PLYOMETRIC TRAINING PROGRAMS IN HANDBALL: A SYSTEMATIC SCOPING REVIEW

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Review
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Abstract:

This systematic scoping review aimed to comprehensively identify and analyze the available evidence pertaining to the effects of plyometric training interventions on handball players. The search for relevant literature was conducted across prominent databases, including PubMed, Scopus, SPORTDiscus, and Web of Science Core Collection. The eligibility criteria focused on healthy handball players, without restrictions on age, sex, or competitive level, who were exposed to plyometric training interventions, either alone or in combination with other training methods. A meticulous screening process was conducted, whereby 3,195 titles were carefully evaluated, resulting in the inclusion of 35 eligible studies in this systematic scoping review, involving a total of 891 participants. Most studies on plyometric training in handball focused on indoor settings, conducted during the in-season period, and involved tier two athletes. The training frequency typically ranged from twice per week, with a duration of between 5 and 12 weeks, and incorporated some form of progressive overload. The number of total floor contacts varied between 20 and 600. There was a considerable variation in outcomes across the included studies, but most of them demonstrated a positive impact of plyometric training on improving jumping ability, sprinting speed, change of direction, strength, and balance. In conclusion, the predominant focus of the studies was on the lower limb, specifically aiming to assess the intervention influence on variables associated with strength and power. Notably, these investigations consistently highlighted favorable effects on enhancing these parameters among handball players. However, further research is needed to explore the effects of plyometric training in handball, particularly regarding exercise selection, optimal volume and intensity, rest intervals, and tapering protocols.

Key words: *team sports, muscle strength, resistance training, stretch-shortening cycle*

Introduction

Plyometric training (PT) exercises involve rapid stretching (i.e., lengthening) of a muscle before a rapid transition to a concentric contraction, and this combined action is commonly called the stretch-shortening cycle (Turner & Jeffreys, 2010). PT exercises have been widely researched for their beneficial effects on strength, speed, power, change of direction (COD), throwing, and jumping (Moran, et al., 2021; Slimani, Chamari, Miarka, Del Vecchio, & Chéour, 2016). Those beneficial effects on athletic performance have been observed in multiple team sports such as soccer (Clemente, et al., 2022; Ramirez-Campillo, et al., 2020c), volleyball (Silva, et al., 2019), basketball (Ramirez-Campillo, et al., 2022), and handball (Ramirez-Campillo, et al., 2020a).

Plyometric training effectively improves athletic performance, does not require much equipment (or any), and can be used anywhere (e.g., sand, water, grass), offering a flexible way to employ in any sport and context (Arazi, Eston, Asadi, Roozbeh, & Zarei, 2016; Lännerström, Nilsson, Cardinale, Björklund, & Larsen, 2021). This fact, combined with effectiveness, may justify the interest and pertinence of this training method. Moreover, PT accommodates well to other training methods (e.g., high-intensity interval training; balance training), i.e., no negative interference or transfer effect has been observed (Chaabene, et al., 2021; Hammami, et al., 2021). Although the body of knowledge regarding PT effects has increased considerably (Ramirez-Campillo, et al., 2020b), some topics still need further research, including optimization strategies for PT volume, intensity, weekly frequency, type of exercise, and its effects on different groups of athletes (Di Giminiani & Petricola, 2016; Ebben, 2007; Ebben, Suchomel, & Garceau, 2014; Matic, et al., 2015; Watkins, Storey, McGuigan, & Gill, 2021).

In team sports such as handball, PT can be substantially promising for improving athletic performance (Chelly, Hermassi, Aouadi, & Shephard, 2014; Mazurek, et al., 2018; Ramirez-Campillo, et al., 2020a), as handball players commonly perform actions such as sprinting, accelerations, jumping or throwing (Karcher & Buchheit, 2014). Additionally, handball is also characterized by frequent physical duels with the opponents and requires accelerations for starting counterattacks or COD to overcome the opponents (Ziv & Lidor, 2009). Indeed, physical fitness attributes may help differentiate among handball players' levels in adult, youth, male, and female handball competition (Chaabene, et al., 2021; Pereira, et al., 2018; Romaratezabala, et al., 2020). Given that handball requires well-developed physical fitness, PT can fit into the regular training schedule of athletes, offering some advantages (e.g., easy to use in any context, beneficial effects on strength and power, low interference with other training methods) over other training methods (e.g., eccentric training). Additionally, PT has positive effects on handball athletic performance markers like strength, power, speed, and COD, which translates positively into handball actions like jumping, throwing, running, and sprinting, both linear and multidirectional (Chaabene, et al., 2021; Chelly, et al., 2014; Hermassi, et al., 2014).

The allure of plyometric training lies in its minimal equipment requirements and inherent flexibility. Coaches possess the ability to manipulate various exercise variables to shape the desired training outcomes. These encompass factors such as frequency and duration (weeks, sessions per week, session duration, total program sessions), intensity (assessed subjectively or quantitatively via tools like video cameras or inertial measurement units), laterality (bilateral and/or unilateral movements), drill types (e.g., squats, skipping, bounding, jumping, hopping), supplemental equipment (e.g., medicine balls, boxes), box height, surface type (e.g., turf, sand, concrete), regimen (sets, repetitions, inter-set and intra-set rest), total repetitions (e.g., jumps, throws), rest intervals between sets, repetitions, and sessions, progressive overload, training period, substitution of jump training, tapering, novel aspects, limitations, considerations, and potential synergies with other training methods. These factors serve as manageable constraints that influence the acute stimulus experienced by players, thereby modulating the intensity and complexity of their training experience.

Although previous systematic reviews (with meta-analysis or scoping focuses) addressed the effects of PT, these did not include analyses of upper-body plyometric training methods (Ramirez-Campillo, et al., 2020a), and they focused on sports other than handball (Ramirez-Campillo, et al., 2020b). In a more recent development, a systematic review (Jakšić, et al., 2023) delved into the impacts of supplementary plyometric training on jump performance of elite handball players. Nonetheless, it is crucial to highlight that this particular review centers solely on lower-limb plyometric training and its distinct effect on vertical jump performance. Limited to a sample size of only six articles, this review exclusively addresses elite male handball players. Moreover, it exhibits certain constraints, notably in its lack of exhaustive insight into the methodological specifics of the encompassed studies. Furthermore, it neglects to present a comprehensive overview of the broader body of literature concerning plyometric training in handball, leaving gaps in understanding within the research landscape.

In contrast to a systematic review, a systematic scoping review aims to fill these gaps and provide a comprehensive overview of the research conducted in this area. A systematic scoping review may be well-suited to provide a broader overview of the available evidence regarding the effects of PT on handball players' adaptations (Munn, et al., 2018). Using a scoping review, we go beyond the narrow focus on lower-limb training and vertical jump performance, as we also include upper-limb plyometric training and consider both male and female athletes. Moreover, we may encompass a broader range of participants, including youth and adults, to explore the potential influences of age and competitive level on training adaptations.

For those reasons, this systematic scoping review aimed to: (i) examine the impact of plyometric training interventions on the physical fitness adaptations of handball players; (ii) examine study design characteristics (e.g., interventions and comparators; the number of groups and randomization; volume-equalization) of the available evidence; and (iii) identify key characteristics of methodological training approaches used (e.g., duration; intensity; previous plyometric training experience).

Methods

This systematic scoping review followed the PRISMA 2020 guidelines and considered the recommendations for scoping reviews checklist (PRISMA-ScR). The protocol was registered at OSF with the code 10.17605/OSF.IO/M65CK on January 11, 2023.

Eligibility criteria

This systematic scoping review only included full-text original articles that had been subjected to peer review. No restrictions were set on language or date of publication. Following the PICOS (population, intervention/exposure, comparator, outcome, study design) approach, the eligibility criteria were as follows:

(Population) Handball and para-handball players of any competitive level, age, or sex.

(Intervention) Jump-based and upper-body based plyometric training for the upper and/or lower limbs and/or combined training, including plyometric training, with the latter comprising at least 50% of the training intervention, considering: i) the number of exercises or ii) time of exposure. No specific time constraint was placed on the training duration, as our objective was to conduct a comprehensive scoping review aimed at identifying various approaches presented in the literature.

(Comparator) Not necessary. Although, in the case of the comparator, it must be regular training-only (i.e., players OR controls exposed to regular on-court training) and/or active controls (exposed to a specific training intervention, not including plyometric training), regardless of being volume-equated. Passive controls would be considered if any study conducted interventions during the off-season.

(Outcomes) Methodological characteristics of training protocol (e.g., frequency, intensity); physical fitness and/or psychophysiological variables measured pre- and post-intervention.

(Study design) No restriction.

Information sources

Two authors (JA and JM) executed the searches for relevant publications on January 12th, 2023, by browsing the electronic databases (PubMed, Scopus, SPORTDiscus, and Web of Science core collection). In addition to the database searches, (i) manual searches were performed using the reference lists of the included studies to identify potentially relevant titles; (ii) snowballing citation tracking was executed, preferably in the Web of Science; and (iii) two external experts were consulted (as recognized by Expertscape at the *World* level for “plyometric exercise” which was accessed at https://expertscape.com/ex/plyometric+exercise on January 12, 2023). The list of the included titles was shared with the experts who employed their search strategy and cross-checked the list. Finally, errata and article retractions were analyzed for any of the included articles.

Search strategy

In the search, the Boolean operators AND/OR were applied. No filters were applied to maximize the chances of identifying relevant studies. Keywords and synonyms were entered in various combinations in all fields:

[Title/Abstract] (Handball* OR “Hand-ball*”)

AND

[All fields/Full text] (plyometric* OR ballistic OR “stretch-shortening cycle” OR reactive OR jump* OR power OR rebound*).

Selection process

Two authors (JR and FMC) independently screened the retrieved records (titles and abstracts). The same authors also independently screened the gathered full texts. Disagreements between the two authors were discussed in a joint reanalysis. In the case of no consensus being reached, the third author (RRC) made the final decision. Where and when required, all co-authors shared opinions about any doubts raised in the selection process to support the final decision. The reference list of the included articles was additionally reviewed by both authors to identify any potentially relevant articles that might have been inadvertently omitted from the selection process. The EndNote™ 20.4 software (Clarivate™) was used for managing records, namely the removal of duplicates either automatically or manually.

Extraction of data

A data extraction sheet, adapted from the Cochrane Consumers and Communication Review Group’s data extraction template, was used to assess inclusion requirements, and subsequently tested on 10% of randomly selected studies (i.e., pilot testing). Two authors (JR and FMC) conducted this process. Full-text articles excluded, with reasons, were recorded. The records were registered in a form created in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

Data items

JR and FMC collected the information and details regarding the study, considering (but not restricted to) the following:

Study details included (but not restricted to): authors, year of publication, study design, treatment, control group (if any), randomization, blinding strategies, the occurrence of injuries, attrition, citation details, country of data collection, funding sources, and competing interests.

Context-related information included (but not restricted to): the moment of the season (e.g., off-season, pre-season, in-season).

Participants-related information included (but not restricted to): the number of participants, sex, age, competitive level (while using the Participant Classification Framework, body mass, height, systematic jump training experience, sport practiced e.g., handball, para-handball, beach handball).

Intervention-related information included (but not restricted to): frequency and duration (the number of weeks; the number of sessions per week; duration of each session; the number of sessions in the entire program; days between PT sessions), intensity (quantification method, if any); if reported, laterality (bilateral and/or unilateral), type of drills (e.g., squats, skipping, bounding, jumping, hopping), additional instruments used (e.g., medicine balls; boxes), box height (if any), type of surface (e.g., turf, sand, concrete), regimen (e.g., sets, repetitions, rest between sets and repetitions); the number of total repetitions (e.g., jumps; throws); rest between sets, rest between repetitions, rest between training sessions; progressive overload (if any); part of training session; jump training replaced, tapering, novel aspect, limitations or considerations; possible combination with another training method.

Outcomes-related information included (but not restricted to): physical fitness variables (e.g., strength, balance, cardiorespiratory); physical fitness tests used (and the reliability or variability of data, if reported), and the number of time points at which tests were applied over the experimental period.

Results

Study identification and selection

The initial search yielded a total of 3,195 titles (Figure 1). The data were imported to the EndNote™ reference manager software (version 20.2, Clarivate Analytics, Philadelphia, PA, USA). Duplicates (795 titles) were subsequently removed, either automatically or manually. The remaining 2,860 titles were screened for their relevance based on their titles and abstracts. Of those, 2,746 titles were removed. The full texts of the remaining 114 titles were then inspected, and 83 were removed based on the reasons presented in Figure 1. Therefore, 31 articles remained for data extraction and further analysis. Following the revision of the list of 31 articles by the PT experts, two further eligible titles were suggested, reviewed, and integrated. Additionally, two articles were also found eligible in the snowballing citation tracking process. Finally, 35 articles were included in the systematic scoping review.

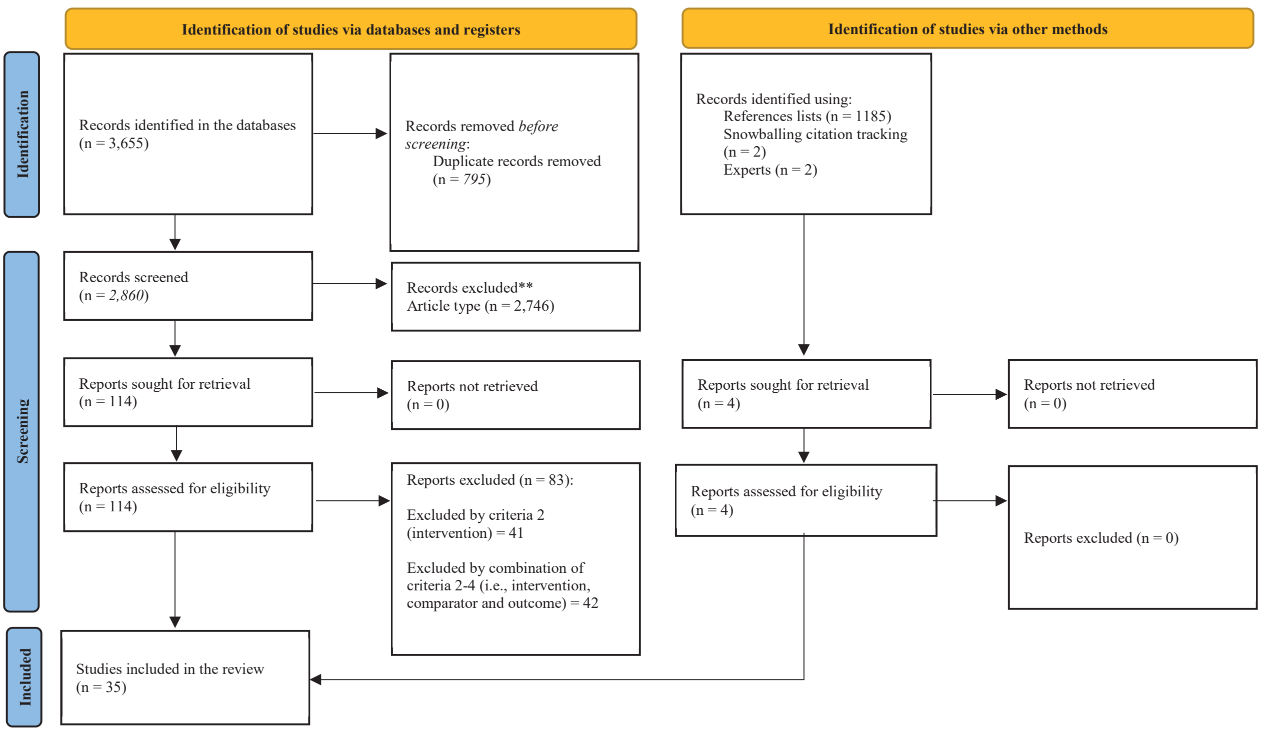

Figure 1. PRISMA 2020 flow diagram.

Study characteristics

Table 1 describes the main study characteristics of the included articles. The overall number of participants was 891. Three studies focused on non-defined tier, 25 studies on tier two, and seven studies on tier three. Moreover, 17 studies were conducted with men, 14 with women, two on both, and two were not defined. Out of the 35 studies, 34 of them were conducted in an indoor handball setting. Regarding the context and randomization, 25 studies were randomized, five were not, while seven others were not defined.

Training intervention characteristics

Regarding the timing of the interventions (Table 1), 23 out of the 35 studies were conducted during the in-season, nine were conducted during the off-season, and only four did not specify in which period of the season the studies had been conducted.

In most of the collected studies, interventions had a frequency of twice per week. However, a significant proportion of studies also had a frequency of three times per week, with values ranging from 24% to 33% across the three tiers. Additionally, most studies had a duration of between five and 12 weeks, with a slightly higher percentage located in the 5-8 week interval. Only two studies had a duration of up to four weeks (Parnow & Hosseini, 2016; Shbib, Rashidlamir, & Hakak Dokht, 2021), and only one (Spieszny & Zubik, 2018) lasted for more than 13 weeks.

Main physical fitness measures analyzed

Considering the assessments performed (Table 1), the following was used: vertical jump (in 30 studies); horizontal jumping (in 5 studies); sprint running (in 23 studies); repeated sprint ability (in 17 studies); change of direction (in 18 studies); cycle-ergometer (in 8 studies).

Characteristics of the training methodologies

Table 2 presents the main methodological characteristics of the training programs implemented in the analyzed handball studies.

Surface

Thirty of the 35 studies did not specify on what kind of surface the plyometric training was done. From the ones that did, two were done on the gym floor (Hammami, et al., 2021; Soto Garcia, Diaz Cruz, Bautista, & Martinez Martin, 2022), one was done on sand (Hammami, et al., 2022), and other on both of them—sand and gym floor (Hammami et al., 2020a). However, given that most of the studies were done with indoor handball players, it is fair to suppose that most of the studies were done on a gym floor surface, but it is not possible to affirm it without confirmation.

Plyometric training drills

The review of 35 studies identified over 40 exercises, with hurdle jumps being the most common exercise in 18 studies. If we include exercises registered under different names such as lateral hurdle jumps, horizontal hurdle jumps, and drop to hurdle jumps, a total of 23 studies involved hurdle jumps. Hops were the second most common exercise, with 11 studies registering their use, along with seven studies using variations such as single-leg hops, bleacher hops, side-to-side hops, diagonal hops, and front hops, making a total of 19 studies using hops. The third most used exercise was some form of drop jump, with nine studies registering their use, and three studies using vertical, horizontal, and drop to hurdle jumps, respectively, totaling 12 studies. Horizontal jumps were equally common, with ten studies registering their use, and two studies using variations such as horizontal hurdle jumps and horizontal drop jumps, totaling 12 studies. This category may also include other types of horizontal jumps, such as frontal multi-jumps, front and back jumps, coordination ladder jumps, and stride jumps. Four studies registered the use of vertical jumps, but other exercises were also done in a vertical vector, such as counter-movement jumps (bilateral and unilateral), box jumps, rope skipping, various jumping squats (barbell jump squats, split squat jumps, half squat jumps, and squat jumps), depth jumps, and drop jump variations. Lateral jumps and their variations were used in five studies, with another study using skater jumps and another using diagonal jumps (zig-zag jumps). Of the seven studies registering the use of upper body plyometrics, six used dynamic/plyometric push-ups, while the other used a dynamic/throwing bench press. These results show a much greater prevalence of lower-body plyometrics than upper-body plyometrics.

The review found that the only exercise specific to the sport of handball was a jump shot drill. One study also registered two types of bounds—alternate leg and double leg bounds (Ramadan & Elsayed, 2022). In addition, there were four exercises performed without much information provided, including stretched-leg jumps, single and double leg jumps, multi-jumps, and jumps over medicine balls.

Based on this information, it can be concluded that the most commonly used plyometric exercises in handball are hurdle jumps (mostly done horizontally) and vertical jumps, which may include drop jumps, depth jumps, box jumps, counter-movement jumps (CMJs), squat jump variations, and hops.

Table 1. Characteristics of the included studies

<table>
<tr><th>Study</th><th>N</th><th>Handball type</th><th>Tier level</th><th>Age (M±SD) | Sex (F or M)</th><th>Type of study</th><th>Season period | Previous practice in plyometrics</th><th>Training duration (weeks)</th><th>Sessions per week (n)</th><th>Total sessions (n) | Adherence (%)</th><th>Control group (description)</th><th>Assessments performed</th><th>Number of assessments</th></tr>
<tr><td>(Alkasasbeh, 2023)</td><td>36</td><td>Indoor</td><td>Tier 2</td><td>15-18 | F</td><td>Two-arm controlled trial (quasi-experimental)</td><td>N. D. | Yes</td><td>10</td><td>3</td><td>30 | ND</td><td>Both groups performed PT, although one started with PT+strength training and changed after 5 weeks while the other group did the opposite</td><td>1-RM back squat, handball throwing, CMJ, CMJA, 30m sprint, COD, Yo-Yo</td><td>3 (pre-intervention, mid-intervention, post-intervention)</td></tr>
<tr><td>(Alonso-Fernández et al., 2017)</td><td>EG: 7
CG: 7</td><td>Indoor</td><td>Tier 2</td><td>15.2 ± 0.6 | F</td><td>Randomized Two-arm controlled trial</td><td>In-season | ND</td><td>8</td><td>2</td><td>16 | ND</td><td>CG: standard handball training</td><td>CMJ, RSA, 20m shuttle run, anthropometry (height, weight, BMI, body fat)</td><td>2 (pre- and post-intervention)</td></tr>
<tr><td>(Aloui et al., 2020)</td><td>CG: 15
EG: 14</td><td>Indoor</td><td>Tier 2</td><td>CG:
18.1 ± 0.5
EG: 17.7 ± 0.3 | M</td><td>Randomized Two-arm controlled trial</td><td>In-season | ND</td><td>8</td><td>2</td><td>16 | ND</td><td>Standard handball training, physical training (aerobic and power) and physical education classes</td><td>Force-velocity on cycle-ergometer, SJ, CMJ, 30m sprint, 1RM back half-squat, T-half, repeated COD</td><td>2 (pre- and post-intervention)</td></tr>
<tr><td>(Aloui et al., 2021)</td><td>EG: 14
CG: 15</td><td>Indoor</td><td>Tier 2</td><td>EG: 17.7 ± 0.3
CG: 18.1 ± 0.5 | M</td><td>Randomized Two-arm controlled trial</td><td>In-season | ND</td><td>8</td><td>2</td><td>16 | ND</td><td>CG: resistance + handball standard training</td><td>Force-velocity on cycle-ergometer, handball throwing, 1RM bench press, 1RM pull-over, anthropometry (arm muscle volume and body fat)</td><td>2 (pre- and post-intervention)</td></tr>
<tr><td>(Büsch et al., 2015)</td><td>STAB: 10
INSTAB: 9</td><td>Indoor</td><td>Tier 2</td><td>STAB:
16.7±0.6
INSTAB:
17.4±0.9 | M+F</td><td>Randomized Two-arm controlled trial</td><td>ND | ND</td><td>10</td><td>2</td><td>20 | ND</td><td>CG: None</td><td>DJ, CMJ, SJ, standing long jump, 20m sprint</td><td>2 (pre- and post-intervention)</td></tr>
<tr><td>(Cetin & Ozdol, 2012)</td><td>PT: 9
CG: 9</td><td>Indoor</td><td>Tier 2</td><td>13.66±0.5 | F</td><td>Two-arm controlled trial (quasi-experimental)</td><td>ND | No</td><td>12</td><td>3</td><td>36 | ND</td><td>CG: standard handball training</td><td>Push-ups, vertical jump height, vertical jump velocity</td><td>2 (pre- and post-intervention)</td></tr>
<tr><td>(Chaabene et al., 2021)</td><td>EG: 12
CG: 9</td><td>Indoor</td><td>Tier 2</td><td>EG: 15.9 ± 0.2
CG: 15.9 ± 0.3 | F</td><td>Non-randomized Two-arm controlled trial</td><td>In-season | Yes</td><td>8</td><td>2</td><td>16 | EG: 94%; CG: 96%</td><td>CG: standard handball training</td><td>Sprint running over 5, 10 and 20m, T-test, CMJ, RSI, RSA</td><td>2 (pre- and post-intervention)</td></tr>
<tr><td>(Chelly et al., 2014)</td><td>EG: 12
CG: 11</td><td>Indoor</td><td>Tier 2</td><td>17.4±0.5 | M</td><td>Randomized Two-arm controlled trial</td><td>In-season | ND</td><td>8</td><td>2</td><td>16 | ND</td><td>CG: standard handball training + strength/circuit training</td><td>SJ, CMJ, force-velocity on cycle-ergometer, handball throwing, sprint running over 5, 25 and 30m, anthropometry (stature, skinfolds and body fat)</td><td>2 (pre- and post-intervention)</td></tr>
</table>

Continuation of table 1

(Cherif et al., 2012)	EG: 11 CG: 11	Indoor	Tier 3	20.18±1.32 | M	Two-arm controlled trial (quasi-experimental)	In-season | ND	12	1-2	18 | ND	CG: standard handball training	SJ, CMJ, CMJA, DJ, RSA	2 (pre- and post-intervention)
(Dahl & Van Den Tillaar, 2021)	SBT: 13 PST: 12	Outfield	Tier 3	19.5±2.0 | F	Randomized Two-arm controlled trial	In-season | ND	8	3	24 | ND	CG: plyometric and spring training	Ball velocity, trunk velocity, core strength 1RM	2 (pre- and post-intervention)
(Falch et al., 2022)	ST: 11 PT: 10	Indoor	Tier 2	ST: 17.5 ± 2.3 PT: 17.1 ± 2.4 | F	Randomized Two-arm controlled trial	ND | ND	8	1-2	12 | 77%	Strength training group	COD tests, squat (bilateral, quarter, lateral), DJ, CMJ, skate jump, sprint running over 5, 10, 20 and 30m	2 (pre- and post-intervention)
(Hammami et al., 2018b)	EG: 14 CG: 14	Indoor	Tier 2	EG: 14.5 ± 0.3 CG: 14.6 ± 0.2 | M	Randomized Two-arm controlled trial	In-season | Yes	8	2	16 | ND	CG: standard handball training	RSTT, Sprint running at 5, 10, 20 and 30m, Modified Illinois, T-half test, SJ, CMJ, CMJA 5-jump, Y-Balance, Stork, 20m shuttle run	2 (pre- and post-intervention)
(Hammami et al., 2021)	EG: 17 CG: 15	Indoor	Tier 2	EG: 16.6 ± 0.5 CG: 16.5 ± 0.8 | M	Randomized Two-arm controlled trial	In-season | ND	8	2	16 | ND	CG: resistance + standard handball training	SJ, CMJ, sprint running over 5, 10, 20 and 30m, modified Illinois, T-half test, 20m shuttle run, RSTT	2 (pre- and post-intervention)
(Hammami et al., 2022)	JST: 24 CG: 18	Indoor	Tier 2	JST: 16.4 ± 0.4 CG: 16.2 ± 0.4 | M	Randomized Two-arm controlled trial	Pre-season | ND	7	3	21 | 90%	CG??: standard handball training	SJ, CMJ, 5-jump, sprint running over 5, 10 and 20m, modified Illinois, modified T-test, RSTT, Y-balance, standing stork	2 (pre- and post-intervention)
(Hammami et al., 2020a)	PT: 10 PS: 11 CG: 10	Indoor	Tier 2	PT: 16.2 ± 0.6 PS: 16.4 ± 0.5 CG: 16.5 ± 0.4 | M	Randomized Three-arm controlled trial	In-season | ND	7	3	21 | ND	CG: standard handball training	20m sprint, modified Illinois, modified T-test, RSTT, SJ, CMJ, 5-jump, Y-balance, Stork	2 (pre- and post-intervention)
(Hammami et al., 2018a)	EG: 14 CG: 14	Indoor	Tier 2	EG: 16.6 ± 0.3 CG: 16.6 ± 0.3 | F	Randomized Two-arm controlled trial	In-season | ND	10	2	20 | ND	CG: standard handball training	Sprint running over 5, 10, 20 and 30m, modified Illinois, modified T-test, RSTT, RSSA, SJ, CMJ, CMJA, 5-jump, Y-balance, stork, 1RM half squat	2 (pre- and post-intervention)
(Hammami, et al., 2020b)	EG: 17 CG: 17	Indoor	Tier 3	EG: 15.8 ± 0.2 CG: 15.8 ± 0.2 | F	Randomized Two-arm controlled trial	In-season | Yes	10	2	20 | ND	CG: standard handball training	Handgrip strength with dynamometer, maximal isometric back extensor strength, med ball throw, sprint running over 5, 10, 20 and 30m, modified Illinois, SJ, CMJ, CMJA, 5-jump, Y-balance, stork, RSTT	2 (pre- and post-intervention)

Continuation of table 1

(Hammami et al., 2019)	EG: 21 CG: 20	Indoor	Tier 2	EG: 13.5 ± 0.3 CG: 13.3 ± 0.3 | F	Randomized Two-arm controlled trial	In-season | ND	9	2	18 | ND	CG: standard handball training	Sprint running over 5, 10, 20 and 30m, modified Illinois, modified T-test, SJ, CMJ, CMJA, 5-jump, handgrip strength, isometric back extensor strength, medicine ball throw, Y-balance, stork	2 (pre- and post-intervention)
(Hermassi et al., 2014)	PT: 14 CG: 10	Indoor	Tier 3	20±0.3 | M	Randomized Two-arm controlled trial	In-season | ND	8	2	16 | ND	CG: standard handball training	RSA, SJ, CMJ	2 (pre- and post-intervention)
(Hermassi et al., 2019)	CRT: 12 NSDT: 10	Indoor	Tier 2	20.6±0.48 | M	Randomized Two-arm controlled trial	In-season | Yes	10	2	20 | ND	Both groups had a plyometric intervention, although one not included sport-specific drills and other included	SJ, CMJ, 1RM bench press, 1RM half squat, handball throwing, med ball throwing, RSA	2 (pre- and post-intervention)
(Hermassi et al., 2020)	EG: 10 CG: 9	Indoor	Tier 2	18.5 ± 0.85 | M	Randomized Two-arm controlled trial	In-season | ND	12	2	24 | ND	CG: standard handball training	Anthropometry (weight, FM), SJ, CMJ, 15 and 30m sprint, T-test, 1RM bench press, 1RM pullover, 1RM squat, Yo-Yo	2 (pre- and post-intervention)
(Iacono et al., 2017)	VDJ: 9 HDJ: 9	Indoor	N. D.	23.4 ± 0.6 | M	Randomized Two-arm controlled trial	In-season | Yes	10	2	20 | ND	Both groups performed PT, resistance training and standard handball training	CMJ, 10m and 25m sprint, COD, jump and sprint kinetic and kinematic variables	2 (pre- and post-intervention)
(Kale, 2016)	PT: 10 CG: 9	Indoor	Tier 3	PT: 20.4±3.0 CG: 19.4±3.3 | F	Two-arm controlled trial (quasi-experimental)	Pre-season | ND	6	2	12 | ND	CG: aerobic, sprint, weight and standard handball training	SJ, CMJ, sprint running over 10, 20 and 30m, Wingate, incremental running	2 (pre- and post-intervention)
(Karadenizli, 2015)	16	Indoor	Tier 2	14.57±0.92 | F	Non-randomized Single-arm trial	ND | ND	10	2	20 | ND	CG: None	30m sprint, Illinois, CMJ, standing long jump, sit and reach, static and dynamic balance	2 (pre- and post-intervention)
(Karadenizli, 2016)	EG: 14 CG: 12	Indoor	Tier 2	15.13±0.87 | F	Randomized Two-arm controlled trial	In-season | ND	10	2	20 | 100%	CG: standard handball training	30m sprint, Illinois, CMJ, bilateral horizontal jump, sit and reach, static and dynamic balance	2 (pre- and post-intervention)
(Mazurek et al., 2018)	PT1: 14 PT2: 12	Indoor	Tier 3	20.2±2.2 | M	Randomized Two-arm controlled trial	Pre-season | ND	5	3	14 | ND	Both experimental groups had plyometric training, however, one group followed a block periodization and the other had daily undulating periodization	Anthropometry (height, weight, BMI, FM, FFM), incremental test on cycle-ergometer, RSA, CMJ, SJ, DJ	2 (pre- and post-intervention)
(Noutsos et al., 2020)	EG: 19 CG: 14	Indoor	Tier 2	EG: 12.47 ± 0.2 CG: 12.35 ± 0.2 | ND	Randomized Two-arm controlled trial	In-season | ND	6	2	12 | ND	CG: standard handball training	Sprint running over 10 and 20m, T-test, SJ, CMJ (unilateral and bilateral)	2 (pre- and post-intervention)

Continuation of table 1

(Pancar et al., 2020)	EG: 14 CG: 14	Indoor	Tier 2	EG: 13.07 ± 0.83 CG: 13.07 ± 0.83 | F	Randomized Two-arm controlled trial	Pre-season | ND	8	3	24 | ND	CG: standard handball training	Anthropometry (height and weight), Wingate, balance, 30m sprint	2 (pre- and post-intervention)
(Parnow & Hosseini, 2016)	RT: 10 PT: 10 CT: 10	Indoor	Tier 2	RT: 16.75±0.36 PT: 16.57±0.26 CT: 16.23±0.50 | M	Randomized Three-arm controlled trial	ND | Yes	4	3	12 | ND	CG: resistance training group (including handball training)	Anthropometry (height, weight, BMI, body fat, squat, bench press, Sargent jump, 10m sprint, T-test, Cornish handball	2 (pre- and post-intervention)
(Ramadan & Elsayed, 2022)	PT: 16	Indoor	N.D.	21.0±1.0 | ND	Non-randomized Single-arm trial	ND | ND	12	1	12 | ND	None	30-15 IFT	2 (pre- and post-intervention)
(Shbib et al., 2021)	EG: 9 CG: 9	Indoor	N. D.	EG: 18.89 ± 2.14 CG: 24.33 ± 5.12 | M	Randomized Two-arm controlled trial	In-season | ND	4	3	12 | ND	CG: both groups were exposed to PT, although one using β-alanine and other receiving a placebo	Anthropometry (weight, BMI, FM%), Wingate	2 (pre- and post-intervention)
(Soto Garcia et al., 2022)	11	Indoor	Tier 2	23.7 ± 2.26 | F	Non-randomized Single-arm trial	ND | ND	8	2	16 | ND	None	Medicine ball throwing, handball throwing, CMJ (unilateral and bilateral) horizontal jump asymmetry	2 (pre- and post-intervention)
(;Spieszny & Zubik, 2018)	ST: 8 PT: 8 CG: 12	Indoor	Tier 3	ST: 23.1 ± 2.53 PT: 21.1 ± 2.17 CG: 23 ± 3.05 | M	Three-arm controlled trial (quasi-experimental)	In-season | ND	17	2	ND | ND	CG: resistance + standard handball training	Anthropometry (height and weight), CMJ, SJ, 10-s on cycle ergometer, handball throwing	2 (pre- and post-intervention)
(Toumi et al., 2004)	PT: 8 WG: 8 CG: 6	Indoor	Tier 2	21±2 | M	Randomized Three-arm controlled trial	In-season | ND	6	4	24 | ND	WG: weight training group; CG: control group (only handball sessions)	SJ, CMJ, maximal isometric leg press extension, dynamic concentric movements in leg press	4 (week 0, week 3, week 6, week 8)
(Van Den Tillaar et al., 2020)	42	Indoor	Tier 2	14.9 ± 0.5 | M+F	Two-arm controlled trial (quasi-experimental)	In-season | ND	12	2	24 | ND	Both groups were exposed to the same intervention, although with an opposite order of introduction.	30m sprint, COD handball specific test, CMJ, CMJA, back squat load-velocity assessment, handball throwing, Yo-Yo	2 (pre- and post-intervention)

Note. M: male; F: female; indoor=1, Outfield =2; N.D.: not described; 30-15IFT: 30-15 Intermittent Fitness test; PT: plyometric training; PS: plyometric training on sand; EG: experimental group; CG: control group; WG: weight training group; ST: strength training group; VDJ: vertical drop jump group; HDJ: horizontal drop jump group; JST: jump and sprint training group; SBT: slingshot based training group; PST: plyometric and spring training group; STAB: plyometric training group on stable surface; INSTAB: plyometric training group on unstable surface; DUP: daily undulating periodization; BP: block periodization; RT: resistance training; CT: complex training; CRT: combined resistance and handball-specific drills; NSDT: resisted training with no specific handball drills; SJ: squat jump; CMJ: countermovement jump; CMJA: countermovement jump with arm movement; DJ: drop jump; TRJ: triple right-leg jump; TLJ: triple left-leg jump; RSI: reactive strength index; RSA: repeated sprint ability; RSSA: repeated shuttle sprint ability; RSTT: repeated sprint t-test; RCOD: repeated change of direction; COD: change of direction; UB: upper body; LB: lower body; BMI: body mass index; BF: body fat; FM: fat mass; FFM: fat free mass; 1RM: 1 repetition maximum

Table 2. Characteristics of the training interventions, including plyometric exercises

<table>
<tr><th>Study</th><th>Surface</th><th>PT drills</th><th>Intensity | Box height (if relevant)</th><th>NTJ</th><th>Laterality</th><th>Direction | Regularity</th><th>Sport-specific</th><th>COD</th><th>Combined</th><th>Regimen (Sets/reps/ rest within and between sets)</th><th>RBTS</th><th>Periodization</th><th>Add/replace | Tapering</th></tr>
<tr><td>(Alkasasbeh, 2023)</td><td>N. D.</td><td>Vertical jumps
Horizontal jumps
Hops</td><td>N. D. | N. D.</td><td>S1: 420
S2: 444
S3: 492
S4: 516
S5: 556
S6: 556
S7: 568
S8: 600
S9: 492
S10: 486</td><td>Bilateral and unilateral</td><td>Vertical and horizontal | N. D.</td><td>NO</td><td>NO</td><td>YES (sprints)</td><td>4-6 x 12-32 / N. D.</td><td>N. D.</td><td>Progressive overload of training volume</td><td>Added | N. D.</td></tr>
<tr><td>(Alonso-Fernández et al., 2017)</td><td>N. D.</td><td>Squat jump
Side to side jumps
Dynamic push-up
Coordination ladder jumps</td><td>N. D. | N. D.</td><td>N. D.</td><td>Bilateral and unilateral</td><td>Vertical and horizontal | N. D.</td><td>NO</td><td>YES</td><td>YES (split squats, mountain climbers, squats)</td><td>N. D.</td><td>N. D.</td><td>Non-progressive</td><td>Added | N. D.</td></tr>
<tr><td>(Aloui et al., 2020)</td><td>N. D.</td><td>CMJ
Split squat jumps</td><td>Maximal effort
S1-4: 41.4kg added; S5-8: 55.2kg added S9-12: 67.2kg added; S13-16: 81kg added
(through elastic band resistance) | N. D.</td><td>S1-2/5-6/9-10/13-14: 60 pS
S3-4/7-8/11-12/15-16: 72 pS</td><td>Bilateral</td><td>Vertical | Cyclical</td><td>NO</td><td>NO</td><td>YES (trunk rotations, hip mobility exercises, squat variations, displacements, skipping with and without COD, sprints with and without COD, push-ups, med ball throws, pull-ups, pullovers, bench press, aerobic training)</td><td>5-6 x 6 / N. D.</td><td>N. D.</td><td>Progressive overload of training intensity</td><td>Replaced | N. D.</td></tr>
<tr><td>(Aloui et al., 2021)</td><td>N. D.</td><td>Plyometric push-ups (standard, diamond and wide)</td><td>Maximal effort
S1-4: 11.2kg added
S5-8: 15.6kg added
S9-12: 21.2kg added
S13-16: 26.8kg added
(through elastic band resistance) | | N. D.</td><td>S1-2/5-6/9-10/13-14: 48
S3-4/7-8/11-12/15-16: 60</td><td>Bilateral</td><td>Horizontal | N. D.</td><td>NO</td><td>NO</td><td>YES (warm up - exercises regarding
running, coordination, trunk rotation, flexibility, jumping, and sprinting. Internal and external rotary, flexion, and extension movements of the shoulders, medicine ball throws)</td><td>4-5 x 6 / N. D.</td><td>N. D.</td><td>Progressive overload of training volume and intensity</td><td>Replaced | N. D.</td></tr>
</table>

Continuation of table 2

<table>
<tr><td>(Büsch et al., 2015)</td><td>Stable and unstable surfaces</td><td>CMJ
Drop jumps</td><td>N. D. | N. D.</td><td>100-150 pS</td><td>Unilateral and bilateral</td><td>Vertical | N. D.</td><td>NO</td><td>NO</td><td>NO</td><td>3-4 x 6 / 1-2min</td><td>N. D.</td><td>Progressive overload of training volume and intensity</td><td>N. D. | N. D.</td></tr>
<tr><td>(Cetin & Ozdol, 2012)</td><td>N. D.</td><td>Hurdle jumps
Jumping back and forth over medicine ball</td><td>N. D. | N. D.</td><td>N. D.</td><td>Bilateral</td><td>Vertical, lateral, horizontal, backward | Cyclic</td><td>NO</td><td>YES</td><td>YES (weight training and bodyweight exercises)</td><td>2 x 12-15 / N. D.</td><td>N. D.</td><td>Progressive overload of training volume</td><td>Added | N. D.</td></tr>
<tr><td>(Chaabene et al., 2021)</td><td>N. D.</td><td>Hops
CMJs</td><td>Maximal height or distance | N. D.</td><td>W1: 80
W2-3: 90
W4-5: 100
W6-7: 110
W8: 120</td><td>Bilateral</td><td>Vertical and horizontal | Cyclic</td><td>NO</td><td>NO</td><td>NO</td><td>4-6 x 10 / 90s</td><td>72h</td><td>Progressive overload of training volume</td><td>Replaced | N. D.</td></tr>
<tr><td>(Chelly et al., 2014)</td><td>N. D.</td><td>Hurdle jumps
Drop jumps
Dynamic push-ups</td><td>Maximal effort | 40 cm</td><td>W1: 50
W2: 70
W3: 100
W4: 50
W5: 40
W6: 40
W7: 40
W8: 40</td><td>Bilateral</td><td>Vertical and horizontal | Cyclic and acyclic</td><td>NO</td><td>NO</td><td>NO</td><td>3x10 to 10x10 / 4-5s / 1min</td><td>N.D.</td><td>Progressive overload of training volume and intensity</td><td>Added | N. D.</td></tr>
<tr><td>(Cherif et al., 2012)</td><td>N. D.</td><td>Drop jumps</td><td>N. D. | 20, 25, 30, 35 40 and 45cm</td><td>W1-4: 40 pS
W5-12: 60 pS</td><td>Bilateral</td><td>Vertical | Acyclic</td><td>YES</td><td>NO</td><td>YES (intermittent running, handball shooting, lateral displacements, sprints)</td><td>1x10 to 3x10 / N. D.</td><td>N. D.</td><td>Progressive overload of training volume and intensity</td><td>Added | N. D.</td></tr>
<tr><td>(Dahl & Van Den Tillaar, 2021)</td><td>N. D.</td><td>Jumps, hops, and jump shots</td><td>N. D. | N. D.</td><td>S1-3: 136 pS
S4: 151 pS
S5-6: 159 pS
S7-8: 180 pS
S9-10: 174 pS
S11-12: 200 pS
S13-14: 188 pS
S15-16: 208 pS</td><td>Bilateral and unilateral</td><td>Vertical and horizontal | Cyclic and acyclic</td><td>NO</td><td>YES</td><td>NO</td><td>4x6 to 3x10 / N. D.</td><td>N. D.</td><td>Progressive overload of training volume</td><td>N. D. | N. D.</td></tr>
<tr><td>(Falch et al., 2022)</td><td>N. D.</td><td>Drop jumps
Unilateral CMJ
Skate jumps</td><td>Maximal effort | N. D.</td><td>S1-2: 40 pS
S3-4: 54 pS
S5-6: 60 pS
S7-8: 76 pS
S9-10: 94 pS
S11-12: 60 pS
S13-14: 21 pS</td><td>Bilateral and unilateral</td><td>Vertical, horizontal and lateral | N. D.</td><td>NO</td><td>YES</td><td>NO</td><td>1-6 x 4-5 / >2min</td><td>Minimum 48h</td><td>Progressive overload of training volume with reduced load in the final week</td><td>Added | Yes</td></tr>
</table>

Continuation of table 2

<table>
<tr><td>(Hammami et al., 2018b)</td><td>N. D.</td><td>Hops
Hurdle jumps
Lateral hurdle jumps
Horizontal jumps</td><td>N. D. | N. D.</td><td>W1-2: 48 pS
W3-6: 96 pS
W7-8: 144 pS</td><td>Bilateral</td><td>Vertical, horizontal and lateral | Cyclic</td><td>NO</td><td>YES</td><td>YES (COD training, strength training, HIIT, weightlifting, powerlifting, gymnastics)</td><td>6 x 2-6 / 90s</td><td>N. D.</td><td>Progressive overload of training volume</td><td>Replaced | N. D.</td></tr>
<tr><td>(Hammami et al., 2021)</td><td>Gym floor</td><td>Hurdle jumps
Horizontal jumps
Hops</td><td>Maximal effort | N. D.</td><td>96 pS</td><td>Bilateral and unilateral</td><td>Vertical and horizontal | Cyclic</td><td>NO</td><td>NO</td><td>YES (HIIT/sprints)</td><td>2x6 / 10s / 3-5min</td><td>N. D.</td><td>Non-progressive</td><td>Replaced | N. D.</td></tr>
<tr><td>(Hammami et al., 2022)</td><td>Sand</td><td>Lateral hurdle jumps
Horizontal jumps
Hurdle jumps</td><td>N. D. | N. D.</td><td>W1: 54 pS
W2-3: 72
W4-5: 90
W6-7: 108</td><td>Bilateral</td><td>Vertical, horizontal and lateral | Cyclic</td><td>NO</td><td>YES</td><td>YES (sprints)</td><td>3-6 x 6 / 90s</td><td>2-3 days</td><td>Progressive overload of training volume</td><td>Replaced | N. D.</td></tr>
<tr><td>(Hammami, et al., 2020a)</td><td>Sand and gymnasium floor</td><td>Hops, lateral jumps, horizontal jumps, hurdle jumps</td><td>N. D. | N. D.</td><td>W1: 54 pS
W2-3: 72 pS
W4-5: 90 pS
W6-7: 108 pS</td><td>Bilateral</td><td>Vertical, horizontal and lateral | Cyclic</td><td>NO</td><td>YES</td><td>YES (sprints)</td><td>6 x 3-6 / N. D.</td><td>2-3 days</td><td>Progressive overload of training volume</td><td>Replaced | N. D.</td></tr>
<tr><td>(Hammami et al., 2018a)</td><td>N. D.</td><td>Hurdle jumps
Horizontal jumps
Hops</td><td>N. D. | N. D.</td><td>N. D.</td><td>Bilateral and unilateral</td><td>Vertical and horizontal | Cyclic</td><td>NO</td><td>NO</td><td>YES (weight training, sprints)</td><td>4 x 6 / 1-2min</td><td>N. D.</td><td>N. D.</td><td>Replaced | N. D.</td></tr>
<tr><td>(Hammami, et al., 2020b)</td><td>N. D.</td><td>Hurdle jumps, Lateral hurdle jumps, Stretched leg jumps, Horizontal jumps, dynamic push-ups</td><td>Maximal height/ distance | N. D.</td><td>W1-2: 120 pS
W3-4: 150 pS
W5-6: 120 pS
W7-8: 150 pS
W9-10: 120 pS</td><td>Bilateral</td><td>Vertical, horizontal and lateral | Cyclic</td><td>NO</td><td>YES</td><td>NO</td><td>2-10 x 6 / 30s</td><td>N. D.</td><td>Progressive overload of training intensity</td><td>Replaced | N. D.</td></tr>
<tr><td>(Hammami et al., 2019)</td><td>N. D.</td><td>Hurdle jumps, lateral hurdle jumps, stretched leg jumps, dynamic push-ups</td><td>Maximal effort | N. D.</td><td>W1/4/7: 60
W2/5/7: 70
W3/6/9: 80</td><td>Bilateral</td><td>Vertical, horizontal and lateral | Cyclic</td><td>NO</td><td>NO</td><td>YES (sprints and handball shooting)</td><td>10 x 6-8 / 90s</td><td>N. D.</td><td>Wave pattern</td><td>Replaced | N. D.</td></tr>
<tr><td>(Hermassi et al., 2014)</td><td>N. D.</td><td>Hurdle jumps
Drop Jumps</td><td>Maximal height/ distance | 40cm</td><td>W1: 50
W2: 70
W3: 100
W4: 50
W5: 50
W6: 50
W7: 50
W8: 50</td><td>Bilateral</td><td>Vertical and horizontal | Cyclic and acyclic</td><td>NO</td><td>NO</td><td>NO</td><td>5-10 x 10 / 5s / 3min</td><td>N. D.</td><td>Progressive overload of training volume and intensity</td><td>Added | N. D.</td></tr>
</table>

Continuation of table 2

(Hermassi et al., 2019)	N. D.	Drop jumps, hurdle jumps	N. D. | 30, 45, 50, 55, 60cm	W1: 109-136 pS W2: 126-144 pS W3: 136-152 pS W4: 134-164 pS W5*: 142-172 pS W6: 118-148 pS W7: 124-154 pS W8: 142-162 pS W9-10: 146-176 pS	Bilateral	Vertical and horizontal | Cyclic and acyclic	N. D.	N. D.	YES (track and field, gymnastics, team sports and weight training)	4 x 5-20 / N. D.	N. D.	Progressive overload of training volume and intensity	Replaced | N. D.
(Hermassi et al., 2020)	N. D.	Diagonal jumps (hops), Depth jumps, Hurdle jumps	N. D. | 50cm	S1-5: 20 S6: 22 S7-12: 24 S13-18: 28 S19-24: 32	Bilateral	Vertical, horizontal and diagonal | Cyclic and acyclic	NO	YES	YES (circuit training with sprints, med ball and resistance exercises)	1 x 10-16 / 3min	N. D.	Progressive overload of training volume	Replaced | N. D.
(Iacono et al., 2017)	N. D.	Vertical and horizontal drop jumps	Maximal height or maximal horizontal frontward distance | 25cm	30-80 pS	Unilateral	Vertical and horizontal | Acyclic	NO	NO	YES (bench press and shoulder press)	5-8 x 6-10 / 10s / 2min	2-3	Progressive overload of training volume	Added | Yes
(Kale, 2016)	N. D.	Hurdle jumps Lateral multi jumps Frontal multi jumps	N. D. | N. D.	144 pS	Bilateral	Vertical, horizontal and lateral | Cyclic	NO	YES	YES (aerobic training, sprint training, weight training)	3x12 / 30-40s / 3min	2-3	Non-progressive	Added | N. D.
(Karadenizli, 2015)	N. D.	Lateral jumps Horizontal hurdle jumps Hops	N. D. | N. D.	N. D.	Bilateral and unilateral	Vertical, horizontal and lateral | N. D.	NO	YES	YES (sprints, pull-ups, med ball exercises)	N.D. / 30-40s / 4-5min	2 days	Non-progressive	N. D. | N. D.
(Karadenizli, 2016)	N. D.	Side to side jumps and hops, Vertical jumps, Horizontal jumps, Diagonal jumps, Hurdle jumps, Forward hops	N. D. | 40cm	W1-2: 120 W3-4: 120-130 W5-6: 130 W7-10: 140	Bilateral and unilateral	Vertical, horizontal, backward, lateral, diagonal | Cyclic and acyclic	NO	YES	NO	2-4 x 3-15 / 1min / 3min	N. D.	Progressive overload of training volume and intensity	Added | N. D.
(Mazurek et al., 2018)	N. D.	Hurdle jumps Vertical jumps Stride jumps Front hops Drop jumps Drop to hurdle jumps	Maximal effort | 20, 40 and 60cm	87 pS	Bilateral	Vertical and horizontal | N. D.	NO	NO	NO	2-5 x 5-10 / 2min	N. D.	Progressive overload of training intensity	Added | N. D.

Continuation of table 2

(Noutsos et al., 2021)	N. D.	Front and back jumps Lateral jumps Half squat jumps Zig zag jumps Horizontal jumps	Maximal effort | N. D.	144 pS	Bilateral and unilateral	Vertical, horizontal, backward, lateral and diagonal | Cyclic	NO	YES	NO	3x6-8 / 30s / 60s	2 days	Non-progressive	Added | N. D.
(Pancar et al., 2020)	N. D.	Rope skipping, single and double leg jumps	N. D. | N. D.	W1-3: 180 W4: 164 W4: 240 W6: 246 W7: 264 W8: 270	Bilateral and unilateral	Vertical, horizontal, lateral* and diagonal* | Cyclic	NO	YES	NO	N.D. / 1-4min	N. D.	Progressive overload of training volume	Added | N. D.
(Parnow & Hosseini, 2016)	N. D.	Vertical jumps Hops Jump squats Dynamic push-ups	Maximal height/ distance | N. D.	W1: 80 pS W2: 100 pS W3: 180 pS W4: 150 pS	Bilateral	Vertical and horizontal | Cyclic and acyclic	NO	NO	YES (weight training for complex group)	2-3 x 8-12 / 90s-2min	N. D.	Progressive overload of training volume	N. D. | N. D.
(Ramadan & Elsayed, 2022)	N. D.	Single leg hops; Bleacher hops; Double leg bound; Alternate leg bound; Squat jumps; Depth jumps; Box jumps	N. D. | N. D.	W1: 40 pS W2: 45 pS W3: 80 pS W4: 60 pS W5: 120 pS W6: 90 pS W7: 120 pS W8: 90 pS W9: 180 pS W10: 135 pS W11: 160 pS W12: 120 pS	Unilateral and bilateral	Vertical, horizontal | Cyclic and acyclic	NO	NO	NO	1-4 x 10-15 / 1min	N. D.	Progressive overload of training volume	N.D. | N. D.
(Shbib et al., 2021)	N. D.	Hurdle jumps; Lateral multi jumps; Frontal multi jumps	N. D. | N. D.	144 pS	Bilateral	Vertical, horizontal and lateral | Cyclic	NO	YES	NO	3x12 / 30-40s / 3min	N. D.	Non-progressive	Added | N. D.
(Soto Garcia et al., 2022)	Gym floor	Drop jumps Lateral jumps Horizontal jumps	N. D. | N. D.	59 pS	Bilateral and unilateral	Vertical, horizontal and lateral | N. D.	NO	YES	YES (core training, bodyweight and resistance exercises*)	2x5-6 / N. D.	N. D.	Non-progressive	Added | N. D.

Continuation of table 2

(Spieszny & Zubik, 2018)	N. D.	Barbell jump squats Dynamic bench press Hurdle jumps Drop jumps Multi jumps	N. D. | N. D.	N. D.	Bilateral	Vertical and horizontal | Cyclic and acyclic	NO	YES	NO	3-4 x 5-10 / N. D.	N. D.	N. D.	Added | N. D.
(Toumi et al., 2004)	N. D.	Hurdle (bench) jump (with and without pause)	N. D. | 35- 50cm	30 pS	Bilateral	Vertical and horizontal | Cyclic and acyclic	NO	NO	YES (weight training)	3x5 / 3s (exercise 1) / 3min	N. D.	N. D.	Added | N. D.
(Van Den Tillaar et al., 2020)	N. D.	Jumps and hops	Maximal height/ distance | N. D.	S1-3: 136 S4: 151 S5-6: 159 S7-8: 180 S9-10: 165 S11-12: 185	Bilateral and unilateral	Vertical and horizontal | Cyclic and acyclic	NO	NO	YES (sprints)	2-5 x 8-25 / N. D.	N. D.	Progressive overload of training volume	Replaced | N. D.

Note. N.D.: not defined; NTC: number of total contacts; PT: plyometric training; RBS: rest between sets; RBR: rest between repetitions (in seconds); RBTS: rest between training sessions (in number of days); W: week; S: session; pS: per session; HIIT: high-intensity interval training.

Number of total contacts with the surface OR total ground contacts

There was a considerable variation in the number of total contacts per session, ranging from as little as 20 to as high as 600. To facilitate data analysis, the number of total contacts was grouped into different categories.

Fifteen out of the 35 studies had a number of total contacts in the category of 0-100 contacts per session, while 10 presented a number of total contacts between 100 and 200.

Two studies registered higher numbers, with one of them (Pancar, Biçer, & Ozdal, 2020) registering 200-300 contacts in most of the sessions, and the other (Alkasasbeh, 2023) registering more than 300 (up to 600).

Besides that, there are three studies that have numbers that place them in a mixed category. In one the number of total contacts per session ranged from 40 to 180 (Ramadan & Elsayed, 2022), in other the range was 80-120 contacts per session (Chaabene, et al., 2021) and, lastly, in the third, it was 48-144 (Hammami et al., 2018b).

Intensity

Intensity is a parameter that is not typically considered in most studies of plyometric training in handball. Out of the 35 studies reviewed, more than half (approximately 61%) did not mention any defined intensity levels.

Two of the studies (Aloui, et al., 2020, 2021) were done with added weight in the form of elastic band resistance. The remaining 12 studies that considered the intensity, did that by instructing maximal effort, height, or distance, being the most commonly used parameter of intensity.

Box height

Twenty-six out of the 35 studies did not specify any box height, and there are studies that refer to the use of drop jumps or depth jumps without specifying the box height.

From the studies that did consider the box height, six used boxes varying between 30-60cm, one up to 30cm (Iacono, Martono, Milic & Padulo, 2017), and the remaining two studies (Cherif, et al., 2012; Mazurek, et al., 2018) implemented different heights, ranging from 20 to 60cm.

Frequency

Most of the collected studies (approximately 63%) had a frequency of two times per week. However, a considerable portion (approximately 25%) of the studies also registered a frequency of three times per week.

Duration

Most of the studies (32 out of 35) employed interventions that lasted between 5 and 12 weeks, with a slightly higher percentage located in the interval 5-8 weeks. Only two studies (Parnow & Hosseini, 2016; Shbib, et al., 2021) had a duration of up to four weeks (one with tier 2 players and one with non-defined tier players), and only one (Spieszny & Zubik, 2018), with tier 3 players, lasted for more than 13 weeks.

Regularity/cyclical

Regarding the regularity of the exercises, 14 out of the 35 studies implemented exercises in a cyclical pattern, while 11 did it both cyclically and acyclically. Only two studies implemented PT acyclically (Cherif, et al., 2012; Iacono, et al., 2017), and in the remaining eight studies the pattern of PT implementation was not defined.

Direction

Most studies were comprised of exercises (16 out of 35) that were done in both a vertical and horizontal vector, and a considerable number (14) also implemented other directions (e.g., lateral, diagonal) besides those. Three studies (Aloui, et al., 2020; Büsch, Pabst, Mühlbauer, Ehrhardt, & Granacher, 2015, Cherif, et al., 2012) implemented only exercises in a vertical vector, and one (Aloui et al., 2021) implemented only exercises in a horizontal vector.

Laterality

Twenty out of the 35 studies implemented exercises done only bilaterally. Fourteen studies implemented exercises done both bilaterally and unilaterally, and only one study (Iacono, et al., 2017) was comprised of just unilateral exercises.

Change-of-direction

Only in one study (Hermassi, Haddad, Bouhafs, Laudner, & Schwesig, 2019) it was not specified whether the exercises involved a change of direction or not. Of the remaining studies, an equal number of interventions were conducted with and without a change of direction. Fifteen studies did not involve any change of direction, while the other 15 involved a change of direction.

Sport-specific drills

Only two out of the 35 studies registered the use of sport-specific exercises (Dahl & Van Den Tillaar, 2021, Karadenizli, 2016).

There was one study (Hermassi, et al., 2019) that did not specify it, and the remaining 32 did not use any sport-specific exercise.

Rest—intra-set

In terms of the rest used intra-set, 27 out of the 35 studies did not specify any details. Six studies implemented intra-set rest periods under one minute (Chelly, et al., 2014; Hermassi, et al., 2014; Iacono, et al., 2017; Kale, 2016; Noutsos, Meletakos, Athanasiou, Tavlaridis, & Bayios, 2021; Toumi, Best, Martin, & Poumarat, 2004). Two studies (Chelly, et al., 2014; Toumi, Best, Martin, & Poumarat, 2004) used short periods (3-5 seconds, one used specifically 5-second rest (Hermassi, et al., 2014), one specifically 10-second rest (Iacono, et al., 2017), one (Noutsos, Meletakos, Athanasiou, Tavlaridis, & Bayios, 2021) specifically 30-second rest, and one (Kale, 2016) between 30-40-second rest. Two studies (Hammami, et al., 2018b; Karadenizli, 2016) used intra-set rest periods longer than one minute.

Rest—inter-set

There is more information about the inter-set rests compared to the intra-set rests.

Only one study implemented inter-set rest periods shorter than one minute (Hammami et al., 2020b). A considerable number of studies (11) used inter-set rest periods lasting between 60 and 149 seconds, and nine used periods longer than 150 seconds.

One study (Pancar, et al., 2020) used a mix of rest times located in different intervals (1-4 minutes), and the remaining 13 did not mention the use of any inter-set rest period.

Periodization

Most of the studies registered the use of various forms of progressive overload in their interventions.

The most common form of progressive overload regarded training volume, present in 14 out of the 35 studies, with one of them (Falch, Haugen, Kristiansen, & van den Tillaar, 2022) implementing an unload in the final week. The second most common progressive overload regarded training volume and intensity, in seven studies, and a similar number did not implement any form of progressive overload.

Three studies (Aloui, et al., 2020, Hammami et al., 2020b; Mazurek, et al., 2018) implemented a progressive overload of training intensity, and one (Hammami, et al., 2019) implemented a wave pattern throughout their study.

In the remaining three the form of overload was not defined.

Moment of season

Twenty-three out of the 35 studies were done in-season, nine were done off-season, and only four did not mention in what period of the season the studies had been done.

Added/replaced

Seventeen plyometric interventions were added to standard handball training, and 13 replaced the standard training regimen. In the remaining five, it was not specified.

Taper

Only two studies mentioned that they did a taper period in their intervention (Falch, et al., 2022; Iacono et al., 2017). The remaining 33 did not mention anything regarding a taper period.

Physical fitness adaptations after plyometric training

Table 3 presents a comprehensive summary of the evidence regarding the impact of plyometric training on handball performance. The table focuses on various parameters related to jumping, sprinting, change of direction, strength, ball throwing velocity, power, balance, and VO2max.

Regarding jumping abilities, the majority of studies (26 out of 27) reported significant improvements in countermovement jump (CMJ) performance following PT interventions. Similarly, improvements were observed in the squat jump (SJ) in 17 out of 18 studies and in the drop jump (DJ) in two out of three studies. In terms of horizontal jumping, all seven studies evaluating this parameter reported positive results, indicating that plyometric training can enhance both vertical and horizontal jumping ability.

When examining sprinting, a substantial proportion (19 out of 21) of the included studies demonstrated significant enhancements after implementing PT, highlighting its positive effects on speed-related factors in handball. Change of direction, both repeated and non-repeated, was evaluated in a total of 16 articles, and all of them reported positive results, indicating that PT can improve this important aspect of handball performance.

Strength assessment was performed in 12 articles, and all of them reported positive outcomes, suggesting that PT can contribute to increased strength in handball players. Ball throwing velocity, measured in 10 articles, showed improvements in a significant number of studies (eight out of 10), indicating that plyometric training can positively influence throwing performance.

Other parameters such as power (all nine studies), balance (seven out of eight), and VO2max (all six studies) also exhibited mostly positive results, supporting the effectiveness of PT in enhancing these aspects of handball performance.

Although there were studies evaluating parameters like RSI, MAS, and flexibility, the limited number of articles prevented us from drawing conclusive findings on their effects.

Table 3. Summary of the findings regarding physical fitness adaptations following plyometric training

Study	Main outcomes	Innovations, considerations and limitations
(Alkasasbeh, 2023)	**Plyometric-strength group:** COD: pre to mid-test +5.5%; CMJ: pre to mid-test +9%; CMJA: pre to mid-test 6.9%; Strength: pre to mid-test + 14%; Endurance: pre to mid-test +12%; Sprint: pre to mid-test +0.1%; Standing throw: pre to mid-test +0.1%; Running throw: pre to mid-test +1.2% **Strength-plyometric group:** COD: pre to mid-test +6.5%; CMJ: pre to mid-test +7%; CMJA: pre to mid-test +5.9%; Strength: pre to mid-test +11%; Endurance: pre to mid-test +9%; Sprint: pre to mid-test +0.3%; Standing throw: pre to mid-test +0.2%; Running throw: pre to mid-test +0.9%	No additional control group that did not perform the training intervention. Not clear how COD and strength were evaluated. The authors just referenced <2% in all mid-to-post test results. Strange results when comparing Tables 3 and 4. Abusive volume of PT. Longer treatments, more exact measurements, and an analysis of putative mechanistic components are needed.
(Alonso-Fernández et al., 2017)	CMJ height: +1.37cm (4.66%) RSA: -1.21s (7.22%) VO2max: +2.72ml/kg/min (6.19%)	HIIT was the main focus of the study Exercises were done by time and not by sets/reps Results cannot solely be attributed to plyometrics and disregard the other exercises implemented
(Aloui et al., 2020)	Peak power in force-velocity test: +143W (23.1%) 1RM half back squat: +10kg (7.6%) 5m sprint time: -0.1s (8.7%) 30m sprint time: -0.35s (7.2%) T-half test: -0.57s (9.2%) Repeated COD test: -3s (7.1%) CMJ height: +3.6cm (9.1%) SJ height: +3.5cm (9.4%)	Elastic bands were utilized in the PT intervention There is a need to extend observations to cover female players, other age groups, and other skill levels. Despite efforts to match participants across groups, there were some pre-test differences in anthropometric parameters There remains a need to compare the gains in performance with improvements in actual play on the handball court

(Aloui et al., 2021)	Peak power in force-velocity test: +95W (23.3%) Jumping throw speed: +4.1m/s (18.6%) Three-step running throw speed: +4.4m/s (19.1%) Standing throw speed: +4.4m/s (20.4%) 1RM pullover: +6.2kg (22.5%) 1RM bench press: 11.6kg (15.9%)	Elastic bands were utilized in the PT intervention Only study that only implemented upper-body exercises and tests The neuromuscular mechanisms which underpin the improvements reported may be an area for future research Future studies should evaluate and extend these findings to female players, other age groups, and other competition levels There is a need to compare the gains in the test performances with the actual improvement of play on the handball field Having a control group performing the plyometric push-up program without elastic bands would allow for the determination of whether the addition of bands is beneficial for this type of program versus performing unloaded upper extremity plyometrics training, as it is possible that performing the plyometric push-up program without elastic bands may lead to comparable improvements
(Büsch et al., 2015)	SJ height: +3.9cm (11.6%) CMJ height: +1.5cm (3.6%) DJ height: +3cm (11.2%) Standing horizontal jump distance: +3.7cm (1.5%) 5m sprint time: = 10m sprint time: -0.02s (1%) 20m sprint time: -0.05s (1.6%) Figure-of-8 dribbling (s): -0.46s (2%)	Article in German
(Cetin & Ozdol, 2012)	Vertical jump: +3.6cm (12.4%)	Number of repetitions not clear in the article It was not specified how the vertical jump was measured Results cannot solely be attributed to plyometrics and disregard the other exercises implemented
(Chaabene et al., 2021)	5m sprint time: -0.08s (6.45%) 10m sprint time: -0.11s (5.1%) 20m sprint time: -0.13s (3.46%) T-test: -0.87s (7.1%) CMJ height: +2.24cm (10.45%) RSI: 0.14 a.u. RSA: -1.24s (2.3%)	Future studies should address the underlying pattern and mechanisms of adaptations to PT in youth female players Future studies are needed to examine the potential neuromuscular mechanisms underpinning COD performance improvements after PT in youth female players The potential mechanistic factors underpinning RSI adaptations need to be addressed in future studies The explanation for the improvements in RSA has to be substantiated by future studies
(Chelly et al., 2014)	Upper body peak power in force-velocity test: +117W (27.4%) Lower body peak power in force-velocity test: +109W (12.19%) SJ height: +5cm (12.8%) CMJ height: +4cm (9.5%) Sprint velocity: +1.2m/s (11.65%) Jumping shot throw speed: +6.6m/s (22.68%) Three-step running throw speed: +6.2m/s (20.46%) Standing throw speed: +5.4m/s (18.88%)	Findings were limited to one particular category of handball players—elite adolescent males. Future studies should extend the observations to women, to other age groups, and to other levels of competition. Furthermore, observations are also needed with differing intensities and volumes of plyometric training to determine their optimum dosage for this form of preparation.
(Cherif et al., 2012)	SJ height: +0.8cm (2.4%) CMJ height: +0.8cm (2.78%) CMJA height: +0.8cm (2.42%) DJ height (right leg): +0.6cm (2.62%) DJ height (left leg): -0.3cm (0.39%) RSA: -0.1m/s (1.56%)	Players showed many difficulties in maintaining exercise intensity during training sessions Throwing is considered as one of the most important technical skills in competitive handball as it is a major determinant of all actions taken by the players. Studying the effects of the additional combined training program sprint repetition and vertical jump on ball velocity would be useful
(Dahl & Van Den Tillaar, 2021)	7m standing shot: -2.4% Running shot: -3.9% Jump shot: -2.8% Core rotational strength predicted 1RM: -1.3%	PT was not the main focus of the study Results were not presented in a clear way Authors measured different shot metrics but the PT intervention was not adequate for that The focus of the sling-based training was to stimulate the pelvic and trunk rotation strength necessary for shooting. However, a complete shooting sequence involves both the external and internal rotation of both the hips and trunk, and tilting the core in various directions together with various arm joint movements In the future, three dimensional kinematic studies, together with electromyography measurements of the involved muscles should be conducted to investigate how sling-based training influences maximal ball velocity

(Falch et al., 2022)	Bilateral squat relative strength: +0.01kg/BM (2.35%) Quarter squat relative strength: +0.21kg/BM (49.88%) Lateral squat relative strength: RSI: 0.47 a.u. CMJ height: +2cm (20.48%) Skate jump height: +14.7cm (9.36%) 5m sprint time: -0.02s (1.46%) 10m sprint time: -0.06s (2.64%) 20m sprint time: -0.05s (1.32%) 30m sprint time: -0.11s (2.07%)	No control group that did not perform any intervention Generally, strength training group had better results in strength tests (except for the quarter squat) and plyometric group had better results in plyometric tests There is an error in Table 3 (results) regarding the values of the lateral squat improvement in the PT group Magnitude of the COD results is not presented in a very clear way Lack of improvements in the force-oriented CODs in the PT group may be due to insufficient stimulus/reduced number of foot-ground contacts Lack of general improvements in the PT group explained by their low age Lack of improvements in velocity-oriented COD might be due to inadequate exercise selection No possibility of measuring kinematics due to lack of equipment Replication with greater participation and measurements of step kinematics in the velocity-oriented COD is warranted
(Hammami et al., 2018b)	5m sprint time: -0.11s (9.1%) 10m sprint time: -0.16s (7.65%) 20m sprint time: -0.26s (7.32%) 30m sprint time: -0.43s (8.9%) T-half test time: -0.38s (5.3%) Illinois modified test time: -0.6s (4.5%) SJ height: +9.6cm (35.8%) CMJ height: +10.6cm (36.9%) CMJA height: +7.9cm (23.9%) 5-jump test length: +1.1m (12.2%) RSTT total time: -2s (2.4%) MAS 20m shuttle run: +0.5km/h (3.38%) Predicted VO2max: +1.9ml/kg/min (3.99%) Stork balance test (Right): -0.2s (9.5%) Stork balance test (Left): +0.5s (29.4%)	PT was combined with COD exercises, so it is not possible to attribute the results to just one mode of training Right leg balance titles in the table are wrong
(Hammami et al., 2021)	5m sprint time: -0.1s (8.3%) 10m sprint time: -0.16s (7.6%) 20m sprint time: -0.25s (6.8%) 30m sprint time: -0.42s (8.8%) T-half test time: -0.37s (5.1%) Illinois modified test time: -0.55s (4.2%) SJ height: +9.1cm (34.9%) CMJ height: +9.7cm (34.4%) RST total time: -6s (7.2%) MAS 20m shuttle run: +1.1km/h (7.5%) Predicted VO2max: +4.4ml/kg/min (9.2%)	PT was combined with HIIT, so it is not possible to attribute the results to just one mode of training
(Hammami et al., 2022)	5m sprint time: -0.12s (10.8%) 10m sprint time: -0.19s (9.64%) 20m sprint time: -0.24s (6.78%) T-half test time: -0.59s (8.59%) Illinois modified test time: -0.5s (3.85%) SJ height: +8.9cm (34.5%) CMJ height: +8.4cm (33.47%) RSTT total time: -6.2s (7.66%) Stork balance test (Right): +3.11s (80.15%) Stork balance test (Left): +1.68s (40%) Y Balance test right leg forward: +4.3cm (8.19%) Y Balance test right leg background left: +18.1cm (17.1%) Y Balance test right leg background right: +13.1cm (15.7%) Y Balance test left leg forward: +3.8cm (7.38%) Y Balance test left leg background right: +13cm (12.15%) Y Balance test left leg background left: +4.3cm (5.1%)	PT was combined with sprints and was done on sand, so that should be taken into consideration when interpreting the results

(Hammami, et al., 2020a)	Sand surface group: 5m sprint time: -0.22s (18.18%) 10m sprint time: -0.49s (22.58%) 20m sprint time: -0.43s (12.04%) T-half test time: -0.63s (9%) Illinois modified test time: -1.1s (8.46%) SJ height: +8cm (27.97%) CMJ height: +11.1cm (38%) 5-jump test length: +0.7m (6.7%) RSTT total time: -13.8s (15.77%) Stork balance test (Right): +11.87s (365,2%) Stork balance test (Left): +10.77s (244.2%) Y Balance test right leg back: +16.2cm (15.24%) Y Balance test right leg background left: +14.5cm (17.34%) Y Balance test right leg background right: +4.3cm (8.37%) Y Balance test left leg back: +11.4cm (10.3%) Y Balance test left leg background right: +4.2cm (4.85%) Y Balance test left leg background left: +4.4cm (8.99%) Stable surface group: 5m sprint time: -0.08s (6.56%) 10m sprint time: -0.13s (6.1%) 20m sprint time: -0.18s (5.03%) T-half test time: -0.43s (5.99%) Illinois modified test time: -0.6s (4.6%) SJ height: +8.4cm (30.88%) CMJ height: +8.3cm (27%) 5-jump test length: +1.3m (13.27%) RSTT total time: -9.9s (11.39%) Stork balance test (Right): +1.65s (32.29%) Stork balance test (Left): +0.99s (22.35%) Y Balance test right leg back: +17.9cm (17.1%) Y Balance test right leg background left: +10.4cm (12.44%) Y Balance test right leg background right: +3.3cm (6.3%) Y Balance test left leg back: +15.2cm (14.7%) Y Balance test left leg background right: +6.4cm (7.59%) Y Balance test left leg background left: +3.9cm (7.65%)	There were two groups doing PT, but one did it on sand and the other on a stable surface. Results differed considerably in certain parameters
(Hammami et al., 2018a)	5m sprint time: -0.13s (10.4%) 10m sprint time: -0.25s (11.7%) 20m sprint time: -0.4s (10.4%) 30m sprint time: -0.45s (8.1%) T-half test time: -0.37s (5.1%) Illinois modified test time: -0.57s (4.2%) SJ height: +4.8cm (19%) CMJ height: +5.7cm (20.3%) CMJA height: +5.9cm (19.4%) 5-jump test length: +1.3m (15.2%) Back extensor strength: +20.2kg (25.1%) 1RM back half squat: +17.4kg (24%) RSSA total time: -0.8s (1.8%) RSTT total time: -4.7s (5.3%) Stork balance test (Right): +0.92s Stork balance test (Left): +1.03s Y Balance test right leg back: +3.6cm Y Balance test right leg background left: +4.6cm Y Balance test right leg background right: +0.6cm Y Balance test left leg back: +7.6cm Y Balance test left leg background right: +6.7cm Y Balance test left leg background left: 2.3cm	Experimental group did complex training and not regular/standard PT It was not specified how back extensor strength was evaluated During the intervention, both the experimental and control groups reduced their weekly fitness training sessions, maintaining the strength training component but eliminating the circuit training. The complex strength training intervention and associated testing were directed to enhancement of performance in the lower limbs. In contrast, the circuit training element contained exercises designed to strengthen the upper limbs, and its elimination is thus most unlikely to have influenced the statistical comparison between the experimental and control groups following the intervention.

(Hammami, et al., 2020b)	Handgrip right: +62N (26.3%) Handgrip left: +52N (23%) Back extensor strength: +215N (28.4%) Med ball throw: +0.9m (27.6%) 5m sprint time: -0.13s (10%) 10m sprint time: -0.14s (6.7%) 20m sprint time: -0.21s (5.7%) 30m sprint time: -0.36s (7.8%) Illinois modified test time: -0.97s (7.4%) SJ height: +4cm (18.2%) CMJ height: +5.1cm (21.1%) CMJA height: +5.1cm (20%) 5-jump test length: +1.2m (15.3%) RSTT total time: -5.5s (6.1%) Stork balance test (Right): +1.4s (56.4%) Stork balance test (Left): +0.7s (22.2%) Y Balance test right leg anterior: +4cm (4.9%) Y Balance test left leg anterior: +4cm (4.2%) Y Balance test right leg background left: +3cm (4.2%) Y Balance test left leg background right: +7cm (7.5%) Y Balance test right leg background right: +6cm (12.4%) Y Balance test left leg background left: +3cm (7.1%)	The training load was not monitored over the training intervention If the group of players played an official match, then a friendly match or physical work was scheduled for the other group so that the load was the same for the two groups. Nevertheless, there is a difference in feeling between an official match, a friendly match and physical workload
(Hammami et al., 2019)	5m sprint time: -0.9s (6.7%) 10m sprint time: -0.12s (5.4%) 20m sprint time: -0.37s (9.6%) 30m sprint time: -1.19s (20.9%) T-test time: -1.18s (14.5%) Illinois modified test time: -1.1s (7.9%) SJ height: +5.7cm (29.8%) CMJ height: +5.9cm (29.4%) CMJA height: +6.4cm (25%) 5-jump test length: +1.2m (16.3%) Stork balance test (Right): +0.09s (4.2%) Stork balance test (Left): +0.98s (49.9%) Y Balance test right leg back: +5cm (6.6%) Y Balance test right leg background left: +1cm (3.6%) Y Balance test right leg background right: +2cm (3.2%) Y Balance test left leg back: +3cm (3.6%) Y Balance test left leg background right: +2cm (3.1%) Y Balance test left leg background left: +2cm (9.4%) Handgrip right: +81N (43.2%) Handgrip left: +72N (42.5%) Back extensor strength: +175N (26.7%) Med ball throw: +0.8m (27.9%)	Interlimb measurements were not taken, which could have influenced the interpretation of some results Lack of physiological data to explore mechanisms underlying the demonstrated effects, particularly measures of biological maturation Further research is needed to observe the relative role of maturation in the effects of PT on the physical fitness of youth female handball players
(Hermassi et al., 2014)	SJ height: +9.7% CMJ height: +11.4%	Absolute values were not provided and precise percentage values of some parameters were also missing
(Hermassi et al., 2019)	CRT group: RSA total time: -2.9s (6.92%) SJ height: +3.7cm (9.18%) CMJ height: +4cm (9.35%) Jump shot throwing velocity: +11m/s (44%) Running shot throwing velocity: +9.3m/s (32.63%) Med ball throwing velocity: +7.7m/s (41.18%) 1RM half back squat: +15kg (8.7%) 1RM bench press: +19.2kg (30.3%) NSDT group: RSA total time: -2.5s (5.99%) SJ height: +4.4cm (11.34%) CMJ height: +2.9cm (6.73%) Jump shot throwing velocity: +4.9m/s (20.16%) Running shot throwing velocity: +6.5m/s (22.57%) Med ball throwing velocity: +9.1m/s (33.83%) 1RM half back squat: +3kg (1.8%) 1RM bench press: +12kg (18.46%)	PT exercises were combined with other exercises, so results cannot be attributed to PT alone Both groups performed PT exercises It was not practical to classify players into specific playing positions (e. g., pivot, back, wing) and to determine performance improvements on a position-by-position basis. These facts limit the scope of the results and should be considered in the interpretation Authors could not show that higher physical performance leads to an improved match performance. For this purpose, the measurement of the match performance would have been necessary The total volume of training between the two groups was not controlled

(Hermassi et al., 2020)	15m sprint time: -0.1s (3.89%) 30m sprint time: -0.1s (2.35%) T-test time: -0.16s (2.6%) CMJ height: +3.4cm (7.8%) SJ height: +4.8cm (12.5%) 1RM half squat: +23kg (15.2%) 1RM bench press: +15.1kg (18.5%) 1RM pullover: +9.8kg (22%) YoYo IRT distance: +800m (69.2%)	Circuit training was the main focus of the study PT exercises were combined with other exercises, so results cannot be attributed to PT alone There is a need to extend the present observations to players of other age groups and skill levels, including female participants, and to analyze differences in response to this type of training by a playing position
(Iacono et al., 2017)	VDT group: 10m sprint time: -0.08s (3.99%) 25m sprint time: -0.2s (3.7%) COD time: -0.01s (0.84%) CMJ height: +3.71cm (8.7%) HDT group: 10m sprint time: -0.18s (8.58%) 25m sprint time: -0.19s (3.58%) COD time: -0.09s (7.57%) CMJ height: +1.74cm (4.17%)	Both groups did plyometric exercises, one horizontally and the other vertically Further studies are needed to obtain evidence of the optimal combination (i.e., combined vertical and horizontal conditioning regimens) and training dose of exercises (i.e., proportion of vertical and horizontal exercises) required for effective neuromuscular abilities
(Kale, 2016)	SJ height: +2cm (9.4%) CMJ height: +2.9cm (12.6%) 10m sprint time: -0.1s (5.2%) 20m sprint time: -0.11s (3.2%) 30m sprint time: -0.12s (2.47%) Anaerobic power: +0.45W/kg (6%) VO2max: +2.4ml/kg/min (4.9%)	PT exercises were combined with other exercises, so results cannot be attributed to PT alone
(Karadenizli, 2015)	Sit and reach: +5.31cm (21.3%) Standing long jump: +23.75cm (15.36%) Anaerobic power: +40.24 W (6.8%) 30m sprint time: -0.01s (0.2%) Illinois test time: -0.02s (0.12%) CMJ height: +0.72cm (2.57%) Unipedal (left leg) static balance – ellipse area (mm²)*: -355.21mm² (24.7%)	PT exercises were combined with other exercises, so results cannot be attributed to PT alone Subjects were school handball players *Many balance indicators evaluated. Only the one with the most significant result was mentioned.
(Karadenizli, 2016)	Anaerobic power: +38.27W (6.4%) Sit and reach: +3.6cm (13.5%) CMJA height: +4.1cm (10.9%) Standing long jump: +12.59cm (7.13%) 30m sprint time: -0.45s (8.36%) Illinois test time: -1.61s (10%) DB-bipedal slalom-CUO: +63.5% DB-bipedal slalom-PE: -0.3% Static balance – LFEA: -485.53mm² (30.8%) Static balance – RFEA: -98.63mm² (6.2%)	PT was combined with sprints, so that should be taken into account when interpreting the results Absence of measurements of core and leg muscle strength
(Mazurek et al., 2018)	VO2max: +3ml/kg/min (6.98%) SJ height: -0.01m (2.4%) CMJ height: -0.01m (2.1%) DJ height: +0.01m (1.8%)	The cycle ergometer test has been previously widely used to evaluate adaptation to physical exercise training, but does not involve the stretch-shortening cycle, which is widely represented in the plyometric training program and could limit the possibility of detecting changes in performance. In addition, sprint cycling is somewhat unfamiliar to handball players More investigations are needed with different intensities and volumes of PT to determine the optimum load for this form of pre-season training. It should be noted that an on-court training program supplemented with plyometric strength training may produce excessive physical loads for the adaptive capabilities of young athletes and, with the lack of a supercompensation phase, it could have a negative influence on subsequent measurements Lack of an additional control group practicing handball without additional jumping or plyometric drills Slight errors in the reported values of some results
(Noutsos et al., 2021)	T-test time: -1.43s (9.39%) 10m sprint time: -0.03s (1.66%) 20m sprint time: -0.15s (3.59%) SJ height: +1.64cm (9.08%) CMJ height: +0.38cm (1.78%) CMJ left leg height: +1.46cm (16.1%) CMJ right leg height: +1.21cm (12.97%)	

(Pancar et al., 2020)	30m sprint time: -0.36s (5.9%) Anaerobic power: +23.32W (7%) Overall Balance Score: -0.49AU (32.67%) Anterior-posterior balance point: -0.44AU (37%) Medial-lateral balance point: -0.21AU (27.27%)	Measurements of the balance scores not well specified
(Parnow & Hosseini, 2016)		CT group and PT group both implemented plyometric exercises Results were not presented in a clear way The structure of the article is not good
(Ramadan & Elsayed, 2022)	VO2max: +4.34ml/kg/min (8%)	Questionable validity of the running economy measures It is necessary to conduct some comparative studies on speed and plyometric protocols in order to gain a better understanding of how to obtain the ultimate improvement of VO2max, running economy, and performance of different players
(Shbib et al., 2021)	Peak power: +56W (9.1%)	PT was used in the intervention, but the focus was on beta-alanine supplementation Studies are required with differing intensities and volumes of plyometric training to determine their optimum dosage. All training sessions were supervised by the investigators, which minimizes variability in training sessions.
(Soto Garcia et al., 2022)	CMJ height: +2.04cm (9.64%) CMJ right leg height: +2.03cm (22.38%) CMJ left leg height: +2.48cm (28.87%) Standing shot throwing speed: -2.72km/h (4.18%) Step running throwing speed: -0.11km/h (0.16%) Dominant hand throwing velocity: -0.32km/h (0.53%) Non dominant hand throwing velocity: +1.46km/h (2.18%) Medicine ball throwing velocity: -0.1m (1.9%) Standing horizontal jump: -9.57 cm (6.08%)	PT exercises were combined with other exercises, so results cannot be attributed to PT alone It is strange that shot throwing velocity decreases in the standing shot, 3-step-running shot and dominant hand shot, and increases in the non-dominant hand There are errors in the calculations of the results, so they cannot be trusted Study was conducted with self-adjusted loads. Intensity was not controlled, only volume
(Spieszny & Zubik, 2018)	CMJ height: +2.7cm (5.7%) SJ height: +1.9cm (4.5%) Power in cycle-ergometer test: +39W (3.8%) Standing throw: +0.8km/h (0.9%) Leaning back throw: +1.4km/h (1.5%) Jumping throw: +0.8km/h (0.9%)	Only study that implemented a wave pattern Slight differences between absolute and relative values
(Toumi et al., 2004)	Maximal isometric force: Week 0-3: +257N Week 3-6: +27N Week 6-8: +15N	Plyometric exercises were combined with weight training, so the results cannot be attributed to PT alone Results not presented in a clear way Pre-mid-post intervention values were not presented for SJ and CMJ
(Van Den Tillaar et al., 2020)	Strength-plyometrics group (pre-to-post): Standing 7m throwing velocity: = 3-step running throwing velocity: +0.4m/s CMJ height: +2.9cm CMJA height: +3cm YoYo distance: +214,3m Squat: +3.15kg 30m sprint time: = COD test: -0.3s Plyometrics-strength group (pre-to-post): Standing 7m throwing velocity: = 3-step running throwing velocity: +0.1m/s CMJ height: +5cm CMJA height: +4cm YoYo distance: +200m Squat: +13.6kg 30m sprint time: = COD test: -0.2s	Both groups did PT, only the training order was different PT exercises were combined with other exercises, so results cannot be attributed to PT alone Results were not presented clearly

Discussion and conclusions

The primary objective of this systematic scoping review was to investigate the implementation of plyometric training within the context of handball training, with a particular focus on the targeted physical fitness variables. The findings revealed that the majority of research conducted on plyometric training in handball was in the context of indoor handball, with limited studies on beach handball or other game variations. Additionally, most of the studies included tier 2 athletes, indicating that the majority of the population studied was in the developmental stage. The interventions utilized were of a relatively low volume, with work intensity being a parameter that was mostly disregarded.

The frequency of the interventions was mainly twice per week, with a significant proportion of the studies also implementing three times per week. The majority of the interventions lasted between five and 12 weeks and used mainly cyclic exercises, although a considerable number also included acyclic exercises in conjunction with cyclic ones. Virtually all studies utilized exercises that did not involve any external load, relying instead solely on the body weight of the participants to execute the PT interventions. The exercises used various force vectors, with the majority of them being in the vertical and horizontal planes of movement and primarily bilaterally or bilaterally and unilaterally. Almost all selected exercises were not sport-specific, and many studies did not consider rest periods. However, studies that did register rest periods used mainly inter-set rest periods lasting between one and two minutes.

The majority of the conducted studies adopted a form of progressive overload and were predominantly conducted during the in-season period. Notably, almost none of these studies mentioned the incorporation of any tapering phase. In essence, the primary outcomes of these investigations align with the hypothesis that plyometric training stands as an efficacious method for enhancing muscle power, strength, and balance among handball players, regardless of their competitive level and the extremity of the targeted lower and upper limbs.

Methodological considerations in reporting plyometric training programs

Surface

In this systematic scoping review, focused on the methodological aspects of plyometric training in handball, several limitations were identified in the available information presented in the included articles. One limitation was the lack of clear identification of the type of floor on which the plyometric interventions were performed. Plyometric exercises such as jumps and bounds generate high impact forces on the body. These forces are absorbed primarily by the muscles and bones of the lower extremities when landing on a hard surface such as concrete. On the other hand, when landing on a softer surface, such as sand or turf, the impact forces are absorbed more by the surface itself, resulting in less stress on the muscles and bones. Therefore, the type of floor used for plyometric training in handball may have an important impact on the effectiveness and safety of the training program (Arazi, Mohammadi, & Asadi, 2014; Arazi, Eston, Asadi, Roozbeh, & Zarei, 2016; Lännerström, et al., 2021; Ojeda-Aravena, et al., 2022). Additionally, it is important to note that different surfaces may also affect the specific mechanics of the exercises being performed, like, for example, landing on sand or turf requiring more stabilization and balance compared to landing on a hard surface (Ahmadi, et al., 2021; Donoghue, Shimojo, & Takagi, 2011; Giatsis, Panoutsakopoulos, & Kollias, 2022; Hammami et al., 2020a).

Although not the main objective of their study, Montoro-Bombú et al. (2023) made some notable observations and recommendations regarding the effects of different surfaces on plyometric training. According to the authors Montoro-Bombú et al. (2023), soft surfaces are more appropriate for maximal dynamic strength production and can be used during the plyometric preparation or general preparation phases of an athlete. Additionally, soft surfaces are beneficial during the first developmental phase of sprint acceleration and can be used for a wide variety of jumps in the general preparation of top athletes. During training on soft surfaces, athletes should avoid heel strikes against the ground to prevent them from being transferred to hard surface work. On the other hand, hard surfaces are recommended to be introduced after training on soft surfaces and are associated with short ground contact times and bouncing jumps with open knee joint angles. Hard surfaces are more conducive to the development of power, muscle stiffness, and reactive strength, so they should be gradually introduced during the specific preparation phase and used in the pre-competitive and competitive phases. A wide variety of jumps that require short ground contact times and are primarily based on fast bouncing can be introduced while training on hard surfaces, as long as metrics such as maximum power output and best reactive strength are monitored. Therefore, it is important to consider the athlete's specific goals and needs when selecting the surface on which to train.

The lack of identification of the type of surface on which plyometric training was performed may result in potential biases in the generalization of the findings. As observed in this systematic scoping review, only 11% of the included articles presented a clear description of the type of surface used, which is a concern since it may not allow for fair comparisons in future discussions. Therefore, it is important for researchers to explicitly report the type of surface used in plyometric training programs to help clarify potential discrepancies in findings and to facilitate the replication of interventions in future studies.

Intensity and box height

Intensity was a parameter that was often not considered by the authors/practitioners of the collected studies. Ramirez-Campillo et al. (2021a) pointed out that it is difficult to identify an adequate marker of plyometric intensity and, the majority of the studies that did consider intensity in their interventions, did that by instructing maximal effort. In their study, Ramirez-Campillo et al. (2021a) found that the greater performance improvements were associated with maximal intensity, in line with what they found in other meta-analyses, but, in contrast, the same authors referred to a study by Thomas, French & Hayes (2009) where that was not the case. Box height is also a parameter that is often considered to determine intensity when doing drop or depth jumps (Lees & Fahmi, 1994; Prieske, et al., 2019; Taube, Leukel, Lauber, & Gollhofer, 2012; Tong, Chen, Xu, & Zhai, 2022) and it was also mostly disregarded in the studies found in this systematic scoping review that used boxes in their interventions. However, as can be seen in the cited studies, there is still no consensus regarding an optimal drop height when doing this type of intervention.

A recent study by Montoro-Bombú et al. (2023) also provided insight into determining parameters for the implementation of plyometric programs, including the importance of considering factors beyond drop height in determining training intensity. While drop height can be a useful intensity determinant, the authors emphasized that it is not the only factor to consider, as variables such as ground reaction forces, power output, and reactive strength also play important roles. The authors suggest that training intensity can be individualized by evaluating performance parameters such as the optimal height for maximum power output, reactive strength, rate of force development (RFD), ground reaction forces, stiffness, and reactive jump height. However, the authors acknowledge that evaluating all these parameters may be difficult in a team context or in situations where certain measures cannot be obtained. We recommend the reading of Montoro-Bombú et al. (2023) for more information about PT intensity and for recommendations regarding the implementation of PT programs.

Periodization

Periodization is a widely discussed topic in the field of sports science and strength and conditioning. However, it is important to note that some studies have raised questions and concerns about the efficacy of periodization and its definition (Afonso, Nikolaidis, Sousa & Mesquita, 2017; Afonso et al., 2019; Hornsby, Fry, Haff, & Stone, 2020; Kiely, 2012, 2018). While most studies on plyometric training in handball implemented some form of progressive overload, the results were mixed regarding whether the programs were periodized or not, and regardless of the type of periodization used. This was true whether the plyometric training was performed in-season or during the pre-season, and whether it was added to or replaced the standard handball training regimen.

It is important for researchers and practitioners to carefully consider the evidence regarding periodization before implementing it into their training programs (Afonso et al., 2017, 2019; Hornsby, et al., 2020; Kiely, 2012, 2018). Despite these cited discussions regarding periodization lying beyond the scope of this article, it is important to note, as already mentioned above, that there is still no consensus on the definition of periodization. As a result, studying a topic where the definition is not clearly defined can be challenging.

Despite these facts, the study conducted by Lievens, Bourgois, and Boone (2021) aimed to investigate if a specific form of plyometric progressive overload would lead to better results than others. The researchers found that, when the training load was equated, there was no significant difference in the chronic performance benefits between increasing volume, intensity, or both. These results were observed in recreational team sport athletes. Watkins et al. (2021) reported different periodization strategies (undulating, linear, or a combination) in their study on the implementation of PT. However, it is important to consider the previously mentioned concerns regarding the definition of periodization when interpreting findings from studies like this. The lack of a clear and consistent definition of periodization makes it difficult to compare and generalize results across studies. Therefore, future research should strive to use consistent terminology and clearly define their periodization strategies to improve the quality and applicability of the findings.

In their articles that researched the practices of strength and conditioning coaches of different sports and countries, Weldon et al. (2020, 2022) reported that the majority of S&C coaches implemented plyometric exercises year-round. Considering the range of implementation methods and ongoing discussions about periodization in plyometric training literature, it is crucial for sports scientists and coaches to work collaboratively to determine optimal strategies for PT implementation and to arrive at more definitive conclusions on periodization. By incorporating a more standardized approach and ensuring that key variables are monitored and reported, such as type of surface used, progression models, and program periodization, we can develop a better understanding of the most effective PT methods for different sports and athletic populations. Furthermore, by combining the expertise of both researchers and practitioners, we can ensure that these methods are effectively integrated into training programs and have a positive impact on athletic performance.

Tapering

One limitation found in the included articles of this systematic scoping review was the lack of information about tapering, as only two out of 35 studies mentioned the utilization of any taper strategy. Tapering is an essential component of training programs that involves reducing training volume and intensity prior to a competition, with the aim of maximizing performance (Bosquet, Montpetit, Arvisais, & Mujika 2007; Le Meur, Hausswirth, & Mujika, 2012; Murach & Bagley, 2015). The absence of information about tapering in the majority of studies limits our understanding of how it affects the effectiveness of PT interventions in handball players. The only study we found specifically addressing tapering in PT was a systematic review with meta-analysis (Ramirez-Campillo, et al., 2021b). The authors of the review (Ramirez-Campillo, et al., 2021b) recognize that the implementation of taper strategies can be difficult over the course of competitive seasons due to the high volume of matches and technical-tactical workouts typically faced by elite players in team sports. However, the authors (Ramirez-Campillo, et al., 2021b) note that adequate tapering approaches have been shown to be very effective during training periods lasting between four and eight weeks, such as pre-season or less congested in-season phases. Moreover, they also found that tapering strategies seemed to be equally effective for both shorter (≤7 days) and longer (>7 days) time periods, and that lower reductions in training volume (≤40%) appeared to be more effective in significantly improving jumping performance.

To date, the research on tapering strategies for PT and team sports is limited (Vachon, et al., 2021). Therefore, it is crucial for future studies to consider tapering strategies and evaluate their effects on PT and team sports. It is recommended that the authors of future interventions focus on tapering strategies to provide more information about the optimal ways to implement tapering in a team sport context, given the typically congested schedules that teams face. By doing so, we may gain a better understanding of how to best implement tapering and its effects on PT and other types of training in team sports.

Type of exercises (and if they were sport-specific/involving COD)

In the section “Study characteristics”, it was noted that the studies included in this systematic scoping review registered over 40 different exercises. However, only one exercise was deemed to be sport-specific, as it involved the use of a ball and was utilized in only two studies. Additionally, there was no clear consensus on the use of change of direction (COD) exercises, with nearly an equal number of studies utilizing them as those that did not. The most commonly implemented exercises were variations of hurdle jumps, hopping, drop jumps, horizontal jumps, and vertical jumps. These are exercises commonly used in PT (Weldon, et al., 2020, 2022) and they have been proven effective in improving some physical fitness parameters on many occasions (Kons, et al., 2023; Slimani, et al., 2016).

It is noteworthy that the majority of the studies included in this systematic scoping review only incorporated plyometric exercises for the lower body, with a limited number of studies including any form of plyometric exercise for the upper body. Considering that handball requires coordinated movements of both the upper and lower body, it is surprising that upper body plyometric exercises are not more commonly employed in training. As noted by Deng et al. (2023), there have been multiple reviews and meta-analyses published that examine the effect of lower limb plyometrics on various physical fitness indices, but the same has yet to be done regarding PT for the upper limbs. The authors (Deng, et al., 2023), reviewed 15 studies that combined PT for both upper and lower limbs and found that, for the most part, the combination had advantages for both upper and lower body physical performance of athletes. This indicates not only increased flexibility, upper body muscle strength and power, but also substantial gains in lower body muscle power, sprint speed, and agility. Given these findings, in a sport like handball, which includes actions for both the upper and lower limbs, coaches should be encouraged to implement plyometric exercises for both parts of the body to enhance the physical performance of their players.

Despite handball being a sport that already incorporates a considerable number of plyometric actions like jumping and changes of direction, Jakšić et al. (2023) considered that there is value in adding PT exercises to regular handball training. A study by Asadi et al. (2016) emphasizes the importance of performing exercises in different movement vectors to improve change of direction (COD) and the ability to move in different directions. Asadi et al. (2016) highlights that, since vertical jump exercises are not specific to COD, they do not show any effect on COD performance. However, when exercises are specific to COD, such as lateral bounds, side hops, and angle hops, the training program has a positive effect on COD performance. Despite the previously mentioned findings, the umbrella review of Kons et al. (2023) only found benefits in implementing plyometric exercises to improve COD in two of the studies presented in their review, while the other studies that evaluated the benefits of PT to improve COD had unclear effects. This information should be considered cautiously when planning PT.

Regularity

The majority of studies included in this systematic scoping review utilized a cyclic pattern for their plyometric exercises, although a significant proportion also incorporated both cyclic and acyclic patterns. A study by Makaruk, Czaplicki, Sacewicz, and Sadowski (2014) found that using repeated jump training methods might be more effective than single jumps for reducing vertical landing force in common plyometric exercises, but both methods improved jump height. The authors concluded that repeated jumps during PT might reduce landing force and improve jumping performance simultaneously, whereas single jumps improved jumping performance and changed the landing pattern for a stiffer technique in common plyometric exercises without reducing landing force.

Considering that handball involves both cyclic and acyclic movements, both types of patterns should be included in PT programs aimed at improving handball performance. However, given the previously mentioned findings by Makaruk et al. (2014), repeated jumps may be implemented more frequently, given the reduction in landing forces.

Laterality

Although it is common to perform actions with both legs in handball, such as jumping to block, and with only one leg, such as jumping to shoot, it is important to note that unilateral movements are more prevalent in the game. Therefore, it is somewhat surprising to find that a considerable percentage of the studies in this systematic scoping review implemented only bilateral exercises. Nevertheless, it is encouraging to see that there was an almost equal number of studies conducting their exercises either bilaterally or bilaterally and unilaterally, indicating that some coaches and researchers are aware of the importance of both types of movements in handball performance. This goes hand in hand with the study of Bogdanis et al. (2019), which found greater improvements with unilateral PT compared to bilateral PT. The authors (Bogdanis, et al., 2019) reported that unilateral PT was more effective than bilateral training at increasing both single and double-leg jumping performance, isometric leg press, maximal force, and RFD. They detailed that the main finding of their study was that unilateral lower limb PT was effective at improving both single and double-leg explosive performance, while an equal volume of bilateral training only improved bilateral performance. One possible explanation for the superiority of unilateral plyometric exercises could be related to neural factors. The authors (Bogdanis, et al., 2019) explain that, during unilateral plyometric exercises, muscles contract at slower velocities closer to their optimal level, resulting in a greater impulse. In contrast, during bilateral vertical jumps, muscles contract at greater velocities, which, due to the force-velocity relationship, produce less force. In handball, where both unilateral and bilateral movements are common, coaches should consider implementing both types of exercises, and give special attention to unilateral plyometric exercises due to their potential effectiveness in improving explosive performance.

From a biomechanical standpoint, unilateral plyometric exercises tend to place greater demands on the stabilizing muscles of the core and lower extremities, as the body must work to maintain balance and control during the movement (Bogdanis, et al., 2019).

On the other hand, bilateral plyometric exercises tend to generate greater forces and power outputs than unilateral exercises, as both limbs can contribute to the movement. This can be particularly beneficial for activities that require symmetrical or coordinated movements, such as sprinting, jumping, and throwing. Additionally, bilateral exercises can help to develop the elastic properties of the muscles and tendons, which can improve energy storage and return during explosive movements (Bogdanis, et al., 2019; Wallace, et al., 2010).

With this information in mind, coaches should implement exercises in their PT training programs that aim to improve performance either bilaterally or unilaterally, in order to adequate their training intervention to the scenarios that players will find in the game. Given the previously mentioned findings, it might be reasonable to affirm that unilateral plyometric exercises should be given preference in relation to bilateral ones, although the systematic review of Slimani et al. (2016) affirms that the combination of unilateral and bilateral jump drills seems more advantageous to induce significant performance improvements during high-intensity short-term PT in team sport players.

Direction

Most of the studies in this systematic scoping review implemented exercises in both the vertical and horizontal vectors, but a considerable amount also introduced other directions (e.g., lateral or diagonal). As noted by Asadi et al. (2016), performing PT with a combination of different types of plyometric exercises such as, for example, drop jumps, vertical jumps and standing long jumps, is better than a single form of exercise alone. As previously mentioned, the authors emphasize the importance of implementing COD-specific plyometric exercises in order to improve COD performance. They found that exercises such as lateral bounds, side hops, and angled hops had a positive effect on COD performance, while non-specific exercises such as vertical jumps did not. The reason for this is attributed to the different movement characteristics and the use of stretch-shortening cycle (SSC) characteristics. In COD movements, the SSC is utilized in a different way compared to vertical jumps, highlighting the importance of specificity in PT programming.

The umbrella review by Kons et al. (2023) shows that, in the studies conducted with team sports athletes, PT exercises done in different directions had moderate-to-large effects on improving various performance parameters, showing the greater relevance of PT to enhancing performance in this target population.

From a biomechanical perspective, the selection of exercises in plyometric training can have a significant impact on training adaptations. Exercises that emphasize movements in different planes can place varying demands on the musculoskeletal system, which can lead to differences in muscle activation and adaptation. For instance, exercises that target sagittal plane movements, such as vertical jumps or forward bounds, tend to emphasize the quadriceps and hip extensors, while exercises that target frontal or transverse plane movements, such as lateral jumps or rotational bounds, engage different muscle groups. Furthermore, exercises that involve landing in different directions can enhance the body's ability to absorb and dissipate force. Therefore, coaches should strive to implement exercises that are appropriate for the specific situations that occur more frequently in handball competitions, which involve movements in all planes.

Number of total contacts with the surface OR Number of total ground contacts

As said in the 'Study characteristics' section, there is a considerable disparity in the number of total ground contacts per session applied in the studies. Despite some studies recommending relatively low volumes of plyometric training (Ebben, 2007; Ebben, et al., 2014), and highlighting that higher volumes were not more effective than lower volumes, this systematic scoping review found one study (Alkasasbeh, 2023) that utilized as much as 600 ground contacts per session. However, it is important to note that this was the exception rather than the rule, since almost all the studies used less than 200 contacts per session, with the majority of them staying under 100 contacts per session.

It would be useful to see if the studies using lower volumes were equally effective compared with the ones with higher volumes. However, the six studies that registered the lower volumes are not adequate to draw conclusions, since four of them (Cherif et al., 2012; Hermassi, Laudner, & Schwesig, 2020; Soto Garcia, et al., 2022; Toumi, et al., 2004) combined PT with other training methods, one (Hermassi, et al., 2014), that lasted only eight weeks, reported some improvements in some parameters for the plyometric training group, but not for others, and the one by Chelly et al. (2014), that also lasted eight weeks, was the one that has shown the most promising results. However, even if these six studies coincided in their findings, it would still be a reduced sample to evaluate the effect of PT interventions with an average of up to 60 ground contacts per session compared to the ones with slightly higher volumes.

As handball is a sport that already has a considerable amount of jumping volume and other plyometric movements from the sport itself, some might ask if there are additional benefits of performing PT. The study by Jakšić et al. (2023) addressed that question and concluded that, when done two times per week for, at least, six weeks, PT in addition to handball practice is beneficial to athletes. However, it is important to note that the study has some limitations, in particular the fact that they included just six studies, and that there is no recommendation regarding the number of total ground contacts, so coaches cannot get any useful and practical information regarding this specific parameter.

Rest

Regarding intra-set rest intervals, most of the studies in this systematic scoping review did not consider this parameter. That did not happen so much with inter-set rest intervals, since a considerable number of studies specified that parameter.

Intra-set rest interval time is a topic that is not much studied in plyometric training literature. Two studies (Asadi & Ramírez-Campillo, 2016; Moreno, Brown, Coburn, & Judelson, 2014) addressed, and found, contrasting results regarding rest effects on different physical parameters. Given that, we suggest that intra-set rest intervals in plyometric intervention should be more researched, so we can give coaches and practitioners more information regarding this topic.

Regarding inter-set rest intervals, studies affirm that better results are reached with, at least, two minutes of inter-set rest intervals to improve change of direction (Asadi, et al., 2016) or three minutes to improve power (Willardson, 2006). However, the studies by Ramírez-Campillo et al. (2014) and, more recently, Guan et al. (2021), do not support those affirmations and have not shown greater benefits of longer (>2min) rest times compared to shorter (30s-1min) to a vast number of parameters.

Most of the studies included in this systematic scoping review utilized inter-set rest intervals that were superior to one minute. While this is not necessarily wrong, the conflicting findings of the aforementioned studies raise questions regarding whether the applied rest intervals were ideal. Given that time is a limited resource and that in handball, as in other team sports, there might not be enough time to optimally develop physical abilities, it may be beneficial to conduct more studies to determine whether longer rest intervals are necessary when doing plyometric exercises to reap greater benefits.

PT frequency and duration

Most of the studies in this systematic scoping review implemented a frequency of two plyometric training sessions per week, and a considerable number did it three times a week. Given that handball players and coaches already have to dedicate their time to improve other aspects of the game, that seems to be an adequate number of training sessions devoted to PT.

Regarding the duration of the interventions, most of the studies lasted from five to 12 weeks. The general recommendations state that more than eight weeks of systematic application of PT is necessary to improve physical performance in elite players, but short PT interventions (<8 weeks) have the potential to enhance a wide range of athletic performance parameters (e.g., jumping and sprinting) in children and youth amateur players (Slimani, et al., 2016).

While it is a somewhat common practice in sports science studies, due to a different number of factors, to have study durations that are somewhat reduced, it would be useful to have longer studies researching the effectiveness of, not only PT, but also other training means and methods for greater periods of time. Given that most of the team sports' seasons last almost a year, it would be useful for sports scientists, coaches and practitioners to be able to know the effects of some training interventions during longer periods of time, although we recognize the difficulty of doing that.

Main physical fitness adaptations observed

Vertical jumping

Jumping was the most common assessment performed, especially some forms of vertical jumping. Vertical jumping was evaluated in a total of 28 articles, specifically by countermovement jump—with or without arm movement—in 27 articles, squat jump in 18 articles, and drop jump in three articles. The results between them were mixed, ranging from negative changes in the CMJ and SJ (Mazurek, et al., 2018) to improvements of 38% (Hammami et al., 2020a) and 35.8% (Hammami, et al., 2018b) in the CMJ and SJ, respectively. Despite being present in only three articles, the drop jump values were also mixed, ranging from a decrease of 0.39% (Cherif, et al., 2012) to improvements of 11.2% (Büsch, et al., 2015).

It is hard to find a justification for the disparity in the vertical jumping results, as there is not a single factor that we can use to justify the discrepancy in values. The authors of the study with the poorest results (Mazurek, et al., 2018) point out some factors like short study duration, athletes' level, lack of progressive overload and absence of other training methods (e.g., resistance training) as a possible cause for the results. Although we found studies with all these characteristics that presented considerable differences in the results, maybe the combination of these characteristics (short study duration/reduced number of sessions, with the lack of progressive overload and no combination with other training methods in this specific population of tier 3 athletes) can justify the weak results in this specific study. The study by Cherif et al. (2012) presented a decrease in a drop jump performed unilaterally with the left leg, and, as the athletes only performed bilateral drop jumps, that goes in hand with the already mentioned findings of Bogdanis et al. (2019) that have shown that unilateral lower limb PT is effective at improving both single and double-leg explosive performance, while an equal volume of bilateral training only improves bilateral performance.

Some of the commonalities of the studies with the best results (Hammami, et al., 2020a; Hammami, et al., 2018b) were that they were performed with young age athletes (between 14-16 years), with interventions lasting 7/8 weeks and with a combination of the same exercises (hops, hurdle jumps, lateral jumps and horizontal jumps) done cyclically, in multiple vectors and implementing a progressive overload of training volume. Both were combined with other training methods, although different ones, and an important feature of the Hammami et al. (2020a) study that might have influenced the results was that a part of the group performed the intervention on sand.

In their article that studied the effect of PT on the jumping performance of handball players, Ramirez-Campillo et al. (2020a) suggest that the improvements in vertical jump height after PT probably encompass potential mechanisms such as enhanced neural drive to agonist muscles, alterations in musculotendinous stiffness, increases in muscle size and architecture, improved intermuscular coordination, greater excitability of the stretch reflex and changes in muscle fiber mechanics. As noted by Saéz-Saez De Villarreal, Kellis, Kraemer, and Izquierdo (2009), the specific effects of plyometrics on vertical jump performance in different types of jumps could be of particular importance, since PT is more effective in improving vertical jump performance in SSC jumps because of the enhancement of the subjects' ability to use the elastic and neural benefits of the SSC, what could be attributed to differences in the use of SSC characteristics, as an SJ consists mainly of a concentric phase, whereas a CMJ involves an eccentric and concentric phase. The authors (Saéz-Saez de Villarreal, et al., 2009) affirm that plyometrics produce slightly better effects in the fast SSC jumps (i.e., DJ) than in the concentric-only jumps (i.e., SJ) or even the slow SSC jumps (i.e., CMJ), so it is plausible to conclude that plyometric training effects are expected to be greater on DJs and CMJs than on SJs. To explain the difference in the effects of plyometric training between them, the biomechanical differences between the slow and fast SSC jumping exercises should be considered, as there are substantial differences in the mechanical output and jumping performance between slow SSC vertical jumps (e.g., CMJs) and fast SSC vertical jumps (e.g., DJs), and factors of jumping technique like corporal position, movement amplitude and ground-contact time represent some of the most important factors to consider when designing PT programs (Saéz-Saez de Villarreal et al., 2009).

Horizontal jumping

Horizontal jump ability was measured mainly by a standing long jump or a 5-jump test, in seven articles, and they have shown improvements from 1.5% (Büsch, et al., 2015) to 16.3% (Hammami, et al., 2019). Regarding horizontal jumping results, we can speculate that the poorest results (Büsch, et al., 2015) might be attributed to the fact that some of the interventions were made on unstable surfaces (Lesinski, Prieske, Demps & Granacher, 2016; Lesinski, Prieske, Beurskens, Behm & Granacher, 2018a; Lesinski, Prieske, Borde, Beurskens & Granacher, 2018b; Prieske, et al., 2013, 2015; Prieske, Demps, Lesinski & Granacher, 2017), and the best results (Hammami, et al., 2019) might be attributed to the low age of the athletes who were 13 years old (Peitz, Behringer, & Granacher, 2018; Radnor, et al., 2018), since this is the most distinguishable factor of that study, and they have presented great improvements in other parameters as well.

Although there are similarities in some mechanisms between vertical and horizontal jumps, Moran et al. (2021) point out some differences like the position of the center of mass during take-off, where vertical jumps show practically no displacement of the center of mass in a horizontal direction, but a vertical displacement of the center of mass was comparable between both types of jump, meaning that there are both the horizontal and vertical component of horizontal jumps, whereas vertical jumps possess a vertical component only. Given this, the authors conclude that horizontal jumps are more effective in enhancing horizontal performance but are no less effective than vertical jumps at enhancing vertical performance. Other significant difference is that horizontal jumps display shorter ground contact times, higher vertical ground reaction forces, greater limb stiffness and generally higher muscle activation in the rectus femoris, biceps femoris and gastrocnemius compared to vertical jumps, so coaches should consider this information when planning any type of jump training (Moran, et al., 2021).

Sprinting

After jumping, the second most common assessment performed was sprint time, from five to 30 meters, evaluated in 21 articles. Results varied from no changes (Büsch, et al., 2015; Van Den Tillaar, Roaas. & Oranchuk, 2020) to improvements of 22.58% (Hammami, et al., 2020a). Directly related to sprinting is repeated sprint ability, which was assessed in 10 articles, and registered improvements between 1.56% (Cherif, et al., 2012) and 15.77% (Hammami, et al., 2020a).

It is curious to see that the two studies (Büsch, et al., 2015; Cherif, et al., 2012) that reported the poorest results in jumping also had the poorest results in sprinting, and that might be due to the neuromuscular and biomechanical similarities between jumping and sprinting (Gheller, Kons, Pupo, & Detanico, 2022; Markovic & Mikulic, 2010; Marques & Izquierdo, 2014; Pruyn, Watsford, & Murphy, 2014). The results of Büsch et al. (2015) might be due to the fact that some of the exercises were performed on unstable surfaces, as already mentioned before, and the lack of improvements in sprinting in the study by Cherif et al. (2012) might be due to the fact that only drop jumps were performed in the intervention, although that explanation does not make as much sense when trying to explain the decrease in jumping performance. The best results, from the study of Hammami et al. (2020a), might be explained by the fact that the PT intervention was combined with sprints, or by the fact that some part of the intervention was performed on sand (Markovic & Mikulic, 2010), and the group that did it was the one with better results in sprinting, although that was not the case in some other parameters.

Plyometrics target the stretch-shortening cycle (SSC), which involves rapid muscle stretching and contraction. Through neuromuscular adaptations, such as increased motor unit recruitment and improved intermuscular coordination, plyometric training enhances muscle power and rate of force development (RFD) and, biomechanically, it improves joint stiffness, extension during takeoff, and landing mechanics, optimizing energy transfer and, consequently, better sprinting performance (Oxfeldt, Overgaard, Hvid & Dalgas, 2019). Sprinting is a multidimensional movement skill that requires an explosive concentric and SSC force production of a number of lower-limb muscles, so it is expected that sprint performance benefits from PT (Markovic & Mikulic, 2010). It is important to note that it has been suggested that the greatest effects of PT on sprinting performance occur in the acceleration phase, since the velocity of muscle action in bounding plyometric exercises is closer to the velocities of muscle action in the acceleration phase of the sprint (Markovic & Mikulic, 2010; Saéz-Saez de Villarreal, Requena & Cronin, 2012).

Change of direction

This systematic scoping review includes 16 articles that evaluated COD, repeated COD, or used tests like the T-test or Illinois test (or some variations of those) that are commonly said to evaluate agility, although the definition of agility may make it impossible to measure. However, that goes beyond the scope of this article, and we will use the definition utilized by the authors of the articles.

From all those tests, we registered results that varied from marginal gains of less than 1% (Iacono, et al., 2017; Karadenizli, 2015) to improvements of 14.5% (Hammami, et al., 2019). These positive results might be due to factors such as the development of force and high-power output, and the ability to efficiently use the SSC in ballistic movements, decreasing ground-reaction times through an increase in muscle-force output and movement efficiency (Asadi, et al., 2016; Markovic & Mikulic, 2010). Another potential mechanism that supports the use of PT to improve COD is that the pre-stretch of the muscles may enhance the concentric contraction due to neural potentiation, allowing the recruitment of a greater number of motor units, with a larger effect at increasing velocities (Falch, et al., 2020). Some of the previous authors (Falch, et al., 2020; Markovic & Mikulic, 2010) highlighted the important difference between force-velocity COD (>90º) and velocity-oriented COD (<90º), stating that PT has been shown to be beneficial in improving both but, especially in the case of velocity-oriented COD (with small angles), one of the benefits of PT is that it allows to keep reactive strength as the main contributor to maintain velocity.

The studies with the poorest results (Iacono, et al., 2017; Karadenizli, 2015) both completed a total of just 20 sessions, but we do not know if that explains the weak results. Some better justifications might be the fact that the study of Iacono et al. (2017) has a considerably low volume and was conducted with athletes of a relatively high age (compared with the other studies), while the study by Karadenizli (2015) did not provide important information that would be useful to try to justify the results. Meanwhile, the results of Hammami et al. (2019) might be attributed to the previously mentioned factors.

Strength

There were 12 articles doing some type of strength test. However, in this analysis, we will only mention the results from squat (and its variations) and bench press tests, since they were the most common strength assessments performed. The athletes saw their squat improving from 2.35% in the bilateral squat to 49.88% in the quarter squat, both in the same study (Falch, et al., 2022), and their bench press improved between 15.9% (Aloui, et al., 2021) and 30.3% (Hermassi, et al., 2019).

Regarding the study with the better squat results (Falch, et al., 2022), it is important to note that it is relevant to measure squat results with different amplitudes, as squats with shallow amplitudes might have better transfer to some court performance markers, and the almost 50% increase in the quarter squat is a great improvement to consider.

Regarding the bench press improvements, it is important to note that the study with the poorest results (Aloui, et al., 2021) has only performed elastic-banded plyometric push-ups in their intervention, while the group with the better results (Hermassi, et al., 2019) have not done any upper-body plyometric exercises and did weight training and other exercises together with their plyometric intervention, which may be a better justification for the registered improvements in the bench press.

Ball throwing velocity

Ten articles measured ball throwing velocity, whether with a handball (with standing, jumping, or running shots) or with a medicine ball. Handball throwing velocity varied from negative results (Dahl & Van Den Tillaar, 2021; Soto Garcia, et al., 2022) to increases of 44% (Hermassi, et al., 2019), and medicine ball throwing velocity varied from negative results (Soto Garcia, et al., 2022) to improvements of 41.18% (Hermassi, et al., 2019).

As already mentioned in the outcomes table, the exercises implemented in the study by Dahl and Van Den Tillaar (2021) were not particularly well suited to the tests that they utilized, and the exercises in the study by Soto Garcia et al. (2022) were done with self-adjusted loads, so that might explain the weak results in both. In contrast, the study by Hermassi et al. (2019) utilized a variety of exercises and training modalities, so it is hard to attribute the good results to one particular factor.

Power

There were nine articles evaluating power in many different ways. The lowest improvement was 3.8% (Spieszny & Zubik, 2018), and the highest was 27.4% (Chelly, et al., 2014). Seven out of the nine studies evaluated anaerobic power, mainly with the Wingate test, and the highest registered improvement (27.4%) pertains to the upper body peak power in the cycle-ergometer test. As there were many ways to measure power in its different forms and regarding different body parts, it is hard to attribute a cause to the results. However, in their article that researched the effects of PT on anaerobic power, (Luebbers, et al., 2003) suggested that the increases in power following PT could be due to increases in muscle fiber size, as improvements in muscle force production have been associated with increases in muscle fiber size and plyometrics can increase both type I and type II fibers, as well as increased motor unit functioning, since neuromuscular adaptations like increased inhibition of antagonist muscles as well as better activation and co-contraction of synergistic muscles may account for the improvements in power output.

Balance

Balance was evaluated in eight articles, mainly by the Y-balance and Stork tests, but other tests were also utilized. Balance results varied from negative (Pancar, et al., 2020) to improvements of 365.2% (Hammami, et al., 2020a). These results must be interpreted carefully, as the results in Pancar et al. (2020) were not well explained, and an improvement with a magnitude of 365.2% must always be looked at with caution, not to say with suspicion.

Maximal oxygen uptake (VO2max)

VO2max was measured in six articles, and increases varied from 3.99% (Hammami, et al., 2018b) to 9.2% (Hammami, et al., 2021). It is important to note that four out of the six articles implemented PT together with other training methods such as HIIT, sprint or COD training, so that must always be considered when interpreting the results. We could speculate that the positive results might be attributed to improvements in running economy that are common with PT, but improvements in running economy may occur independent of changes in VO2max (Barnes & Kilding, 2015; Saunders et al., 2006; Turner, Owings, & Schwane, 2003). In their study with low-level runners, Turner et al. (2003) emphasized that PT improved running economy without altering the indicators of the ability of muscles to return strain energy, explaining that the improvement might have occurred by way of a mechanism not involving storage and return of elastic energy, or it involved enhanced storage and return of elastic energy but in a way that could not be detected with the indirect measurements used. Alterations in running mechanics that allow for better coordination and timing of ground force application would offer a mechanism to improve running economy (Saunders, et al., 2006), so that might be another explanation for the benefits of PT. Given these inconclusive findings, one should be cautious when making the connection between PT and improved running economy and, consequently, a possible increase in VO2max.

Future research

Given the limitations found in this study, there is a need for future research in the following fields:

The recent study by Montoro-Bombú et al. (2023) provided great advancements regarding the concern raised by Ramirez-Campillo et al. (2021a) about the lack of adequate markers for intensity in plyometric exercises, citing power output, reactive strength, rate of force development (RFD), ground reaction forces, stiffness, and reactive jump height as some markers to take into account while measuring PT intensity. However, Montoro-Bombú et al. (2023) recognized that it is difficult to evaluate these parameters in a team sport context or in an environment where there are no financial resources to acquire the necessary equipment to obtain those parameters. Given that, sports scientists should strive to find ways to better evaluate plyometric intensity in these contexts, despite all the limitations and difficulties that it might entail.

About periodization, the sports science community should strive to reach a consensus regarding the definition of periodization, and always take that same definition into account while conducting future research on it. However, as noted by Hornsby et al. (2020), past research should never be disregarded, and should always be considered while trying to evolve it. Nevertheless, the aforementioned concerns (Afonso, et al., 2017, 2019; Kiely, 2012, 2018) that were raised should also be considered, and only by merging together all the information about this topic can better recommendations be provided.

Given that tapering protocols can be difficult to implement in a team sport context (Vachon, et al., 2021), it might not be easy to conduct many studies about it. However, more studies about tapering protocols in PT can and should be done, in order to enrich the findings by Ramirez-Campillo et al. (2021b).

Since coaches implement a vast number of plyometric exercises (Weldon, et al., 2020, 2022), it could be studied if there is a need to include all these different exercises in training programs, or if there are any particular exercises that are more efficient than others in improving physical markers (e.g., drop jumps vs depth jumps vs CMJ vs hurdle jumps vs hops vs bounds). Given that the time dedicated to improving the physical characteristics of team sport athletes is limited, this kind of information would be very useful for coaches. Besides this, it would also be useful to gather more information about the influence of different force vectors and their effect on improving COD with plyometric exercises, given the conflicting findings by Asadi et al. (2016) and Kons et al. (2023).

Given the lack of evidence regarding an ideal volume of PT, more studies researching the effects of different numbers of total ground contacts per session (e.g., 50 vs 100 vs 200 vs 400) would be useful for coaches and practitioners.

As mentioned before, more studies about the effect of different rest intervals should be done, whether inter-set or intra-set.

Conclusions and practical applications

The conclusions drawn from the present review underscore a prevalent emphasis on the lower limb, accompanied by considerable heterogeneity in methodological aspects, such as exercise types, and challenges in accurately gauging exercise intensity. Nonetheless, the overarching consensus points towards a discernible positive impact of plyometric training on strength and power-related indicators among handball players.

Based on the comprehensive insights gleaned from this systematic scoping review and the amassed literature, the following practical applications emerge as pertinent considerations:

Surface selection: Given the nature of handball being practiced on hard surfaces, plyometric training (PT) is best conducted on similar terrain. However, if specific adaptations achievable through PT on soft surfaces, such as maximal dynamic strength production, are desired, coaches may incorporate such surfaces strategically to achieve those effects.

Intensity guidance: Coaches should heed the intensity recommendations outlined by Montoro-Bombú et al. (2023) when designing their plyometric exercises. This involves carefully considering optimal parameters for maximum power output, reactive strength, rate of force development (RFD), ground reaction forces, stiffness, and reactive jump height.

Exercise selection: While more research on exercise efficiency is awaited, coaches can confidently integrate common plyometric exercises such as hurdle jumps, drop jumps, depth jumps, vertical jumps, horizontal jumps, hops, bounds, and upper-body plyometric exercises.

Repeated jumps emphasis: Building upon the findings by Makaruk et al. (2014), coaches may consider incorporating repeated jumps more frequently than single jumps, as they may offer reduced landing forces and bring potential benefits.

Unilateral emphasis: A blend of both bilateral and unilateral plyometric exercises can be included in training regimens. However, prioritizing unilateral exercises and allocating a significant portion of the program to them is recommended.

Multidirectional preparation: To simulate diverse scenarios prevalent in handball competition, coaches should integrate plyometric exercises across all planes of movement, ensuring athletes are well-prepared for the multifaceted demands of the sport.

Volume and rest management: As the evidence does not substantiate the advantages of higher-volume PT programs, coaches should structure sessions with a total ground contact count ranging between 50-100 per session. Customizable rest intervals, varying from 30 seconds to two minutes, can be introduced based on available training time.

Frequency and consistency: Considering the multifaceted commitments of team sport athletes and coaches, a recommended frequency of 2-3 PT sessions per week aligns well with the need for balanced training and ample recovery.

In summation, these derived practical applications offer a comprehensive roadmap for optimizing plyometric training within the context of handball, underpinned by the amalgamation of research findings and expert insights.

Following Table 4, a compilation of overarching recommendations is presented concerning the optimal surface type and recommended ground contact times for the incorporation of plyometric training. These insights are predominantly drawn from the comprehensive findings of recent research (Montoro-Bombú, et al., 2023):

Table 4. Practical applications of plyometric training for handball players

Hard surface	Soft surface
Recommended to be introduced after working on soft surfaces.	Longer contact times, slower reactivity
Associated with short ground contact times, and bouncing jumps with open knee joint angles	Associated with the production of maximal dynamic strength,
Allow shorter ground contact times, which guarantees better reactivity	Can be used for DJ when a greater emphasis on CMJ and jump height is sought and when short contact times are not required
Associated with the development of power, muscle stiffness and reactive strength	Can be used for rehabilitation
Ideal for jumps that require short contact times and are primarily based on fast bouncing	More adequate during the first developmental phase of sprint acceleration, where more work on high-force production at relatively low speeds is sought for

Longer contact times	Shorter contact times
Involve a countermovement and higher drop heights	More open knee and hip angles
Better for producing maximal dynamic strength	Better for the development of maximum power output production, RFD and reactive strength
Increases ground reaction forces and maximal eccentric force production	Less ground reaction forces
Can be combined with general or maximal strength work	Can be combined with power-oriented weight training work
Recommended exercises: depth landings, depth jumps, horizontal drop jumps, and jumping between high hurdles	Recommended exercises: tuck jumps, drop jumps, and jumping between medium hurdles

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