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REVIEW ARTICLE

# Methodological Characteristics and Future Directions for Plyometric Jump Training Research: A Scoping Review

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**Abstract** Recently, there has been a proliferation of published articles on the effect of plyometric jump training, including several review articles and meta-analyses. However, these types of research articles are generally of narrow scope. Furthermore, methodological limitations among studies (e.g., a lack of active/passive control groups) prevent the generalization of results, and these factors need to be addressed by researchers. On that basis, the aims of this scoping review were to (1) characterize the main elements of plyometric jump training studies (e.g., training protocols) and (2) provide future directions for research. From 648 potentially relevant articles, 242 were eligible for inclusion in this review. The main issues identified related to an insufficient number of studies conducted in females, youths, and individual sports (~ 24.0, ~ 37.0, and ~ 12.0% of overall studies, respectively); insufficient reporting of effect size values and training prescription (~ 34.0 and ~ 55.0% of overall studies, respectively); and studies missing an active/passive control group and randomization (~ 40.0 and ~ 20.0% of overall studies, respectively). Furthermore, plyometric

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jump training was often combined with other training methods and added to participants' daily training routines (~ 47.0 and ~ 39.0% of overall studies, respectively), thus distorting conclusions on its independent effects. Additionally, most studies lasted no longer than 7 weeks. In future, researchers are advised to conduct plyometric training studies of high methodological quality (e.g., randomized controlled trials). More research is needed in females, youth, and individual sports. Finally, the identification of specific dose-response relationships following plyometric training is needed to specifically tailor intervention programs, particularly in the long term.

**Key Points**

Recently, there has been a proliferation of published articles on the effect of plyometric jump training in various populations.

There have been relatively few studies conducted in females, youths, and individual sports, with insufficient reporting of effect size values and training prescription, studies missing an active/passive control group and randomization, and most studies lasting no longer than 7 weeks.

In the future, researchers are advised to conduct plyometric training studies of high methodological quality (e.g., randomized controlled trials), with more research needed on specific dose-response relationships, particularly in the long term.

## 1 Introduction

Efficient use of the stretch-shortening cycle is a key factor in jump performance, with the accumulation of elastic energy in a muscle action facilitating greater mechanical work in subsequent actions [1–3]. Jump exercises are an effective means of physical conditioning for the promotion of health, injury prevention, and skill-related measures of athletic performance [4–6]. Jump training is commonly associated with plyometric training and, in particular, with drills that stress the musculotendinous unit [1, 2]. In this sense, plyometric jump training involves the utilization of different types of jumping movements [7–9] that are incorporated into comprehensive strength training programs [5, 10, 11]. Numerous plyometric jump training articles have been published in peer-reviewed journals in recent years [12]. However, between the years of 2000 and 2017, scientific publications on plyometric jump training have increased 25-fold compared with any previous period [12]. This rapid expansion has been driven by the technology-related advancement of appropriate measuring devices [13, 14] and an increased awareness amongst scientists of plyometrics' potential benefits for athletic performance [15], health (e.g., improvement in bone mineral density) [16–19], injury prevention [20], rehabilitation [21], and application to special populations [22–24].

Several high-quality reviews related to plyometric jump training have been published [15, 25–30], with a particular focus on the effects on athletic performance (e.g., agility, muscular strength, sprint, and jump performance), as well as in specific populations (e.g., male youth athletes) and various sports (e.g., soccer). Such reviews and meta-analyses generally adopt strict inclusion criteria for studies' eligibility [25, 27, 31, 32], thus reducing the limitation of potential bias. However, the application of such rigorous inclusion criteria tends to limit the number of studies in

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these reviews, resulting in the capture of only some of the large number of articles that have been published. Accordingly, conclusions from reviews and meta-analyses may thus be limited [33, 34] in their facility to assess the methodological gaps and limitations among the articles that have been published.

Given the above observations, the aims of this scoping review article were to (1) characterize the main methodological features of the body of literature relating to plyometric jump training studies (e.g., participants' characteristics; training protocols) and (2) recommend future directions for plyometric jump training research. Information gathered for this scoping review could be useful for sports scientists, practitioners, and, ultimately, athletes, as it may help in the understanding of the methodological gaps and limitations in the current plyometric jump training literature. Additionally, this review may inspire the design of more high-quality studies in the field, resulting in fewer sources of bias and greater generalizability to relevant populations.

## 2 Methods

### 2.1 Search Strategy

A literature search for published studies on the PubMed database (https://www.ncbi.nlm.nih.gov/pubmed/?term=plyometric+training) [35] was performed up to April 17, 2017. This search was conducted using the term 'plyometric training.'

Considering the broad international scope of the current review, we searched for articles in all languages (i.e., 54) available on the PubMed database. Only original research was included. However, to reduce the chances of excluding potentially relevant studies, 72 article types available on the PubMed database were included during the initial search, with no restriction for journal categories, including those found on MEDLINE. In addition, no age, sex, or publication date criteria were imposed during the initial search. Default values of the PubMed database search engine were used in search fields, PubMed commons, text availability (e.g., abstract, free full text, and full text), and participants. Manual data checking was performed to increase the precision of data collection from relevant studies.

### 2.2 Retrieved Articles Selection

After an initial search, an account was created in the National Center for Biotechnology Information (https://www.ncbi.nlm.nih.gov). Through this account, the lead investigator received automatically generated emails for updates regarding the search terms used. These updates were received on a daily basis, and studies were eligible for inclusion until the initiation of manuscript preparation on July 1, 2017.

To facilitate the inclusion of a sufficiently high number of articles, many different study designs were considered. This is in line with the principles of scoping reviews [36–38], including those in the field of resistance training [5, 39]. This resulted in the accumulation of a rather broad body of research and, consequently, the review of studies with different levels of quality and research questions. Several limitations were systematically identified according to standard data extraction criteria (e.g., PEDro scale) and applied to selected articles for quality assessment [40]. This is detailed in subsequent sections of this article. In line with the aforementioned principles of scoping reviews [5, 36–39], both non-randomized and non-controlled studies were included [41].

#### *2.2.1 Inclusion Criteria*

Included studies were those that incorporated pre- and post-intervention performance testing with six or more plyometric jump training sessions over a period $\geq$ 2 weeks, including plyometric jump drills as a primary component (individually or embedded in a wider training program). Articles that used plyometric jump training with added resistance were also included. Conference contributions were considered if full-text articles were available.

#### *2.2.2 Exclusion Criteria*

Articles were excluded if they were cross-sectional (transversal), a review, or a training-related study without plyometric jump training. Also excluded were retrospective studies, prospective studies, studies in which the use of jump exercises was not clearly described, studies for which only the abstract was available, case reports, studies with ambiguous study protocols, non-human investigations, special communications, repeated bout effect interventions, repeated references, letters to the editor, invited commentaries, errata, overtraining studies, and detraining studies. In the case of detraining studies, if there was a training period prior to a detraining period, the study was considered for inclusion.

### 2.3 Data Extraction

From potentially relevant retrieved articles, generic information (e.g., author name, journal name, and year) and abstracts were saved for analyses. Two investigators (RRC and CA) independently processed all data, with one extracting and the other verifying. Based on previous recommendations for improving searching in PubMed [42], suggestions for plyometric jump training searches [25, 27, 29, 32] and expert opinion on methodological gaps

**Table 1** Items considered for data extraction from eligible articles

| Main methodological gaps and limitations | Methodological gaps and limitations related to participants' characteristics | Shortcomings of key elements of plyometric jump training design |
|---|---|---|
| *Treatment description quality*. The plyometric jump training treatments were further categorized as (1) well described, when treatment description allowed for adequate study replication, including the reporting of duration, frequency, intensity, type of exercises, sets, and repetitions; or (2) insufficiently described, when the treatment description omitted any of the six aforementioned descriptors | *Sex*. The sex of the participants was categorized as male or female. When both male and female participants were mixed in a study, this was registered | *Type of jump drills*. Identified as unilateral or bilateral. They were also identified according to plane of movement (with lateral direction, diagonal direction, vertical direction, horizontal direction, backward direction, jump with turn, or spin jump [e.g., 180°]). In addition, drills were also categorized as cyclical, non-cyclical, and sport-specific jumps. Some specific jumps, although mainly concentrically, were also considered due to their high power or velocity profile (e.g., jump squat). In some studies, due to a poor description of drills, incomplete data were available to extract |
| | | *Box height*. For studies were plyometric jump training interventions incorporated drop jump drills, the height (cm) of the box (or boxes) was identified. For studies where a very similar technique of jump drill to that of the drop jump was used, the height of the box obstacle was also recorded |
| | *Age*. The age of the participants was registered in years | *Surface type*. The type of surface used during plyometric jump training was identified as aquatic, mat, grass, sand, clay, machine (e.g., force plate), tartan or indoor running track, unstable or perturbed, concrete or cement, wood, and uphill. In some studies, special footwear or barefoot plyometric jump training was used. In some cases, mixtures of surfaces were employed. When authors reported the use of land surface without further detail, this was considered as not clearly reported |
| | | *Total jumps*. The total number of jump repetitions was identified as jumps per leg unless stated otherwise (e.g., foot contacts). In some studies, jump volume was reported as jumped distance (meters) or duration (seconds). It is worth noting that studies in which jumps were performed as warm-up were not included in this scoping review. In some studies, the maximum number of jumps was not clearly reported, compared to the lower value. In the later cases, the lower number of jumps clearly reported by the authors was recorded |
| | | *Replaced*. Studies in which plyometric jump training replaced part (or, in some studies, all) of the habitual training routine or was added to the regular training activities of participants were recorded |
| *Control group*. The incorporation (or not) of a control group was identified. In an athletic setting, a control group was deemed as one composed of participants with similar training habits, but not exposed to plyometric jump training | *Body mass*. The mean body mass (kg) for each experimental group was identified unless stated differently (e.g., range values). In some studies, mean body mass was reported including values of control groups or non-trained experimental groups | *Combined*. Experimental groups were identified as 'combined' when they performed additional training (e.g., resistance training). In such cases, although the independent effect of plyometric jump training is difficult to characterize, it was deemed acceptable to consider these articles, as one aim of this study was to identify potential limitations related to plyometric jump training interventions. Combination was also identified for plyometric jump training experimental groups that performed additional training and no control group was incorporated for comparison, or when compared to another training group performing a 'non-combined' form of training |
| | *Height*. The mean standing height (m) of experimental groups was identified. In some studies, authors provided mean height values for the whole group of participants, without differentiation per group (e.g., control; experimental). In these cases, the mean height value indicated represents all groups | *Training duration*. The total plyometric jump training duration (weeks) was recorded. For studies ending mid week, this was considered as a complete week |
| | | *Frequency*. The frequency of plyometric jump training sessions applied per week (number of sessions per week) was identified |

**Table 1** continued

| Main methodological gaps and limitations | Methodological gaps and limitations related to participants' characteristics | Shortcomings of key elements of plyometric jump training design |
|---|---|---|
| *Randomization*. If randomization of participants into groups occurred (or not), this was registered, using the dichotomous categorization 'yes' or 'no.' The same criterion was applied whether or not a control group was included, such as in studies with no control group but including $\geq 2$ experimental groups | *Performance/playing level*. For this review, performance/playing level was categorized following an adaptation of previous recommendations for plyometric jump training reviews and meta-analysis (Asadi, Arazi, et al. 2016; de Villarreal, Kellis, Kraemer, and Izquierdo, 2009; Markovic, 2007; Saez-Saez de Villarreal, Requena, and Newton, 2010; Saez de Villarreal et al. 2012; Moran, Sandercock, et al. 2017), and after consensus among authors from the current review. In this sense, the performance/playing level of experimental groups was classified as follows: (1) not clearly reported; (2) *high*, for professional/elite athletes with regular enrollment in national and/or international competitions, highly trained participants with $\geq 10$ training hours per week or $\geq 6$ training sessions per week and a regularly scheduled official and friendly competitions; (3) *moderate*, for non-elite/professional athletes, with a regular attendance in regional and/or national competitions, between 5 and 9.9 training hours per week or 3–5 training sessions per week and a regularly scheduled official and friendly competitions; (4) *normal*, for recreational athletes with $< 5$ training hours per week with sporadic or no competitions' participation, and for physically active participants (World Health Organization-recommended, or higher level) and school-age youths regularly involved in physical education classes; (5) *low*, for healthy but sedentary participants, healthy older adults, and participants under medical treatment (e.g., anterior cruised ligament reconstruction; pain rehabilitation), (6) *mixed*, for groups of participants composed of two or more of the aforementioned levels. Of note, the jump training load was not considered as part of the regular training load of participants; hence, it was not considered to classify participants' performance/playing level | *Intensity*. The intensity of plyometric jump training was categorized as low; moderate; high; very high; maximal; low to moderate; moderate to high; low to high; optimum power load (usually determined based on the loaded countermovement plyometric jump test); RPE-based; and not clearly reported. Of note, technical-based intensity description and the mere mention of the concept of intensity (without further adequate quantitative-qualitative parameter description to sustain the prescribed intensity) were categorized as not clearly reported. Also of note, in this scoping review, maximal intensity was consider for different parameters reported by authors, including maximal height, maximal distance, and maximal velocity, among other so-called maximal indicators of intensity |
| *Number of participants*. Only participants that completed the training intervention were considered. The number of participants in the control(s) group(s) was not considered | *Sport practiced*. If participants in the plyometric jump training groups(s) practiced a given sport, this was identified as a team sport (e.g., soccer) or individual sport (e.g., tennis). If participants from team and individual sports were embedded in the same group, this was also identified. If participants were not imbedded in a particular sport (e.g., recreationally, active; sport science students), this was also identified, using the denomination *non-applicable* | *Progressive overload*. Application of progression was verified among articles. Overload was usually applied as volume based, technique based (e.g., exercises increased in complexity), and intensity based. A mixed model of progression was identified in some studies, with experimental groups using two or more of the aforementioned progressive-overload techniques. If the training traits were kept constant across time, the study was categorized as non-progressive. Of note, in some studies, progressive overload occurred in a weekly fashion, whereas in others, it occurred at some mid-point during training |
| *Dependent variables (tests)*[a]. The number of dependent variables measured in experimental groups was recorded, as well as effect size values, significant and non-significant changes, and percentage pre-post changes. As this investigation did not have a meta-analytical approach, it should be noted that identified effect size values are those reported by authors. Moreover, although dependent variables were identified, as well their changes, data are not shown in this scoping review, as these are part of a different meta-analytical review | *Systematic plyometric jump training experience before intervention*. If authors stated that participants had previous experience, a dichotomy characterization identifier was used as 'yes' or 'no,' without consideration of the extent of the experience<br>*The training period of the season*. In the studies where competitive athletes were recruited (and studies with participants in a year-round training plan), the training period was identified as in-season, pre-season, and off-season. In the studies where participants were not embedded in a year-round training plan (i.e., healthy sedentary participants), training period was deemed as not applicable | *Taper*. Taper was considered to have occurred if a reduction in the training load (usually volume) was applied in the last part of the training program (most often the last week of training). A dichotomy identification system ('yes' or 'no') was used to categorize studies<br>*Rest between repetitions, sets and/or exercises, and training sessions*. The rest time between jump repetitions (seconds), sets and/or exercises (seconds), and training sessions (hours) was registered |

% percentage of change for dependent variables, ES effect size change for dependent variables

[a]Although dependent variables (test) were identified, as well their changes (%; ES), data are not shown in this scoping review, as they are part of a different meta-analytical review

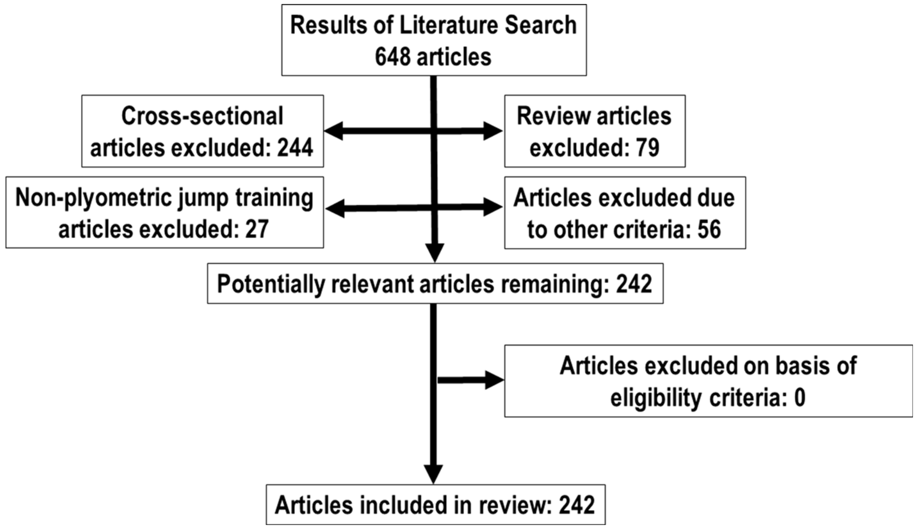


**Fig. 1** Flow chart illustrating the different phases of the search and study selection

and limitations of plyometric jump training studies, several data items were considered for extraction. A detailed outline of each of these items is provided in Table 1. The items were grouped into three broad subjects for results presentation and discussion purposes: (1) main general characteristics; (2) participants' characteristics; and (3) key elements of plyometric jump training design.

### 2.4 Eligible Articles

From 648 articles, 406 (62.7%) were excluded (Fig. 1) leaving 242 (37.3%) eligible for data extraction [19, 20, 22, 24, 43–279] (see Table S1 in the electronic supplementary material, online resource 1).

## 3 Results

The 242 eligible articles appeared in 47 different journals. The majority ($n$ = 241) were published in English, with a clear exponential increase in number in recent years (Fig. 2).

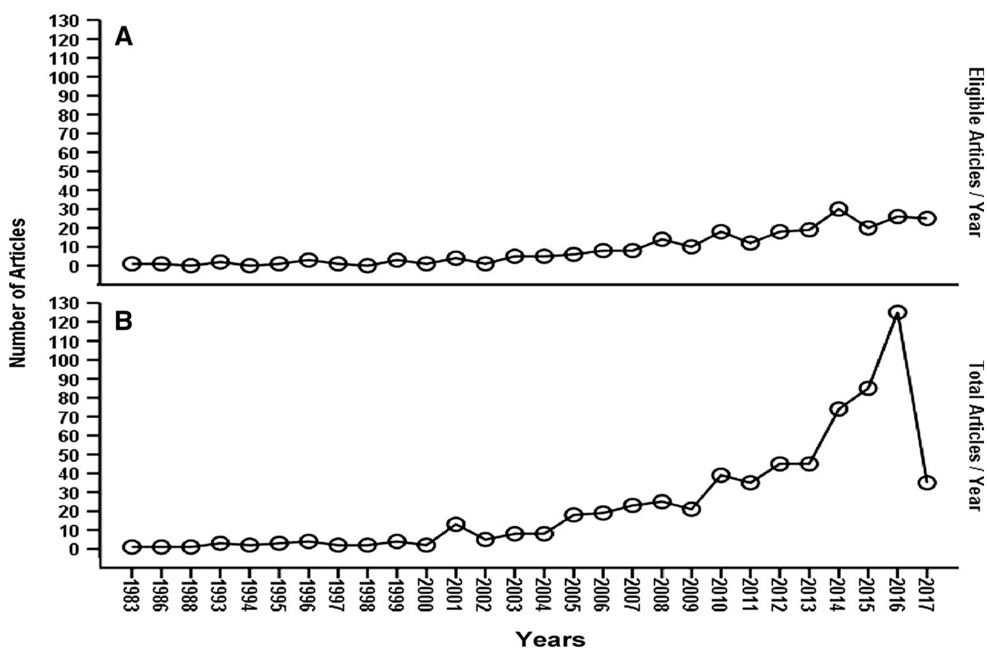


**Fig. 2** Eligible (**a**) and total (**b**) articles published per year related to plyometric jump training

**Table 2** Identified research characteristics and recommendations for future studies

| Identified characteristics from scoping review | Implications for future research |
|---|---|
| Main general characteristics | |
| Insufficient studies description and reporting | Describe plyometric jump training protocols in more detail (e.g., rest periods between repetitions, sets, and training sessions; jump execution technique; total volume of plyometric jumps), reaching consensus on uniform reporting methods (e.g., training intensity unit of measure) |
| Insufficient randomized controlled studies | Conduct more randomized controlled studies, particularly comparative experiments regarding the effects of common traits (i.e., of drop jump box heights; surface type; total volume; type of jump and their combinations; frequency of training; progressive overload; taper strategy; recovery periods; *intensity*) used in plyometric jump training studies, usually supported only on empirical practice |
| Insufficient effect size values reporting | Incorporate effect size reporting (in addition to *p* value reporting) |
| Participants' characteristics | |
| Insufficient studies conducted in female, youth, and older adults, from different training backgrounds | Conduct more research in female and youths, including the effects of menstrual cycle and biological maturity, respectively. In addition, more research is needed in older adults, considering the beneficial effects that muscle power training might offer to this population |
| Insufficient studies conducted in high and low athletic performance participants | More studies should be conducted in participants with high athletic performance (e.g., professional athletes), as well as participants with low athletic performance (e.g., older adults; studies in rehabilitation settings) |
| Insufficient studies conducted in individual sport athletes, as well as insufficient studies comparing the effects of plyometric training on different types of sports | Conduct more investigations in individual sport athletes, and studies comparing the effects of plyometric training on different types of sports |
| Insufficient studies analyzing the effect of previous plyometric training experience in adaptations outcomes | Conduct more investigations in relation to the effect of previous plyometric training experience in adaptations outcomes, implicating long-duration interventions |
| Key elements of plyometric jump training design | |
| Insufficient studies conducted at long-term and season-long period for athletes | Conduct more long-term and season-long investigations |
| Insufficient studies have identified the independent effect of plyometric jump training | Conduct more studies with an adequate methodology in order to elucidate the effects of plyometric jump training as an independent (not added) load |
| Insufficient uniformity regarding intensity-related prescription | More research should focus on reaching an international consensus regarding quantification and prescription of intensity for plyometric jump training, including studies to clarify the effects of intensity on measures of physical performance, health-related traits, and physiological variables |
| Lack of studies analyzing the effects of plyometric jump training imbedded in well-rounded and long-term training programs, including injury-related measures, body composition and anatomic adaptations (e.g., bone mass; tendon adaptations), fitness and proxies of athletic performance | This research area merits further exploration, particularly considering that plyometric jump training is usually one of several training components needed to maximize improvement in fitness and athletic performance, in interventions programs over long periods of time. The study of the interactive effects of plyometric jump training with other training methods during rounded training programs is of paramount importance in future studies, including comparison of its interaction with different types of resistance training methods (e.g., Olympic lifts; low-speed resistance training) in different groups according to age, sex, and training state going into the program, type of sport practiced, among others |

### 3.1 General Characteristics

From eligible articles, 54.5% were classified as being insufficiently described (see Table 1 for further information regarding the identification of treatment description quality).

Note: the remaining results are derived from Table S1 (unless stated otherwise) (see the electronic supplementary material).

From the 242 eligible studies, 40.5% did not incorporate an active/passive control group and 19.4% did not consider any form of randomization. However, the number of eligible articles that have incorporated a randomized and controlled design increased from 1987 to 2017, comprising up to 52.0% of relevant literature in recent years, compared to 33.3% previously. The number of participants included per study averaged 15.9 participants. From the total number of reported dependent variables ($n = 3982$), 14.6% were deemed not clearly or quantitatively available (e.g., presented in graphical form only), whilst changes reported as effect sizes were available for only 34.0% of these (data not shown in this scoping review).

### 3.2 Participants' Characteristics

Most studies included male participants (57.2%), whilst 23.9% were female participants, and 16.6% were a mixture of both sexes. Of note, the sex of participants was not clearly reported in 2.3% of the studies. Most of the studies included participants with a mean age of $\geq$ 18 years, and 36.7% included youth participants, with groups' mean age equal to 19.6 years old. Participants' mean body mass, stature, and body mass index were 65.6 kg, 170.4 cm, and 22.6 $kg{\cdot}m^{-2}$, respectively.

The physical performance/playing level of participants was high (e.g., professional/elite athletes) in 14.9% of the studies, low (e.g., participants under medical treatment) in 8.3% of the studies, and not clearly reported in 5.3% of the studies. Participants with moderate (e.g., non-elite/non-professional athletes) or normal (e.g., recreational athletes) physical performance or playing level featured in 46.3% of studies. Participants with mixed physical performance or playing level were included in 25.2% of studies (see Table 1 for a detailed depiction of physical performance/playing level classification). With regard to the type of sport practiced, 44.2% included athletes from team sports [mostly soccer players (31.1%)], 12.0% undertook individual sports [mostly endurance runners (6.7%)], 8.7% played both individual and team sports, whilst 30.1% were non-competitive (e.g., recreational) athletes. In 5.0% of studies, this information was not clearly reported. Twelve percent of studies included participants with experience of plyometric jump training, 46.7% included those without experience, and 41.3% did not clearly report these details. Amongst the included studies, 14.0% focused on training during the pre-season period of the season, 28.5% during the in-season, and 5.8% during the off-season. In 17.8% of studies, this information was not clearly reported, whilst 33.9% of the studies did not include participants who were competitive athletes or who were engaged in a year-round training plan.

### 3.3 Key Elements of Plyometric Jump Training Design

The types of plyometric jump drills were not clearly reported in 2.9% of the studies, whilst 72.3% used a mixture of two or more jump types. In addition, 24.8% employed one type of jump only. Drop jumps were included in 32.1% of studies, with a combination of heights used in 17.4% and individualized prescription of heights used in 1.3% of studies. Box heights for drop jumps ranged from 10 to 110 cm.

Underfoot surface type was not clearly reported in 64.2% of studies. A proportion of 7% of studies reported either clay, wood, athletic track, cement, or gymnasium-type floors. With regard to softer surfaces, 2.2% of studies reported the use of athletic mats, 7.8% utilized grass surfaces, and 4.0% incorporated aquatic, elastic, or sand-based surfaces. A mixture of surface types were used in 7.0% of the studies (e.g., inclined–flat; land–aquatic). In 7.0% of studies, plyometric jump training was completed using special equipment, which included force plates, unstable surfaces, sledge apparatus, or similar commercially available apparatus, other than boxes or barriers. With regard to training loads, 5.2% of studies did not clearly report the number of jumps completed during the intervention period. Amongst those that did report the number of jumps, a wide range of values was observed, with 250 jumps per week as a mean. However, values varied according to training design (e.g., duration).

Plyometric jump training was added to the habitual training of participants in 38.5% of studies. In 20.5% of studies, part of the habitual training strategy of participants was replaced with plyometric jump training; however, 22.1% of the studies did not clearly report the approach taken on this issue. Approximately 18.9% of the studies recruited subjects who were not involved in habitual physical training. Plyometric jump training was combined with other methods of training as part of an intervention in 47.1% of studies, but no clear information was identified in 2.5% of the studies. Most of the studies that applied a combination of plyometric jump training with other methods used resistance (29.7%), speed (14.3%), and agility (8.0%) training. Other training methods that were used in combination with plyometric jump training were sport-specific, balance, electrostimulation, stretching, core, footwork, endurance, coordination, and high-intensity interval training methods. Most commonly, two or more of these methods were used in combination with plyometric jump training.

Training duration ranged from 2 to 96 weeks. Most studies applied $\leq$ 7 weeks of training (mode), with a mean number of 8.3 weeks observed. However, there was high variability for this statistic, with a standard deviation of

7.2 weeks. With regard to training frequency, 5.6, 50.6, 28.5, 1.6, and 0.4% of the studies used one, two, three, four, and six sessions per week, respectively. From the included studies, 12.9% used a combination of training frequencies, more commonly two and three sessions per week. Some groups were submitted to a range of training frequencies, ranging from zero up to five sessions per week. Plyometric jump training intensity was not clearly reported for 42.0% of the included studies, while 52.0% reported it as maximal using criteria such as height, distance, reactive strength index, optimal power, percentage of one repetition maximum, time, voluntary effort, velocity, rate of execution, force, or a mixture of these. Training intensity was submaximal in 6.0% of studies, and this was quantified using similar measures such as percentage of one repetition maximum, height, distance, velocity, and rating of perceived exertion.

A proportion of 17.7% of the studies did not feature progressive overload as an element of program design, and 6.7% did not present clear information relating to this factor. Individual overload techniques (e.g., volume based, technique based, and intensity based) were applied in 34.2% of the studies, whereas 41.4% of studies used a mixed model of progression, combining two or three individual overload techniques during the training program. Information relating to the tapering of training was not reported in 11.1% of the studies. Conversely, 15.5% applied a tapering strategy, but 73.4% did not present clear information with respect to this factor.

The rest time between sets and/or exercises was not clearly reported for 42.4% of the studies. The rest interval extended from 0 to 600 s, with a mean of 119 s, a standard deviation of 80 s, and a mode of 120 s. With regard to the rest period between plyometric jump repetitions, 79.3% of the studies did not clearly specify the interval (if any) between plyometric jumps. For those that reported the duration, this ranged from 4 to 120 s, with a mean of 13 s, a standard deviation of 8 s, and a mode of 15 s. The rest period between training sessions was not clearly reported in 45.6% of the studies. Among those studies that reported this value, 48 and 72 h were the most common rest period durations reported, with intervals ranging from 24 to 168 h.

## 4 Discussion

The aims of this scoping review article were to (1) characterize the main methodological features of the literature relating to plyometric jump training studies and (2) provide recommendations for future plyometric jump training research. The main results allowed a comprehensive characterization of the main methodological features of the literature of plyometric jump training studies. In the following paragraphs, a discussion is provided on the implications of the identified elements and future directions for plyometric jump training research (Table 2).

### 4.1 Main General Characteristics

From the 242 eligible articles, ~ 51% were not described in sufficient detail, meaning that their findings could not be effectively leveraged for future research or practice. Accordingly, just under 50% of the studies in this review demonstrate the quality of description required to leverage their findings for future research and practice. Examples of insufficiently described study features relate to the omission of one or more basic treatment descriptors, such as training duration, frequency, intensity, exercise type, and number of prescribed sets and repetitions. Moreover, around 40% of the included studies did not incorporate a control group per se, and approximately 25% were non-randomized or did not clearly report information relating to this design element. However, randomization and controlled design implementation has become more common, increasing from 33.3 to 52% of published articles in recent years. This seems to indicate that the growing number of published articles is mirrored by a concurrent improvement in the methodological design of plyometric jump training interventions. With regard to the reporting of results, around 15.0% of dependent variable changes were not clearly described, often being presented in graphical form only, whilst effect size changes were reported for just 34% of dependent variables. Given the growing consensus with regard to the importance of effect sizes in intervention studies [280], investigators should consider not only the null-hypothesis test, but also the magnitude-based inference analysis [281]. In relation to this issue, *p* values could be argued to be pernicious given the binary nature of their associated conclusions, which relate to the statistical terms 'significant' and 'non-significant' [282]. In addition, the adequate classification of participant categories according to training experience and level (e.g., professional athlete) should be considered by researchers [283].

Although some limitations are difficult to address (e.g., subjects' blinding), investigators should strive to conduct more randomized and controlled studies, whilst also being mindful that the nature of the control condition will depend heavily on the applied setting in which the study is conducted. For example, researchers must consider the use of physically active control groups in an athletic setting, whilst passive controls are more appropriate in a clinical setting. When using a control group is not possible, a washout period or a cross-over design might serve as a potential alternative in a field setting, though this may be a suboptimal approach in youth athletes who are physically maturing at a fast rate. Studies should include adequate sample sizes which can sustain high rates of participant attrition, and descriptions of utilized methods should be detailed to the degree that studies could be replicated without need for recourse. If necessary, study details should be included in a supplemental file. Results should be comprehensively reported and should include effect sizes and associated inferences.

### 4.2 Participants' Characteristics

As in similar research fields [284], relatively few ($<25\%$) plyometric jump training studies included females, either adults or youths. Most of the included studies recruited participants with a mean age of around 18 years, and less than 37% of the included studies involved youth groups. Amongst the studies that included youth participants, biological age was reported only in around 37% of study groups, an important research gap previously identified [5]. This limitation is compounded by the utilization of different measures of maturity across studies, making it difficult to compare results. This could be viewed as a critical limitation among plyometric jump training interventions performed in youths because biological age seems to influence adaptations to plyometric jump training interventions [25]. Similarly, only one group with a mean age of over 65 years was identified. This is concerning given that modified jump exercises for older adults may be a good alternative [22] to *conventional* jumps. Regarding anthropometric data, most studies were conducted in healthy-weight participants. Some studies included overweight and obese participants [61, 62], whilst others reported changes in participants' body composition [94, 131, 158, 174, 209] or anatomical adaptations related to reduced injury risk (e.g., tendon hypertrophy) [138, 285–287]. Although usually seen as a training method to induce neural-related adaptations, plyometric jump training deserves further consideration as a training strategy to induce musculoskeletal [4] and body composition adaptations.

Only around 15.0% of the included studies were conducted in participants with a high-level of athletic performance or sport playing level. This may be due to the unwillingness of professional or elite athletes' coaches to modify their training schedule. Similarly, although plyometric jump training may have potential relevance as a rehabilitation therapy [24, 61, 62, 96, 107, 116, 145, 177, 179, 200, 225], only around 8% of the included studies were conducted in participants with a low-level of athletic performance or playing level. Moreover, the moderating effect of sports practice is relatively uncertain amongst individual sports as only around 12% of the included studies have been conducted in athletes who were engaged in such activities. Nevertheless, it does seem that plyometric jump training offers beneficial adaptations to participants with different athletic performance or playing levels and in various sports disciplines. Regarding plyometric jump training experience, although some reviews and meta-analyses reported no effects of previous experience on sprint [29], maximal strength [30], vertical jump [28], and agility [27] adaptations after a plyometric jump training intervention, others reported the opposite [26]. Moreover, as of yet, no controlled comparative research has been conducted, and around 41.0% of included studies did not clearly report on this issue. However, it is reasonable to expect that previous experience with jump training (e.g., long-jumpers) could impact on the degree of adaptation in high-level athletes because their ceiling for adaptation could be lower.

Cross-sectional studies have shown that plyometric jump training is applied regularly during athletes' competitive season [288–296]. Its application on a year-round basis might reduce the occurrence of injuries, most notably among youth athletes [297]. However, based on this review, the identification of cases in which the application of plyometric jump training was conducted in a year-round fashion proved difficult. Moreover, only 48.0% of the included studies applied plyometric jump training at some point of the participant's season (e.g., in-season), without long-term follow-up in order to compare its effects during other moments of the season (e.g., pre-season).

### 4.3 Key Elements of Plyometric Jump Training Design

To assess the specific effects of plyometric jump training in isolation with its effects as a part of a wider training program, researchers must clarify whether interventions are carried out with, without, or in place of other forms of physical activity [188]. Despite this, nearly 22.0% of the included studies did not report if plyometric training was added *to* an existing training program or if it *replaced* part of a program. Relatedly, 39% of the included studies reported that plyometric training was added to a program, whilst $\sim$ 47.0% of the included studies reported that it was added to another training method as part of an intervention (resistance, sprint, agility, balance, electrostimulation, stretching, core, footwork, endurance, coordination, and high-intensity interval training). Considering this, researchers should aim to strengthen their methodological approaches by clarifying if the effects of interventions occur because of plyometric jump training only or are due to a combination with another training method within or without a regular program of physical preparation. In this way, researchers could consider replacing part of athletes' habitual training with plyometric jump training, avoiding the introduction of other training methods to prevent the distortion of results.

Most of the included studies combined two or more types of jump drills, which, from a practical perspective, is considered to be a sound approach to optimizing adaptations [88, 91]. Despite this, from a research perspective, the prescription of multiple jump types within a single intervention could confound the independent effect of a single jump type, for example, a drop jump. Accordingly, more research is needed to assess the specific effects of different plyometric jump types with researchers being encouraged to apply programs that have little, if any, variation in the prescribed jump drill. Although ~ 25.0% of the included studies sought to assess the effect of a single type of plyometric jump, these studies did not compare the effect of one type of jump versus another. Moreover, very few investigations have compared the effects of different jump intensities (e.g., drop jump heights) [245] or the effects of intensity distribution (e.g., polarized plyometric training), whilst only three included studies individualized the prescription of jump training. Although it is beyond the scope of the current review to provide a detailed description of the dependent variables analyzed amongst included articles, it is worth mentioning that only three studies analyzed the effect of plyometric jump training on injury rates [20, 221, 248]. Relatedly, injury incidence was not associated with participation in plyometric jump training programs, including those that incorporated drop jumps, thus underlining the apparent safety of plyometric jump training.

The type of training surface used for plyometric jump training may affect the speed of the stretch-shortening cycle that is performed (e.g., fast vs slow), thus implying different biomechanical and physiological effects [298, 299] and possibly different adaptations. However, the surface type was not clearly reported for most (64.2%) of the included studies. The use of soft surfaces was reported by less than 15% of the included studies, and in most cases, their use was related to the specific nature of athletes' competition surface (e.g., grass surface for soccer players) [279]. Plyometric jump training was completed using special equipment in around 7% of the included studies. The utilization of special equipment to aid plyometric jump training adaptations is still a matter of debate, especially with regard to the usefulness of unstable surfaces compared to stable surfaces [300]. Noticeably, only one study quantified (e.g., by means of the restitution coefficient) the hardness of the training surface [137]. It is particularly noteworthy that authors do not typically acknowledge this factor, which could be justifiably considered a key aspect of plyometric program configuration.

Different physiological and physical performance traits (e.g., agility; speed) exhibit different temporal responses to plyometric jump training [22, 27–30, 301]. In this sense, training duration should be adjusted to the type of trait that is being targeted by the coach or athlete. However, most of the included studies lasted just 7 weeks or less. Therefore, the long-term effects of plyometric jump training are difficult to characterize based on evidence from the current body of available literature. In addition, the applied training volume varied widely among studies, with optimal values still yet to be determined. Although plyometric jump training volume recommendations have been provided for some physical performance traits [28–30], a general lack of consensus might partially explain the wide variation in current opinion. Training volume should be closely considered for both athletic performance enhancement and injury prevention purposes [302] as relevant doses could differ [271]. The weekly distribution of plyometric training frequency of included studies ranged from one to six sessions per week, with around 79% of the included studies applying two to three sessions per week. Some studies compared the effects of different training frequencies and revealed that this factor might not be as important as the overall training volume [45, 203, 210]. This corroborates the findings of some meta-analyses [27, 303], yet contrasts with those of others [28–30].

Plyometric jump training intensity has been defined as the amount of stress placed on involved muscles and connective tissue and joints during a given exercise [304]. Commonly, athletes perform drop jumps from progressively increasing heights for a more intense training stimulus [144, 305–307]. Indeed, it has been shown that there is greater muscle activity in drop jumps from a 60-cm box height than from a 40-cm [308] or 20-cm box height [305]. However, these assertions are not without opposition [309–313]. Considering this, although training intensity is a key factor to acknowledge in exercise prescription [11], plyometric jump training lacks consensus on optimal markers of intensity. Relatedly, the intensity of plyometric jump training was not clearly reported in around 42% of included studies. Moreover, when reported, in several cases, the description of how intensity was achieved was difficult to derive or was reported using highly varied criteria, such as height, distance, reactive strength index, optimal power, percentage of one repetition maximum, time, voluntary effort, velocity, rate of execution, force, rating of perceived exertion, or a mixture of these factors.

Progressive overload implicates a gradual increase of the stress placed upon the body during exercise training and is considered to be one of the fundamental principles of training [11, 87]. However, 23.2% of included studies did not incorporate an element of progressive overload or failed to report clear information relating to this factor. While around 33% of the included studies used a one-dimensional form of overload (e.g., volume, technique, or intensity based), approximately 41% used a mixed model of progression. However, the difference between the effects of various progression models adopted in the literature still requires elucidation. After an overload period, the application of a training taper has been identified as a key strategy [314–317]. This generally consists of reducing the training volume towards the end of a program or prior to a competition (or assessment) period [316]. However, only 15.5% of the included studies incorporated a taper strategy. Moreover, around 85% of the included studies did not apply a taper or failed to report it. On that basis, the effects of a taper as part of a plyometric training protocol need to be further examined.

Although evidence has been provided on the acute effects of rest time between plyometric jump repetitions [318] and sets/exercises [319], studies which directly investigate this are scarce [102]. Indeed, the rest time between repetitions and sets/exercises was not clearly reported for 79.3 and 42.4% of the included studies, respectively. When this information was reported, there were wide variations in the rest intervals utilized. Considering that the required rest period may depend on factors such as the duration of the effort [320, 321] and participants' ages [322], the wide variety of rest intervals used among the included studies may be explained by the various type of jump drills and the wide age range of participants. Regarding rest between training sessions, the most commonly used period was 48 to 72 h. Even though anecdotal reports recommend that plyometric jump training sessions should not be performed on consecutive days [323], there is a lack of experimental studies that have addressed this issue [120]. Factors such as training experience, habituation to plyometric jump drills, age, and intensity could be considered when rest periods between sessions are assessed [4].

Aside from several strengths (e.g., the number of analyzed studies; the broad spectrum of items extracted from studies), this review has some limitations. Factors such as the volume of plyometric jumps completed as a warm-up, the training attendance rate, and the coach-to-trainee ratio during interventions were not considered as review criteria. In addition, given the broad aim of this review, only the term 'plyometric training' was used in the search strategy.

## 5 Conclusion

From 648 potentially relevant articles, 242 were eligible for data extraction, with 26 variables from each allowing a comprehensive characterization of the main methodological features of the literature relating to plyometric jump training. This was based on the initial identification of 6292 elements through database searching. The implications of study design features for future directions in plyometric jump training research were described. To our knowledge, this one of the most extensive and comprehensive review studies conducted so far regarding plyometric jump training.

For investigators working in the field of plyometric jump training, a primary goal is to mobilize institutional, political, and government bodies, in addition to coaches and athletes, to increase awareness about the importance of this type of physical training activity. Benefits derived from plyometric jump training may include improvement of neuromuscular, metabolic, and cardiovascular markers as well as body composition and proxies of athletic performance. This can be achieved in both females and males as well as in pediatric and geriatric populations, in sedentary participants and competitive athletes, and in both preventive and rehabilitative therapy settings. Investigators involved in the relevant field should strive to increase funds available for research and should also look to foster international and multicenter collaboration toward a better understanding of the benefits that can be derived from this type of training strategy. This can be achieved through the promotion of a higher quality of research output. Overall, through this scoping review, several methodological elements have been recognized that should be addressed in future studies.

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**Compliance with Ethical Standards**

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