/fspor.2023.1021757

Gaamouri, N., Hammami, M., Cherni, Y., Rosemann, T., Knechtle, B., Chelly, M. S. and Van Den Tillaar, R. (2023b) The effects of 10-week plyometric training program on athletic performance in youth female handball players. *Frontiers in Sports and Active Living* **5**. https://doi.org/10.3389/fspor.2023.1193026

Gaamouri, N., Hammami, M., Shephard, R. J., Chelly, M. S., Knechtle, B., Suzuki, K. and Gaied, S. (2023a) Effects of brief periods of combined plyometric exercise and high intensity running training on the fitness performance of male U17 handball players. *International Journal of Sports Science & Coaching* **18,** 801-811. https://doi.org/10.1177/17479541221090932

Granacher, U., Prieske, O., Majewski, M., Büsch, D. and Mühlbauer, T. (2015) The role of instability with plyometric training in sub-elite adolescent soccer players. *International Journal of Sports Medicine* 386-394. https://doi.org/10.1055/s-0034-1395519

Grgic, J., Schoenfeld, B. J. and Mikulic, P. (2021) Effects of plyometric vs. resistance training on skeletal muscle hypertrophy: A review. *Journal of Sport and Health Science* **10,** 530-536. https://doi.org/10.1016/j.jshs.2020.06.010

Hammami, M., Bragazzi, N. L., Hermassi, S., Gaamouri, N., Aouadi, R., Shephard, R. J. and Chelly, M. S. (2020a) The effect of a sand surface on physical performance responses of junior male handball players to plyometric training. *BMC Sports Science, Medicine and Rehabilitation* **12,** 1-8. https://doi.org/10.1186/s13102-020-00176-x

Hammami, M., Gaamouri, N., Aloui, G., Shephard, R. J. and Chelly, M. S. (2019a) Effects of a complex strength-training program on athletic performance of junior female handball players. *International Journal of Sports Physiology and Performance* **14,** 163-169. https://doi.org/10.1123/ijspp.2018-0160

Hammami, M., Gaamouri, N., Aloui, G., Shephard, R. J. and Chelly, M. S. (2019b) Effects of combined plyometric and short sprint with change-of-direction training on athletic performance of male U15 handball players. *The Journal of Strength & Conditioning Research* **33,** 662-675. https://doi.org/10.1519/JSC.0000000000002870

Hammami, M., Gaamouri, N., Ramirez-Campillo, R., Shephard, R., Bragazzi, N., Chelly, M., Knechtle, B. and Gaied, S. (2021) Effects of high-intensity interval training and plyometric exercise on the physical fitness of junior male handball players. *European Review for Medical & Pharmacological Sciences* **25**.

Hammami, M., Gaamouri, N., Suzuki, K., Shephard, R. J. and Chelly, M. S. (2020b) Effects of upper and lower limb plyometric training program on components of physical performance in young female handball players. *Frontiers in Physiology* **11,** 1028. https://doi.org/10.3389/fphys.2020.01028

Hammami, M., Ramirez-Campillo, R., Gaamouri, N., Aloui, G., Shephard, R. J. and Chelly, M. S. (2019c) Effects of a combined upper-and lower-limb plyometric training program on high-intensity actions in female U14 handball players. *Pediatric Exercise Science* **31,** 465-472. https://doi.org/10.1123/pes.2018-0278

Hermassi, S., Chelly, M. S., Bragazzi, N. L., Shephard, R. J. and Schwesig, R. (2019a) In-season weightlifting training exercise in healthy male handball players: Effects on body composition, muscle volume, maximal strength, and ball-throwing velocity. *International Journal of Environmental Research and Public Health* **16,** 4520. https://doi.org/10.3390/ijerph16224520

Hermassi, S., Gabbett, T. J., Ingebrigtsen, J., Van Den Tillaar, R., Chelly, M. S. and Chamari, K. (2014) Effects of a short-term in-season plyometric training program on repeated-sprint ability, leg power and jump performance of elite handball players. *International Journal of Sports Science & Coaching* **9,** 1205-1216. https://doi.org/10.1260/1747-9541.9.5.1205

Hermassi, S., Schwesig, R., Aloui, G., Shephard, R. J. and Chelly, M. S. (2019b) Effects of short-term in-season weightlifting training on the muscle strength, peak power, sprint performance, and ball-throwing velocity of male handball players. *The Journal of Strength & Conditioning Research* **33,** 3309-3321. https://doi.org/10.1519/JSC.0000000000003068

Higgins, J. P. and Green, S. (2008) Cochrane handbook for systematic reviews of interventions. https://doi.org/10.1002/9780470712184

Higgins, J. P., Li, T. and Deeks, J. J. (2019) Choosing effect measures and computing estimates of effect. *Cochrane handbook for systematic reviews of interventions* 143-176. https://doi.org/10.1002/9781119536604.ch6

Higgins, J. P., Thompson, S. G., Deeks, J. J. and Altman, D. G. (2003) Measuring inconsistency in meta-analyses. *British Medical Journal* **327,** 557-560. https://doi.org/10.1136/bmj.327.7414.557

Huang, P. and Lin, C. (2010) Effects of balance training combined with plyometric exercise in postural control: Application in individuals with functional ankle instability. 6th World Congress of Biomechanics (WCB 2010). August 1-6, 2010 Singapore: In Conjunction with 14th International Conference on Biomedical Engineering (ICBME) and 5th Asia Pacific Conference on Biomechanics (APBiomech), 2010. Springer, 232-235. https://doi.org/10.1007/978-3-642-14515-5_60

Iacono, A. D., Martone, D., Milic, M. and Padulo, J. (2017) Vertical-vs. horizontal-oriented drop jump training: chronic effects on explosive performances of elite handball players. *The Journal of Strength & Conditioning Research* **31,** 921-931. https://doi.org/10.1519/JSC.0000000000001555

Karadenizli, Z. I. (2016) The effects of plyometric training on balance, anaerobic power and physical fitness parameters in handball. *The Anthropologist* **24,** 751-761. https://doi.org/10.1080/09720073.2016.11892072

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., Clarke, M., Devereaux, P. J., Kleijnen, J. and Moher, D. (2009) The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Annals of Internal Medicine* **151,** 65-94. https://doi.org/10.7326/0003-4819-151-4-200908180-00136

Luteberget, L. S. and Spencer, M. (2017) High-intensity events in international women's team handball matches. *International Journal of Sports Physiology and Performance* **12,** 56-61. https://doi.org/10.1123/ijspp.2015-0641

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M. and Elkins, M. (2003) Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical Therapy* **83,** 713-721. https://doi.org/10.1093/ptj/83.8.713

Mahulkar, S. S. (2021) Influence of plyometric and cycle ergometer training on anaerobic capacity of sprinters.

Markovic, G. (2007) Does plyometric training improve vertical jump height? A meta-analytical review. *British Journal of Sports Medicine* **41,** 349-355. https://doi.org/10.1136/bjsm.2007.035113

Markovic, G. and Mikulic, P. (2010) Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Medicine* **40,** 859-895. https://doi.org/10.2165/11318370-000000000-00000

Mazurek, K., Zmijewski, P., Makaruk, H., Mróz, A., Czajkowska, A., Witek, K., Bodasiński, S. and Lipińska, P. (2018) Effects of short-term plyometric training on physical performance in male handball players. *Journal of Human Kinetics* **63,** 137. https://doi.org/10.2478/hukin-2018-0014

Mckinlay, B. J., Wallace, P., Dotan, R., Long, D., Tokuno, C., Gabriel, D. A. and Falk, B. (2018) Effects of plyometric and resistance training on muscle strength, explosiveness, and neuromuscular function in young adolescent soccer players. *The Journal of Strength & Conditioning Research* **32,** 3039-3050. https://doi.org/10.1519/JSC.0000000000002428

Moran, J., Ramirez-Campillo, R. and Granacher, U. (2018) Effects of jumping exercise on muscular power in older adults: a meta-analysis. *Sports Medicine* **48,** 2843-2857. https://doi.org/10.1007/s40279-018-1002-5

Morin, J.-B., Bourdin, M., Edouard, P., Peyrot, N., Samozino, P. and Lacour, J.-R. (2012) Mechanical determinants of 100-m sprint running performance. *European Journal of Applied Physiology* **112,** 3921-3930. https://doi.org/10.1007/s00421-012-2379-8

Murugavel, K. and Balaji, E. (2020) Impact of resistance training plyometric training and maximal power training on strength endurance and anaerobic power of team handball players. *Solid State Technology* **63,** 4259-4271.

Noutsos, S., Meletakos, P., Athanasiou, P., Tavlaridis, A. and Bayios, I. (2021) Effect of plyometric training on performance parameters in young handball players. *Gazzetta Medica Italiana* **180,** 568-574. https://doi.org/10.23736/S0393-3660.21.04588-5

Ortega-Becerra, M., Pareja-Blanco, F., Jiménez-Reyes, P., Cuadrado-Peñafiel, V. and González-Badillo, J. J. (2018) Determinant factors of physical performance and specific throwing in handball players of different ages. *The Journal of Strength & Conditioning Research* **32,** 1778-1786. https://doi.org/10.1519/JSC.0000000000002050

Oxfeldt, M., Overgaard, K., Hvid, L. G. and Dalgas, U. (2019) Effects of plyometric training on jumping, sprint performance, and lower body muscle strength in healthy adults: A systematic review and meta-analyses. *Scandinavian Journal of Medicine & Science in Sports* **29,** 1453-1465. https://doi.org/10.1111/sms.13487

Page, M. J., Mckenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A. and

Brennan, S. E. (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International Journal of Surgery* **88,** 105906. https://doi.org/10.1016/j.ijsu.2021.105906

Pancar, Z., Biçer, M. and Özdal, M. (2020) The effect of 8-week plyometric training on anaerobic power, balance and sprint performance of 12-14 aged female handball players. *Medicina Dello Sport* **73,** 1-10. https://doi.org/10.23736/S0025-7826.19.03302-7

Pereira, L. A., Nimphius, S., Kobal, R., Kitamura, K., Turisco, L. A., Orsi, R. C., Abad, C. C. C. and Loturco, I. (2018) Relationship between change of direction, speed, and power in male and female national olympic team handball athletes. *The Journal of Strength & Conditioning Research* **32,** 2987-2994. https://doi.org/10.1519/JSC.0000000000002494

Popowczak, M., Horička, P., Šimonek, J. and Domaradzki, J. (2022) The functional form of the relationship between body height, body mass index and change of direction speed, agility in elite female basketball and handball players. *International Journal of Environmental Research and Public Health* **19,** 15038. https://doi.org/10.3390/ijerph192215038

Radnor, J. M., Oliver, J. L., Waugh, C. M., Myer, G. D., Moore, I. S. and Lloyd, R. S. (2018) The influence of growth and maturation on stretch-shortening cycle function in youth. *Sports Medicine* **48,** 57-71. https://doi.org/10.1007/s40279-017-0785-0

Ramirez-Campillo, R., Alvarez, C., Garcia-Hermoso, A., Keogh, J. W., García-Pinillos, F., Pereira, L. A. and Loturco, I. (2020) Effects of jump training on jumping performance of handball players: A systematic review with meta-analysis of randomised controlled trials. *International Journal of Sports Science & Coaching* **15,** 584-594. https://doi.org/10.1177/1747954120928932

Ramirez-Campillo, R., Álvarez, C., García-Hermoso, A., Ramírez-Vélez, R., Gentil, P., Asadi, A., Chaabene, H., Moran, J., Meylan, C. and García-De-Alcaraz, A. (2018) Methodological characteristics and future directions for plyometric jump training research: a scoping review. *Sports Medicine* **48,** 1059-1081. https://doi.org/10.1007/s40279-018-0870-z

Ramirez-Campillo, R., Castillo, D., Raya-González, J., Moran, J., De Villarreal, E. S. and Lloyd, R. S. (2020) Effects of plyometric jump training on jump and sprint performance in young male soccer players: a systematic review and meta-analysis. *Sports Medicine* **50,** 2125-2143. https://doi.org/10.1007/s40279-020-01337-1

Ramirez-Campillo, R., García-De-Alcaraz, A., Chaabene, H., Moran, J., Negra, Y. and Granacher, U. (2021) Effects of plyometric jump training on physical fitness in amateur and professional volleyball: a meta-analysis. *Frontiers in Physiology* **12,** 636140. https://doi.org/10.3389/fphys.2021.636140

Ramirez-Campillo, R., García-Hermoso, A., Moran, J., Chaabene, H., Negra, Y. and Scanlan, A. T. (2022) The effects of plyometric jump training on physical fitness attributes in basketball players: A meta-analysis. *Journal of Sport and Health Science* **11,** 656-670. https://doi.org/10.1016/j.jshs.2020.12.005

Saez De Villareal, E., Calleja-González, J., Alcaraz, P. E., Feito-Blanco, J. and Ramírez-Campillo, R. (2023) Positive Effects of Plyometric vs. Eccentric-Overload Training on Performance in Young Male Handball Players. *Journal of Functional Morphology and Kinesiology* **8,** 113. https://doi.org/10.3390/jfmk8030113

Sánchez, M., Sanchez-Sanchez, J., Nakamura, F. Y., Clemente, F. M., Romero-Moraleda, B. and Ramirez-Campillo, R. (2020) Effects of plyometric jump training in female soccer player's physical fitness: a systematic review with meta-analysis. *International Journal of Environmental Research and Public Health* **17,** 8911. https://doi.org/10.3390/ijerph17238911

Sattler, T., Sekulić, D., Spasić, M., Perić, M., Krolo, A., Uljević, O. and Kondrič, M. (2015) Analysis of the association between motor and anthropometric variables with change of direction speed and reactive agility performance. *Journal of Human Kinetics* **47,** 137-145. https://doi.org/10.1515/hukin-2015-0069

Sheppard, J. M. and Young, W. B. (2006) Agility literature review: Classifications, training and testing. *Journal of Sports Sciences,* **24,** 919-932. https://doi.org/10.1080/02640410500457109

Slimani, M., Chamari, K., Miarka, B., Del Vecchio, F. B. and Chéour, F. (2016) Effects of plyometric training on physical fitness in team sport athletes: a systematic review. *Journal of Human Kinetics* **53,** 231. https://doi.org/10.1515/hukin-2016-0026

Spieszny, M. and Zubik, M. (2018) Modification of strength training programs in handball players and its influence on power during the competitive period. *Journal of Human Kinetics* **63,** 149. https://doi.org/10.2478/hukin-2018-0015

Stojanović, E., Ristić, V., Mcmaster, D. T. and Milanović, Z. (2017) Effect of plyometric training on vertical jump performance in female athletes: a systematic review and meta-analysis. *Sports Medicine* **47,** 975-986. https://doi.org/10.1007/s40279-016-0634-6

Taber, C., Bellon, C., Abbott, H. and Bingham, G. E. (2016) Roles of maximal strength and rate of force development in maximizing muscular power. *Strength & Conditioning Journal* **38,** 71-78. https://doi.org/10.1519/SSC.0000000000000193

Taube, W., Leukel, C. and Gollhofer, A. (2012) How neurons make us jump: the neural control of stretch-shortening cycle movements. *Exercise and Sport Sciences Reviews* **40,** 106-115. https://doi.org/10.1097/JES.0b013e31824138da

Wagner, H., Finkenzeller, T., Würth, S. and Von Duvillard, S. P. (2014) Individual and team performance in team-handball: A review. *Journal of Sports Science & Medicine* **13,** 808. https://pubmed.ncbi.nlm.nih.gov/25435773/

Wang, X., Lv, C., Qin, X., Ji, S. and Dong, D. (2023a) Effectiveness of plyometric training vs. complex training on the explosive power of lower limbs: A Systematic review. *Frontiers in Physiology* **13,** 1061110. https://doi.org/10.3389/fphys.2022.1061110

Wang, X., Wang, Y., Yang, X., Nasiruddin, N. J. B. M., Dong, D., Samsudin, S. B. and Qin, X.-M. (2023b) Effects of blood flow restriction training on bone metabolism: a systematic review and meta-analysis. *Frontiers in Physiology* **14**. https://doi.org/10.3389/fphys.2023.1212927

Whitehead, M. T., Scheett, T. P., Mcguigan, M. R. and Martin, A. V. (2018) A comparison of the effects of short-term plyometric and resistance training on lower-body muscular performance. *The Journal of Strength & Conditioning Research* **32,** 2743-2749. https://doi.org/10.1519/JSC.0000000000002083

Zech, A., Hübscher, M., Vogt, L., Banzer, W., Hänsel, F. and Pfeifer, K. (2010) Balance training for neuromuscular control and performance enhancement: a systematic review. *Journal of Athletic Training* **45,** 392-403. https://doi.org/10.4085/1062-6050-45.4.392

Key points

- Plyometric training effectively improves physical fitness.
- Programs lasting over 8 weeks are more effective.
- Normal-weight athletes gain more agility than overweight counterparts

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APPENDIX A

Search Alert

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SPORTDiscus (357)
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Web of Science (610)
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APPENDIX B

The mean ± SD fitness variables reported for the plyometric jump training and control conditions in the included studies.

Study	Fitness attribute	Plyometric jump training			Control		
		Pre	Post	n	Pre	Post	n
Aloui et al. (2020)	1RM back half-squat (kg)	123 ± 15	133 ± 16	14	122 ± 10	125 ± 11	15
	5-m linear sprint time (s)	1.16 ± 0.05	1.06 ± 0.04	14	1.17 ± 0.07	1.16 ± 0.07	15
	30-m linear sprint time (s)	4.82 ± 0.20	4.47 ± 0.19	14	4.83 ± 0.37	4.81 ± 0.35	15
	Agility t-half-test time (s)	6.19 ± 0.34	5.62 ± 0.31	14	6.19 ± 0.20	6.01 ± 0.27	15
	CMJ height (cm)	39.8 ± 3.4	43.4 ± 3.9	14	38.8 ± 5.6	40.4 ± 6.2	15
	SJ height (cm)	37.8 ± 4.2	41.3 ± 4.2	14	36.1 ± 5.2	37.9 ± 5.6	15
	Repeated sprint ability with change-of-direction time (s)	7.12 ± 0.33	6.61 ± 0.21	14	7.13 ± 0.41	7.00 ± 0.43	15
	Lower-limb Force–velocity test (W/kg)	8.5 ± 1.0	10.4 ± 1.2	14	8.4 ± 1.9	8.6 ± 1.7	15
Chaabene et al. (2019)	5-m linear sprint time (s)	1.24 ± 0.12	1.16 ± 0.07	12	1.17 ± 0.06	1.20 ± 0.07	9
	10-m linear sprint time (s)	2.15 ± 0.15	2.04 ± 0.11	12	2.03 ± 0.10	2.04 ± 0.11	9
	20-m linear sprint time (s)	3.76 ± 0.25	3.63 ± 0.21	12	3.53 ± 0.19	3.56 ± 0.18	9
	Agility t -test time (s)	12.24 ± 0.76	11.37 ± 0.37	12	11.74 ± 0.52	12.10 ± 0.49	9
	CMJ height (cm)	21.44 ± 4.20	23.68 ± 3.63	12	27.42 ± 5.35	27.94 ± 5.45	9
	Repeated sprint ability with change-of-direction time (s)	53.82 ± 2.80	52.58 ± 2.66	12	52.35 ± 2.52	52.38 ± 2.50	9
Chelly et al. (2014)	SJ height (cm)	39.0 ± 4.0	44.0 ± 4.0	12	39.0 ± 3.0	40.0 ± 3.0	11
	CMJ height (cm)	42.0 ± 4.0	46.0 ± 4.0	12	41.0 ± 3.0	42.0 ± 3.0	11
	Lower-limb Force–velocity test (W/k)	11.4 ± 2.0	12.8 ± 2.1	12	10.4 ± 2.0	10.7 ± 2.0	12
De Villarreal et al. (2022)	Agility t-half-test time (s)	4.92 ± 0.36	4.39 ± 0.32	12	4.93 ± 0.28	4.81 ± 0.21	12
De Villarreal et al. (2022)	Agility t-half-test time (s)	4.68 ± 0.56	4.35 ± 0.78	12	4.72 ± 0.36	4.62 ± 0.32	12
Ethiraj et al. (2020)	150-m linear sprint time (s)	21.45 ± 0.11	20.12 ± 0.53	20	21.47 ± 0.07	21.47 ± 0.07	20
Gaamouri et al. (2023a)	5-m linear sprint time (s)	1.18 ± 0.05	1.08 ± 0.05	15	1.19 ± 0.04	1.16 ± 0.05	13
	10-m linear sprint time (s)	2.07 ± 0.07	1.96 ± 0.06	15	2.06 ± 0.07	2.05 ± 0.07	13
	20-m linear sprint time (s)	3.48 ± 0.21	3.23 ± 0.16	15	3.48 ± 0.15	3.43 ± 0.11	13
	30-m linear sprint time (s)	4.72 ± 0.36	4.29 ± 0.27	15	4.73 ± 0.13	4.69 ± 0.2	13
	Agility t-half-test time (s)	11.29 ± 0.69	10.52 ± 0.62	15	11.31 ± 0.37	11.14 ± 0.37	13
	SJ height (cm)	29.4 ± 4.5	38 ± 3.1	15	28 ± 2.8	30.6 ± 2.2	13
	CMJ height (cm)	31.3 ± 4.5	40.7 ± 2.8	15	30 ± 3.2	32.2 ± 3.2	13
	CMJA height (cm)	35.2 ± 3.9	42.7 ± 2.6	15	33.4 ± 3	34.4 ± 3.2	13
	Horizontal jump 5JT (m)	9.5 ± 1.1	10.6 ± 1.1	15	9.3 ± 0.7	9.7 ± 0.6	13
	Repeated sprint T-test-Mean time (s)	6.61 ± 0.35	6.11 ± 0.23	15	6.70 ± 0.22	6.65 ± 0.22	13
	20-m shuttle run test (km/h)	14.9 ± 0.6	15.9 ± 0.5	15	15 ± 0.7	15.2 ± 0.6	13
	1-RM half squat	98.2 ± 11.6	117.2 ± 8.8	15	101.7 ± 7.9	117.8 ± 6.8	13
Gaamouri et al. (2023b)	Agility t-half-test time (s)	7.47 ± 0.16	6.70 ± 0.25	14	7.49 ± 0.16	7.42 ± 0.18	14
	SJ height (cm)	22.4 ± 1.6	26.4 ± 1.8	14	22.7 ± 2.3	23.7 ± 1.8	14
	CMJ height (cm)	24.3 ± 1.4	29.3 ± 1.7	14	23.9 ± 2.2	24.9 ± 1.9	14
	Standing long jump distance (m)	1.50 ± 0.13	1.86 ± 0.15	14	1.52 ± 0.15	1.69 ± 0.17	14
	1-RM Half squat (kg)	72.2 ± 16	73.7 ± 19.1	14	73.3 ± 13.4	79.5 ± 14.3	14
	Repeated sprint T-test-Mean time (s)	7.71 ± 0.08	7.50 ± 0.08	14	7.70 ± 0.07	7.66 ± 0.06	14
	Lower-limb Force–velocity test (W/k)	5.5 ± 0.8	6.5 ± 0.7	14	5.3 ± 0.5	5.4 ± 0.5	14
Gaamouri et al. (2023c)	Agility t-half-test time (s)	7.45 ± 0.16	7.02 ± 0.26	17	7.46 ± 0.17	7.40 ± 0.18	17
	SJ height (cm)	21.9 ± 1.7	25.5 ± 1.2	17	22 ± 2.1	23 ± 1.6	17
	CMJ height (cm)	22.8 ± 1.8	26.8 ± 2	17	22.9 ± 2	23.8 ± 1.8	17
	Standing long jump distance (cm)	1.46 ± 0.13	1.56 ± 0.12	17	1.46 ± 0.15	1.57 ± 0.16	17
	Repeated sprint T-test-Mean time (s)	7.66 ± 0.06	7.43 ± 0.06	17	7.69 ± 0.07	7.66 ± 0.05	17
	1-RM Half squat (kg)	78.7 ± 11	95.8 ± 8.5	17	73.8 ± 12.7	77.6 ± 13.2	17
	Lower-limb Force–velocity test (W/k)	5.6 ± 0.7	6.5 ± 0.4	17	5.3 ± 0.5	5.4 ± 0.4	17
Hammami et al. (2019a)	5-m linear sprint time (s)	1.21 ± 0.06	1.10 ± 0.05	14	1.21 ± 0.04	1.18 ± 0.04	14
	10-m linear sprint time (s)	2.09 ± 0.07	1.93 ± 0.07	14	2.10 ± 0.06	2.09 ± 0.06	14
	20-m linear sprint time (s)	3.55 ± 0.24	3.29 ± 0.17	14	3.69 ± 0.19	3.68 ± 0.15	14
	30-m linear sprint time (s)	4.82 ± 0.37	4.82 ± 0.37	14	5.09 ± 0.34	5.05 ± 0.32	14
	Agility t-half-test time (s)	7.17 ± 0.36	6.79 ± 0.28	14	7.14 ± 0.21	7.14 ± 0.21	14
	Illinois agility test time (s)	13.2 ± 0.3	12.6 ± 0.3	14	13.2 ± 0.2	13.2 ± 0.2	14
	SJ height (cm)	26.8 ± 4.5	36.4 ± 3	14	26.8 ± 2.7	29.1 ± 2.5	14
	CMJ height (cm)	28.7 ± 4.4	39.3 ± 2.7	14	28.2 ± 3.5	30.3 ± 3.7	14
	CMJA height (cm)	33.0 ± 4.1	40.9 ± 2.4	14	32.0 ± 2.8	32.4 ± 3.7	14
	Horizontal jump 5JT (m)	9.0 ± 1.1	10.1 ± 1	14	8.3 ± 0.8	8.4 ± 0.7	14
	20-m shuttle run test (km/h)	14.8 ± 0.7	15.3 ± 0.5	14	15.1 ± 0.7	15.2 ± 0.6	14

	Predicted maximal oxygen intake (ml/min.kg)	47.6 ± 2.6	49.5 ± 1.9	14	48.7 ± 2.8	49.3 ± 2.3	14
	Y-balance test composite right-leg distance (cm)	83±7	87 ± 8	14	81 ± 7	83 ± 7	14
	Stork balance test right leg (s)	2.1 ± 0.6	1.9 ± 0.5	14	2.3 ± 0.7	2.1 ± 0.6	14
	Repeated sprint T-test-Mean time (s)	11.8 ± 0.5	11.6 ± 0.5	14	12.1 ± 0.8	11.7 ± 0.8	14
Hammami et al. (2019b)	5-m linear sprint time (s)	1.3 ± 0.11	1.21 ± 0.06	21	1.26 ± 0.06	1.22 ± 0.06	20
	10-m linear sprint time (s)	2.24 ± 0.15	2.12 ± 0.15	21	2.18 ± 0.09	2.15 ± 0.06	20
	20-m linear sprint time (s)	3.86 ± 0.33	3.49 ± 0.33	21	3.79 ± 0.17	3.71 ± 0.17	20
	30-m linear sprint time (s)	5.71 ± 0.4	4.52 ± 0.4	21	5.56 ± 0.27	5.09 ± 0.27	20
	Agility t-half-test time (s)	8.2 ± 0.63	7.02 ± 0.63	21	8.11 ± 0.17	7.84 ± 0.17	20
	Illinois agility test time (s)	13.88 ± 0.46	12.78 ± 0.47	21	13.88 ± 0.49	13.5 ± 0.49	20
	SJ height (cm)	19.6 ± 3.5	25.3 ± 3.5	21	19.3 ± 3.6	21 ± 3.6	20
	CMJ height (cm)	20.8 ± 4.7	26.7 ± 4.7	21	21.6 ± 4.2	23 ± 4.2	20
	CMJA height (cm)	25.7 ± 1.5	32.1 ± 1.5	21	25.5 ± 1.5	27.9 ± 1.5	20
	Horizontal jump 5JT (m)	7.44 ± 0.75	8.64 ± 0.5	21	7.58 ± 0.68	7.98 ± 0.68	20
	Y-balance test composite right-leg distance (cm)	63.8 ± 5.8	65.8 ± 5.8	21	62.2 ± 6.7	63.9 ± 6.7	20
	Stork balance test right leg (s)	2.28 ± 0.68	2.37 ± 0.68	21	2.07 ± 0.56	2.37 ± 0.56	20
Hammami et al. (2020a)	5-m linear sprint time (s)	1.22 ± 0.06	1.14 ± 0.08	10	1.22 ± 0.05	1.21 ± 0.04	10
	10-m linear sprint time (s)	2.14 ± 0.12	2.01 ± 0.11	10	2.16 ± 0.09	2.14 ± 0.10	10
	20-m linear sprint time (s)	3.58 ± 0.22	3.40 ± 0.12	10	3.55 ± 0.20	3.54 ± 0.18	10
	Agility t-half-test time (s)	7.17 ± 0.39	6.74 ± 0.28	10	7.13 ± 0.36	7.14 ± 0.30	10
	Illinois agility test time (s)	13.0 ± 0.4	12.4 ± 0.5	10	13.1 ± 0.2	13.0 ± 0.2	10
	SJ height (cm)	27.2 ± 3.8	35.6 ± 2.5	10	27.3 ± 3.0	29.5 ± 2.7	10
	CMJ height (cm)	30.7 ± 3.4	39.0 ± 3.1	10	30.4 ± 3.4	31.8 ± 3.1	10
	Five-jump test (m)	9.8 ± 1.2	11.1 ± 1.5	10	10.1 ± 1.1	10.2 ± 1.2	10
	Repeated sprint T-test-Mean time (s)	12.4 ± 0.3	11.0 ± 1.1	10	12.4 ± 0.7	12.3 ± 0.6	10
	Y-balance test composite right-leg distance (cm)	52.3 ± 10.8	55.5 ± 11.0	10	52.1 ± 12.1	52.6 ± 12.1	10
	Stork balance test right leg (s)	5.11 ± 5.44	6.76 ± 5.56	10	3.18 ± 1.31	3.54 ± 1.62	10
Hammami et al. (2020b)	5-m linear sprint time (s)	1.25 ± 0.06	1.12 ± 0.05	17	1.28 ± 0.05	1.24 ± 0.05	17
	10-m linear sprint time (s)	2.19 ± 0.05	2.05 ± 0.05	17	2.24 ± 0.05	2.20 ± 0.07	17
	20-m linear sprint time (s)	3.77 ± 0.05	3.56 ± 0.05	17	3.75 ± 0.05	3.68 ± 0.07	17
	30-m linear sprint time (s)	4.64 ± 0.05	4.28 ± 0.07	17	5.54 ± 0.05	5.49 ± 0.07	17
	Illinois agility test time (s)	13.07 ± 0.07	12.10 ± 0.09	17	13.11 ± 0.39	13 ± 0.39	17
	SJ height (cm)	22.4 ± 1.7	26.4 ± 1.9	17	22.8 ± 2.1	23.8 ± 1.6	17
	CMJ height (cm)	24.2 ± 1.6	29.3 ± 1.8	17	24.0 ± 2.0	24.9 ± 1.8	17
	CMJA height (cm)	25.3 ± 1.6	30.4 ± 2.1	17	25.3 ± 2.1	25.8 ± 2.1	17
	Five-jump test; (cm)	8.1 ± 0.3	9.3 ± 0.4	17	8.2 ± 1.5	8.5 ± 1.4	17
	Repeated sprint T-test-Mean time (s)	12.93 ± 0.17	12.15 ± 0.16	17	12.90 ± 0.18	12.77 ± 0.23	17
	Y-balance test composite right-leg distance (cm)	89 ± 8	92 ± 9	17	87 ± 9	92 ± 10	17
	Stork balance test right leg (s)	2.33 ± 1.16	3.37 ± 1.05	17	2.61 ± 1.16	3.92 ± 1.93	17
Hammami et al. (2021)	5-m linear sprint time (s)	1.17 ± 0.06	1.07 ± 0.05	17	1.18 ± 0.04	1.16 ± 0.1	15
	10-m linear sprint time (s)	2.04 ± 0.07	1.88 ± 0.06	17	2.05 ± 0.06	2.04 ± 0.1	15
	20-m linear sprint time (s)	3.46 ± 0.24	3.21 ± 0.17	17	3.65 ± 0.18	3.63 ± 0.15	15
	30-m linear sprint time (s)	4.67 ± 0.36	4.25 ± 0.27	17	5.0 ± 0.34	4.99 ± 0.3	15
	Agility t-half-test time (s)	7.05 ± 0.33	6.68 ± 0.26	17	7.06 ± 0.21	7.05 ± 0.20	15
	Illinois agility test time (s)	13.01 ± 0.27	12.46 ± 0.32	17	13.07 ± 0.23	13.06 ± 0.23	15
	SJ height (cm)	28.9 ± 4.5	38.0 ± 3.0	17	27.9 ± 2.7	30.5 ± 2.2	15
	CMJ height (cm)	30.9 ± 4.6	40.6 ± 2.7	17	29.5 ± 3.4	31.8 ± 3.3	15
	Repeated sprint T-test-Mean time (s)	11.6 ± 0.7	10.7 ± 0.6	17	11.6 ± 0.3	11.4 ± 0.3	15
	20-m shuttle run test (km/h)	14.8 ± 0.6	15.9 ± 0.5	17	15.0 ± 0.7	15.3 ± 0.6	15
	Predicted maximal oxygen intake (ml/min.kg)	47.8 ± 2.5	52.2 ± 1.9	17	48.4 ± 2.9	50.0 ± 2.6	15
Hermassi et al. (2014)	CMJ height (cm)	44.2 ± 0.6	48.6 ± 1.3	14	41.6 ± 0.9	42 ± 0.9	10
	SJ height (cm)	41.7 ± 1.3	44.9 ± 1.1	14	39.8 ± 1.2	40.6 ± 1.6	10
	Repeated sprint T-test-Total time (s)	37.4 ± 1.1	36.1 ± 0.9	14	38 ± 0.5	37.9 ± 0.6	10
	Lower-limb Force–velocity test (W/kg)	13.2 ± 0.5	14.2 ± 0.6	14	9.1 ± 0.8	9.2 ± 1	10
Karadenizli (2016)	Dynamic Balance-bipedal Slalom Test (%)	0.4 ± 0.1	0.1 ± 0.1	14	0.4 ± 0.2	0.1 ± 0.1	12
	Static Balance-unipedal Test (mm^2)	1581.8 ± 581.7	1483.2 ± 418.3	14	1558.6 ± 487.8	1510.2 ± 396.2	12
	Sit-and-reach Flexilibity Test (cm)	26.61 ± 6.32	30.21 ± 8.15	14	25.77 ± 5.30	29.55 ± 6.18	12
	CMJA height (cm)	37.5 ± 5.6	41.6 ± 7.3	14	36.2 ± 5.3	37.3 ± 8.9	12
	Standing long jump distance (cm)	1.77 ± 0.13	1.89 ± 0.15	14	1.76 ± 0.11	1.76 ± 0.11	12
	30-m linear sprint time (s)	5.38 ± 0.23	4.93 ± 0.20	14	5.44 ± 0.25	5.41 ± 0.47	12
	Illinois agility test time (s)	16.02 ± 0.23	16.02 ± 0.38	14	16.88 ± 0.86	16.76 ± 0.49	12

Mazurek et al. (2018)	Aerobic VO2max (ml/kg/min)	43 ± 5	46 ± 6	14	45 ± 10	45 ± 13	12
	DJ height (cm)	55 ± 7	56 ± 6	14	52 ± 9	51 ± 9	12
	CMJ height (cm)	47 ± 6	46 ± 5	14	45 ± 9	44 ± 9	12
	SJ height (cm)	41 ± 4	40 ± 3	14	40 ± 8	39 ± 8	12
	Repeated sprint T-test (W/kg)	10.2 ± 0.6	10.3 ± 0.6	14	10.1 ± 0.9	10.2 ± 1.0	12
Noutsos et al. (2021)	Agility t- test time (s)	15.23 ±1.30	13.80 ±1.02	19	15.31 ±1.45	15.32 ±1.44	14
	10-m linear sprint time (s)	1.81 ±0.18	1.78 ±0.16	19	1.85 ±0.18	1.86 ±0.19	14
	20-m linear sprint time (s)	4.18 ±0.34	4.03 ±0.37	19	4.19 ± 0.31	4.20 ± 0.31	14
	CMJ height (cm)	21.36 ±5.20	21.74 ±5.18	19	19.78 ±5.62	19.74±5.54	14
	SJ height (cm)	18.07 ±4.48	19.71 ± 4.66	19	18.13 ±6.02	18.14 ±6.02	14
Pancar et al. (2020)	30-m linear sprint time (s)	6.10 ± 0.28	5.74 ± 0.36	14	5.86 ± 0.27	5.82 ± 0.26	14
	Anaerobic power (W)	333.9 ± 59.9	356.5 ± 80.7	14	279.7 ± 58.4	291.3 ± 77.1	14
	Overall Balance Score (static)	1.50 ± 0.55	1.01 ± 0.33	14	0.97 ± 0.24	1.01 ± 0.63	14
Spieszny & Zubik (2018)	CMJ height (cm)	45.4 ± 3.4	48.2 ± 3	8	47 ± 3.8	48 ± 3.8	12
	SJ height (cm)	41.1 ± 3	43 ± 2.5	8	42.7 ± 3	44.4 ± 2.9	12

APPENDIX C

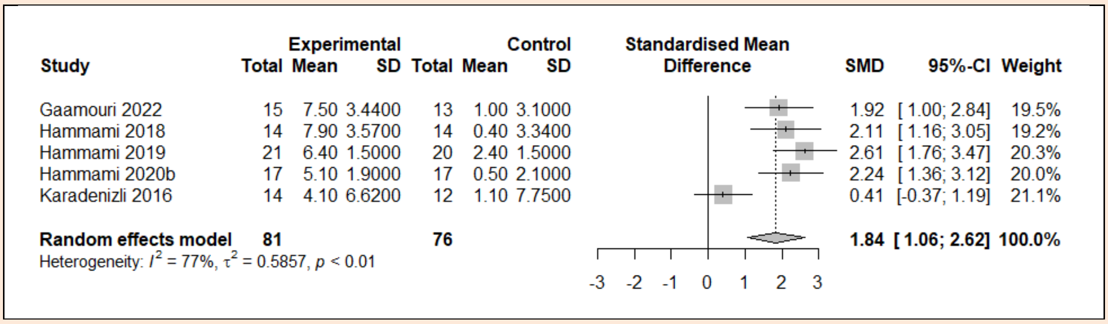
Physiotherapy Evidence Database (PEDro) scale ratings for the included studies.

Study	Item number											Total (from a possible maximum of 10)
	1 [a]	2	3	4	5	6	7	8	9	10	11	
Aloui et al. (2020)	1	1	0	1	0	0	0	1	1	1	1	6
Chaabene et al. (2019)	1	0	0	1	0	0	0	1	0	1	1	4
Chelly et al. (2014)	1	1	0	0	0	0	0	1	1	1	1	5
De Villarreal et al. (2022)	1	1	0	1	0	0	0	1	1	1	1	6
De Villarreal et al. (2022)	1	1	0	1	0	0	0	1	1	1	1	6
Ethiraj et al. (2020)	1	1	0	0	0	0	0	1	1	1	1	5
Gaamouri et al. (2022)	1	1	0	1	0	0	0	1	1	1	1	6
Gaamouri et al. (2023a)	1	0	0	1	0	0	0	1	1	1	1	5
Gaamouri et al. (2023b)	1	0	0	1	0	0	0	1	1	1	1	5
Hammami et al. (2018)	1	1	0	1	0	0	0	1	1	1	1	6
Hammami et al. (2019)	1	1	0	1	0	0	0	1	1	1	1	6
Hammami et al. (2020a)	1	1	0	1	0	0	0	1	1	1	1	6
Hammami et al. (2020b)	1	1	0	1	0	0	0	1	1	1	1	6
Hammami et al. (2021)	1	1	0	1	0	0	0	1	1	1	1	6
Hermassi et al. (2014)	1	1	0	0	0	0	0	1	1	1	1	5
Karadenizli (2016)	1	1	0	1	0	0	0	1	1	1	1	6
Mazurek et al. (2018)	1	1	0	0	0	0	0	1	1	1	1	5
Noutsos et al. (2021)	1	1	0	0	0	0	0	1	1	1	1	5
Pancar et al. (2020)	1	1	0	0	0	0	0	1	1	1	1	5
Spieszny & Zubik (2018)	1	1	0	0	0	0	0	1	1	1	1	5

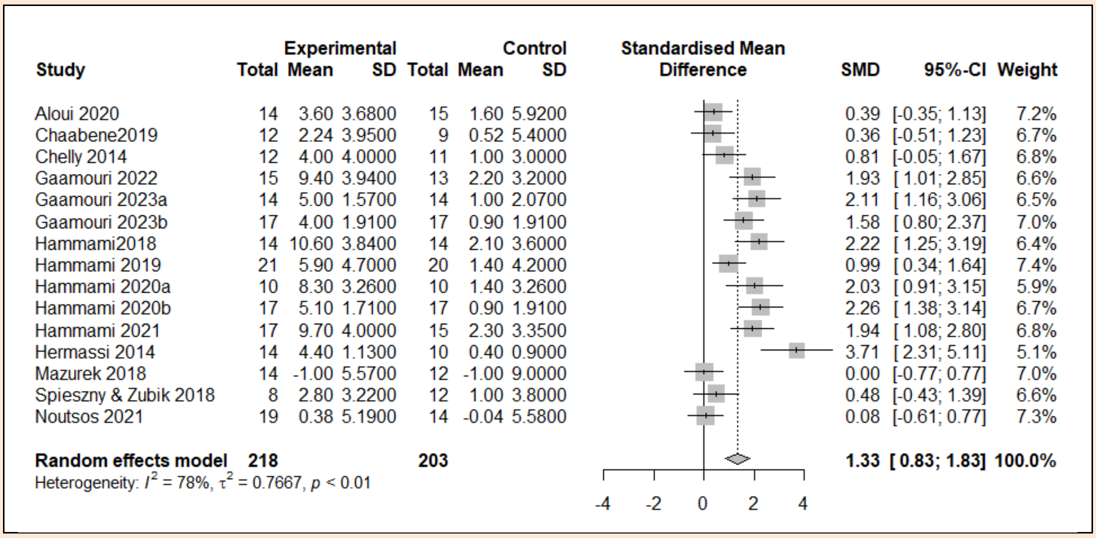
[a] Adetailed explanation for each PEDro scale item can be accessed at https://www.pedro.org.au/english/downloads/pedro-scale (access for this review: June 19, 2020). In brief: Item 1, eligibility criteria were specified (this item is not considered in the total); Item 2, participants were randomly allocated to groups; Item 3, allocation was concealed; Item 4, the groups were similar at baseline; Item 5, there was blinding of all participants regarding the plyometric jump training programme being applied; Item 6, there was blinding of all coaches responsible for the application of plyometric jump training programme regarding its aim toward the improvement of physical fitness; Item 7, there was blinding of all assessors involved in measurement of physical fitness attributes; Item 8, measures of at least one key fitness variable were obtained from more than 85% of participants initially allocated to groups; Item 9, all participants for whom fitness variables were available received the treatment or control condition as allocated, or data for at least one key fitness variable was analysed by "intention to treat"; Item 10, the results of between-group statistical comparisons are reported for at least one key fitness variable; and Item 11, point measures and measures of variability for at least one key fitness variable are provided.

APPENDIX D

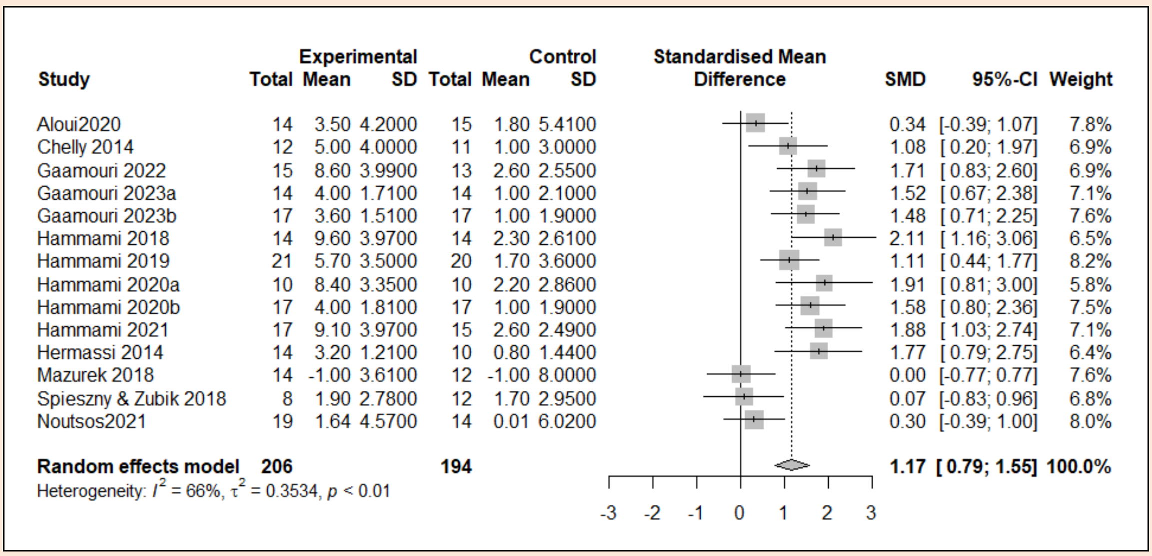
Meta-Analysis Results (Figure 1 to Figure 12)



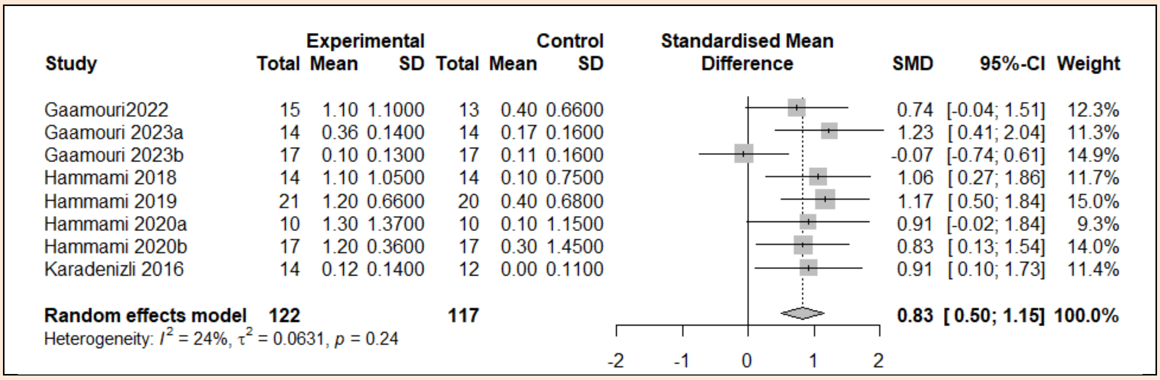
Appendix D (Figure 1). **Forest plot of changes in countermovement jump with arms height in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.**



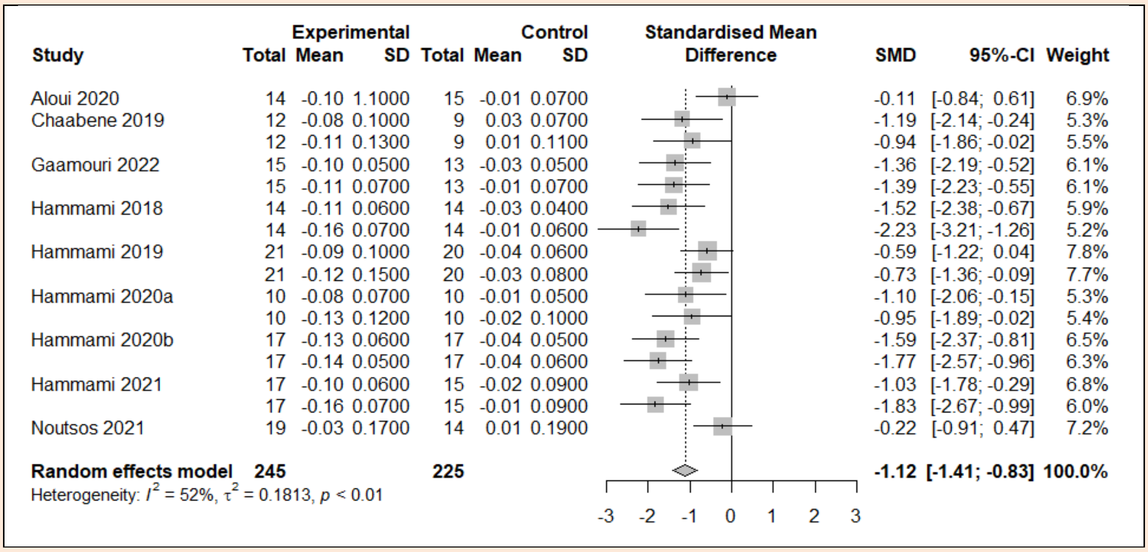
Appendix D (Figure 2). **Forest plot of changes in countermovement jump height in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.**



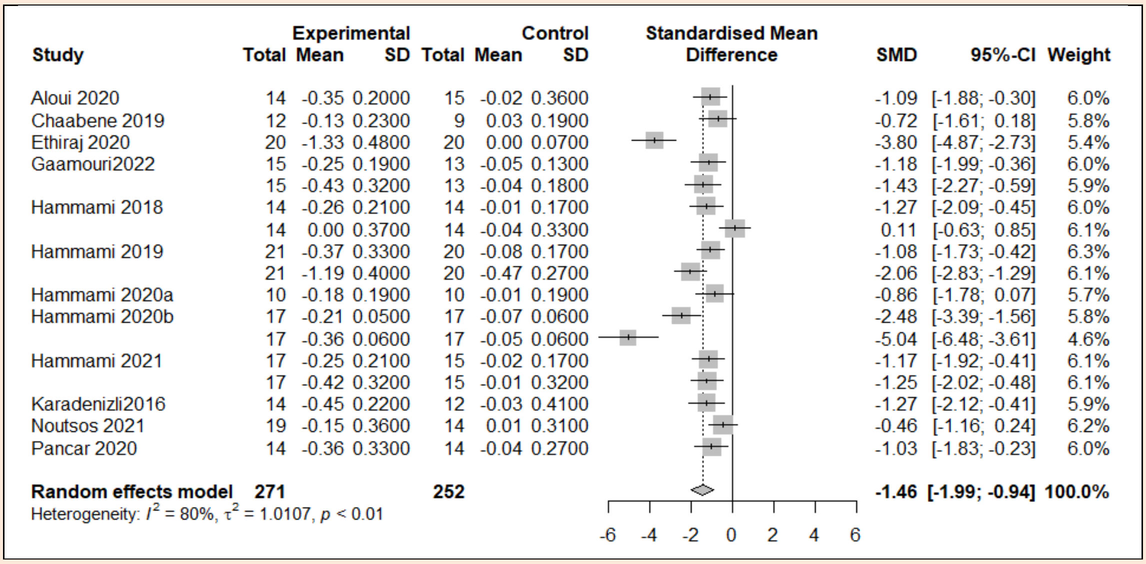
Appendix D (Figure 3). **Forest plot of changes in squat jump height in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.**



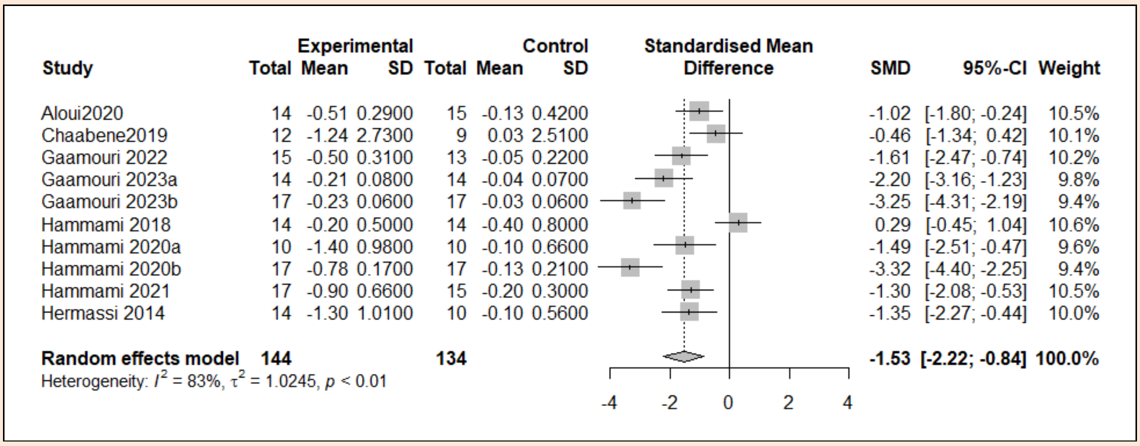
Appendix D (Figure 4). **Forest plot of changes in horizontal jump distance in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.**



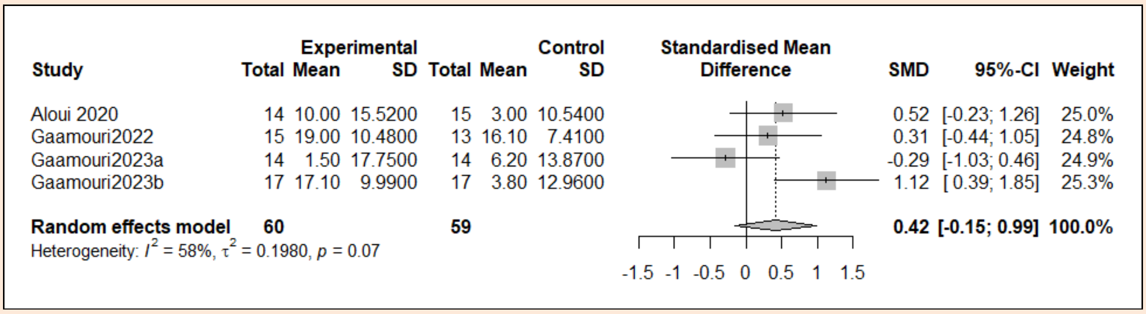
Appendix D (Figure 5). **Forest plot of changes in ≤ 10-m linear sprint time in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.**



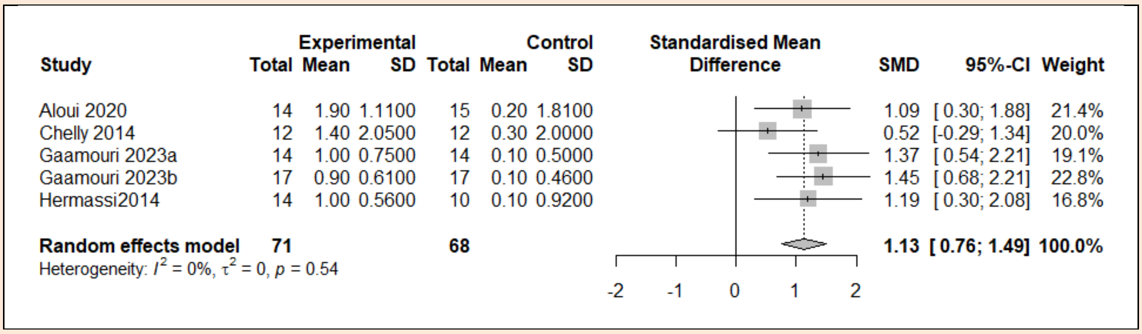
Appendix D (Figure 6). **Forest plot of changes in > 10-m linear sprint time in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.**



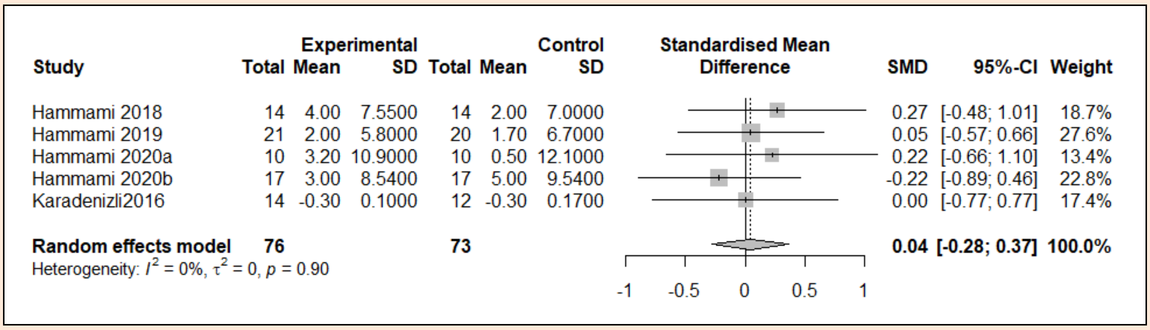
Appendix D (Figure 7). Forest plot of changes in repeated sprint ability with change-of-direction time in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.



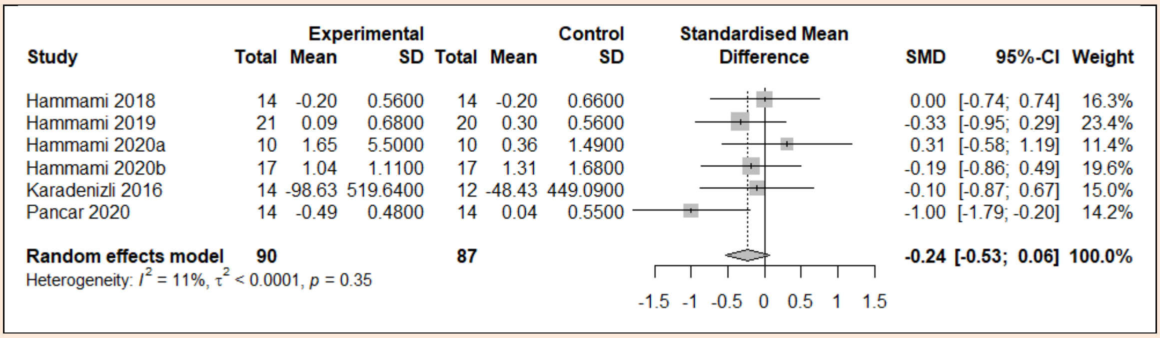
Appendix D (Figure 8). **Forest plot of changes in maximal strength in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.**



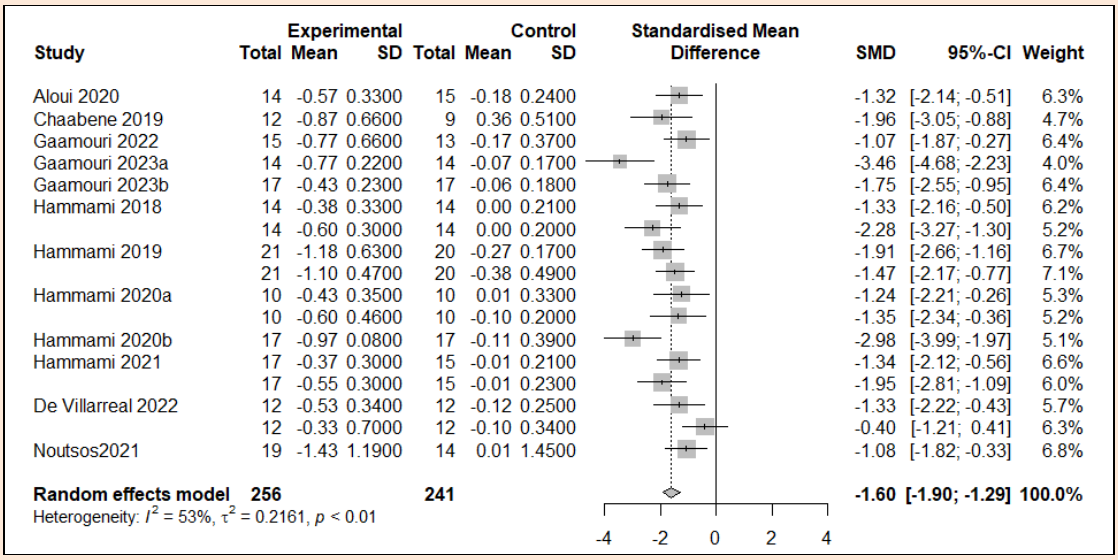
Appendix D (Figure 9). **Forest plot of changes in force–velocity in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.**



Appendix D (Figure 10). Forest plot of changes in dynamic balance in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.



Appendix D (Figure 11). Forest plot of changes in static balance in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.



Appendix D (Figure 12). Forest plot of changes in Agility test time in handball players participating in plyometric jump training compared to handball players allocated as controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of each study.