Plyometric jump training effects on the physical fitness of individual-sport athletes: a systematic review with meta-analysis

Silvia Sole1,2, Rodrigo Ramírez-Campillo3,4, David C. Andrade4,5 and Javier Sanchez-Sanchez6

1 Faculty of Nursery and Physiotherapy, University of Lleida, Lleida, Spain
2 GRECS Research Group, IrB Lleida, Lleida, Spain
3 Department of Physical Activity Sciences, Universidad de Los Lagos, Santiago, Chile
4 Centro de Investigación en Fisiología del Ejercicio, Facultad de Ciencias, Universidad Mayor, Santiago, Chile
5 Centro de Fisiología y Medicina de Altura, Facultad de Ciencias de la Salud, Universidad de Antofagasta, Antofagasta, Chile
6 Research Group Planning and Assessment of Training and Athletic Performance, Pontifical University of Salamanca, Salamanca, Spain

ABSTRACT

Background: The aim of this study is to conduct a systematic review with meta-analysis to explore the effects of plyometric jump training (PJT) on the physical fitness of individual sport athletes (ISA).

Methods: Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, we searched through PubMed, Web of Science, and SCOPUS electronic databases. We included controlled studies that incorporated a PJT intervention among ISA (with no restriction for age or sex), that included a pre-to-post intervention assessment of physical fitness (e.g., sprint; jump). From the included studies, relevant data (e.g., PJT and participants characteristics) was extracted. We assessed the methodological quality of the included studies using the PEDro scale. Using a random-effects model, meta-analyses for a given outcome was conducted. Means and standard deviations for a measure of pre-post-intervention physical fitness from the PJT and control groups were converted to Hedges’ g effect size (ES). Heterogeneity was assessed using the I² statistic. The risk of bias was explored using the extended Egger’s test. The statistical significance threshold was set at \( p < 0.05 \). Moderator analyses were conducted according to the sex, age and sport background of the athletes.

Results: Twenty-six studies of moderate-high methodological quality were included (total participants, \( n = 667 \)). Compared to controls, PJT improved vertical jump (ES = 0.49; \( p < 0.001; I = 0.0\% \)), linear sprint (ES = 0.23; \( p = 0.032; I^2 = 10.9\% \)), maximal strength (ES = 0.50; \( p < 0.001; I^2 = 0.0\% \)) and endurance performance (ES = 0.30; \( p = 0.028; I^2 = 11.1\% \)). No significant effect was noted for sprint with change of direction (ES = 0.34; \( p = 0.205; I^2 = 70.9\% \)). Athlete’s sex, age and sport background had no modulator role on the effect of PJT on vertical jump, linear sprint, maximal strength and endurance performance. Among the included studies, none reported adverse effects related to the PJT intervention.

Conclusions: PJT induces small improvements on ISA physical fitness, including jumping, sprinting speed, strength and endurance.
INTRODUCTION

Physical fitness is of critical importance to several sports, particularly in individual sports. For individual sport athletes (ISA), adequate levels of explosive strength, maximal strength, sprinting, acceleration, deceleration, change of direction, and endurance, are key factors potentially affecting athlete’s performance (Aughey et al., 2013; Coyle, 1995; Kovacs, 2006). Several training methods are routinely used by ISA in order to boost physical fitness, such as plyometric jump training (PJT) (Bazylar et al., 2015; Ebben, Hintz & Simenz, 2005). PJT is characterized by jumping drills with different ground contact times, usually involving a slow muscle-tendon stretch-shortening cycle (SSC) or a fast SSC (Ramirez-Campillo et al., 2020c). Jumping drills involving slow SSC are performed with ground contact times >250 ms, large lower-limb joint excursion, and low stiffness (e.g., counter drop jump) (Bobbert, 1990; Bobbert, Huijing & Van Ingen Schenau, 1987; Komi, 2003). On the other hand, jumping drills involving fast SSC are performed with ground contact times <250 ms, short lower-limb joint excursion, and high stiffness (e.g., bounce drop jump) (Bobbert, 1990; Bobbert, Huijing & Van Ingen Schenau, 1987; Komi, 2003). During both slow and fast SCC, the accumulation of elastic energy facilitates greater mechanical work (i.e., explosive strength) production in subsequent actions (Komi & Gollhofer, 1997; Radnor et al., 2017; Taube, Leukel & Gollhofer, 2012). Indeed, the SSC of the muscle-tendon complex optimize the rate of force development, the relative force per-motor unit recruited, and therefore, muscle power (Radnor et al., 2017). In this sense, PJT, through enhancement of the SSC and associated neuro-mechanical mechanisms (Markovic & Mikulic, 2010), may facilitate improvements in physical fitness.

There is compelling evidence showing that PJT may improve physical fitness regardless of age and sex (Andrade et al., 2018; De Villarreal et al., 2009; De Villarreal, Requena & Cronin, 2012; De Villarreal, Requena & Newton, 2010). However, the studies that explored the effects of PJT on the physical fitness in ISA have reported inconsistent results, with benefits in some (Bishop et al., 2009; Ramirez-Campillo et al., 2014), but not all studies (Blagrove et al., 2018; Bogdanis et al., 2019; Ramirez-Campillo et al., 2020c). Furthermore, one additional methodological limitation of most PJT intervention studies is their relatively small sample size (Ramirez-Campillo et al., 2018; 2020c). A 2020 PJT scoping review including 420 articles reported that an average of ~10 participants was included per study (Ramirez-Campillo et al., 2020c). In PJT studies conducted among ISA, the average sample size was ~13 participants per study, suggesting that some studies may be statistically underpowered to find significant effects. Moreover, even if significant effects emerge from studies with a small sample size, their replicability would be limited (Abt et al., 2020). This problem of underpowered studies may partially be resolved by conducting a meta-analysis. To date, several systematic reviews and meta-analysis that assess the effects of PJT on different components of physical fitness have been published.
These analyses have provided evidence that PJT is effective for inducing large improvements in vertical jump ability (ES = 0.84) (De Villarreal et al., 2009), strength (ES = 0.97) (De Villarreal, Requena & Newton, 2010), and sprint capacity with (ES = 0.96) (Asadi et al., 2016) or without change of direction (COD; ES = 0.97) (De Villarreal, Requena & Cronin, 2012). To date, however, no previous meta-analysis has systematically explored the effects of PJT on the physical fitness of ISA. Moreover, previous meta-analyses incorporated participants across a range of different sports. Because the effects of PJT may vary depending on the sports background of the athlete, findings from these studies cannot be generalised to ISA (Asadi et al., 2016; De Villarreal, Requena & Cronin, 2012; Taylor et al., 2018; Vlachopoulos et al., 2018).

Therefore, considering: (i) the increased scientific awareness of the relevance of PJT, evidenced by a 25-fold increase in PJT-related scientific publications from 2000 to 2017 (Ramirez-Campillo et al., 2018), and (ii) the apparent inconsistent findings of isolated studies on the effects of PJT interventions on the physical fitness of ISA, we aimed to conduct a systematic review with meta-analysis to explore the effects of PJT on the physical fitness of ISA.

**METHODS**

This meta-analysis was conducted following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Liberati et al., 2009).

**Search strategy**

For this meta-analysis, we searched through PubMed/MEDLINE, Web of Science (Core Collection), and SCOPUS electronic databases from the inception of indexing until 30 April 2020. Potentially relevant keywords were collected through experts’ opinions, literature reviews and organized vocabulary (i.e., Medical Subject Headings: MeSH). In the PubMed/MEDLINE database, the following search syntax was used: randomized controlled trial (Publication Type) AND training (Title/Abstract) OR plyometric (Title/Abstract) OR plyometric exercise (MeSH Terms) AND sports (MeSH Terms).

We excluded studies based on the review of the title, abstract, or when needed, the full-text. Following the main systematic searches, lead author’s personal libraries were also examined. Grey literature sources in the form of conference proceedings were also considered provided that the full-text was available. The search process was conducted by RRC and SS. Any disagreement was resolved with the intervention of a third author (DA).

**Eligibility criteria**

We included studies that satisfied the following inclusion criteria: (i) incorporated a PJT intervention, defined as lower-body unilateral or bilateral bounds, jumps, and hops that commonly utilize a pre-stretch or countermovement that initiates the usage of the SSC (Chu & Myer, 2013; Moran, Ramirez-Campillo & Granacher, 2018; Ramirez-Campillo et al., 2018); (ii) included cohorts of ISA, with no restriction for age or sex; (iii) PJT was compared with a control group of athletes that did similar training, with the only difference between the groups being the PJT intervention; and (iv) the study included a
pre-to-post intervention assessment of physical fitness (e.g., sprint; jump) (Girard, Mendez-Villanueva & Bishop, 2011).

Data extraction
Data was extracted using a pre-defined form created in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA), including: the first author’s last name and the year of study publication, PJT treatment description, description of the control comparison, type of randomization, and the total sample size. We also extracted data regarding the participants’ sex, age (years), body mass (kg), height (m) and previous experience with PJT. If applicable, information about the type and level (e.g., professional, amateur) of sport practice was also retrieved. Regarding PJT characteristics, extracted data included training frequency (days/week) and training duration (weeks), intensity level and marker of intensity, jump box height (cm), total number of jumps completed during the PJT intervention, types of jump drills performed, combination (if applicable) of PJT with another form of training type, rest time between sets, repetitions, and between sessions, type of jumping surface, type of progressive PJT overload (e.g., volume-based; technique-based), training period of the year (e.g., in-season), portion of the regular training replaced (if applicable) with PJT (e.g., PJT replaced 20% of the technical-training load), tapering strategy before post-intervention assessment (if applicable).

Methodological quality assessment
We assessed the methodological quality of the included studies using the Physiotherapy Evidence Database (PEDro) scale. This scale evaluates different aspects of the study design, such as participant eligibility criteria, randomization, blinding, attrition, and reporting of data. There are 11 items on the PEDro checklist, but item 1 is not included in the total score. Therefore, the maximum possible score on the checklist was 10. Based on the summary score and in line with previous meta-analyses that focused on PJT (Ramirez-Campillo et al., 2020d; Stojanović et al., 2017), studies that scored ≤3 points were considered as being of “poor quality”, studies scoring 4 or 5 points were considered as being of “moderate quality” and studies that scored 6–10 points were considered as being of “high quality”.

Statistical analysis
Although two studies can be used in meta-analyses (Valentine, Pigott & Rothstein, 2010), considering reduced sample sizes are common in the sport science literature (Pigott, 2012), including in PJT studies (Abt et al., 2020; Lohse et al., 2020; Ramirez-Campillo et al., 2018, 2020c), meta-analysis was only conducted when >3 studies were available (Garcia-Hermoso, Ramirez-Campillo & Izquierdo, 2019; Moran, Ramirez-Campillo & Granacher, 2018; Skrede et al., 2019). Means and standard deviations (SD) for a measure of pre-post-intervention physical fitness from the PJT and control groups were converted to Hedges’ g effect size (ES). The data were standardized using post score SD. In all analyses, we used the random-effects model to account for differences between
studies that might impact the treatment effect (Deeks, Higgins & Altman, 2008; Kontopantelis, Springate & Reeves, 2013). The ES values are presented alongside their respective 95% confidence intervals (CIs). Calculated ES were interpreted using the following scale: <0.2, trivial; 0.2–0.6, small; >0.6–1.2, moderate; >1.2–2.0, large; >2.0–4.0, very large; >4.0, extremely large (Hopkins et al., 2009). For studies that included more than one intervention group, the sample size in the control group was proportionately divided to facilitate comparison across the multiple groups (Higgins, Deeks & Altman, 2008). Heterogeneity was assessed using the I^2 statistic. I^2 values of <25%, 25–75% and >75%, were considered to represent low, moderate and high levels of heterogeneity, respectively. The risk of bias was explored using the extended Egger’s test (Egger et al., 1997). In case of a significant Egger’s test the trim and fill method from Duval and Tweedie was applied for adjustment (Duval & Tweedie, 2000). All analyses were carried out using the Comprehensive Meta-Analysis program (version 2; Biostat, Englewood, NJ, USA). The statistical significance threshold was set at \( p < 0.05 \).

**Moderator analysis**

Based on previously described methods (Sánchez et al., 2020), we used a random-effects model and independent computed single factor analysis, in order to identify potential sources of heterogeneity likely to influence the effects of PJT, including athletes sex, age and sport background. For age-related analyses, participants were divided in adult (i.e., \( \geq 18 \) years of age) compared to youth (\(< 18 \) years of age). For sex-related comparisons, participants were categorized as female, male or combined male-female groups. For sport background-related comparisons, athletes were grouped in a specific sport discipline (e.g., runners; gymnasts) when \( \geq 3 \) studies provided data for the same sport, otherwise the athletes from different sport backgrounds were mixed for analyses.

In addition, moderator analyses were conducted for linear sprint and maximal strength according to type of test. Specifically, moderator analysis was conducted according to linear sprint test of short duration (i.e., \(< 20 \) s) compared to moderate duration (i.e., \( \geq 20 \) s). Regarding maximal strength tests, moderator analysis was conducted according to dynamic compared to isometric tests.

**RESULTS**

**Study selection**

From records that were initially identified \( n = 6,546 \), and after excluding the duplicates and studies based on title, abstract, or full-text, 26 studies were included in the meta-analysis (Table 1). Figure 1 provides a diagram of the study selection process. The included studies involved 27 individual experimental groups and 345 participants and 322 participants in the 27 control groups. The characteristics of the participants from the studies are displayed in Table 1, while the programming parameters of the PJT interventions are presented in Table 2. The physical fitness outcomes for both the control and PJT groups are presented in Table 3.
| Authors, year                  | Ran   | n    | Gender | Age* (years) | BM  (kg)* | Height (m) | SPT   | Sport practiced | Fitness      | TP       | Replace | Tapering |
|-------------------------------|-------|------|--------|--------------|----------|------------|-------|----------------|--------------|---------|---------|----------|
| Ache-Dias et al. (2016)       | Yes   | 9    | F/M    | 24.3         | 63.1     | 160        | No    | Runners        | Normal      | NA      | No      | Yes      |
| Agostini et al. (2017)        | Yes   | 15   | F      | 15.4         | NR       | 169        | NR    | Gymnastics     | High         | All season | No      | NR       |
| Alvarez et al. (2012)         | Yes   | 5    | M      | 24.2         | 68.1     | 172        | Yes   | Golfers        | High         | IS      | Yes     | No       |
| Behringer et al. (2013)       | Yes   | 10   | M      | 15.5         | 65.2     | 177        | No    | Tennis         | Normal-moderate | NR      | No      | No       |
| Berryman, Maurel & Bosquet (2010) | Yes   | 11   | M      | 29           | 74.6     | 178        | No    | Runners        | Moderate-high | NR      | No      | Yes      |
| Bishop et al. (2009)          | Yes   | 11   | M      | 13.1         | 50.6     | 163        | NR    | Swimmers       | Moderate-high | PS      | No      | No       |
| Blagrove et al. (2018)        | Yes   | 9    | F/M    | 16.5         | 57.8     | 170        | No    | Runners        | Normal-moderate | OS      | No      | No       |
| Bogdanis et al. (2019)        | Yes   | 33   | F      | 8.1          | 28.7     | 129        | No    | Gymnasts       | Moderate     | PS      | Yes     | No       |
| Chelly, Hermassi & Shephard (2015) | Yes   | 14   | M      | 11.7         | 43.0     | 158        | No    | Runners (up to 3-km) | Moderate     | IS      | No      | No       |
| Cossor, Blanksby & Elliot (1999) | NR    | 19   | F/M    | 11.7         | 47.4     | 159        | NR    | Swimmers       | Normal-moderate | IS      | NR      | No       |
| Fernandez-Fernandez et al. (2016) | No    | 30   | M      | 12.5         | 44.2     | 157        | No    | Tennis         | Moderate     | IS      | Yes     | NR       |
| Giovannelli et al. (2017)     | Yes   | 13   | M      | 36.3         | 71.9     | 176        | No    | Runners        | Moderate-high | NR      | No      | NR       |
| Hall, Bishop & Gee (2016)     | Yes   | 12   | F      | 12.5         | 40.5     | 146        | NR    | Gymnasts       | Moderate     | NR      | No      | No       |
| Li et al. (2019)              | NR    | 10   | M      | 22.2         | 63.1     | 178        | NR    | Runners        | High         | NR      | Yes     | No       |
| Ludstrom, Betker & Ingraham (2017) | Yes   | 11   | F/M    | 20.8         | 73.5     | NR         | No    | Runners        | Moderate-normal| IS      | Yes     | Yes      |
| Park Lee & Lee (2014)         | Yes   | 5    | M      | 17.6         | 77.2     | 174        | NR    | Throwers       | NR           | NR      | No      | No       |
| Pellegrino, Ruby & Dumke (2016) | Yes   | 11   | F/M    | 32.5         | 68.2     | 172        | No    | Runners        | Normal       | NA      | No      | No       |
| Potdevin et al. (2011)        | Yes   | 12   | M      | 14.3         | 50.0     | 161        | NR    | Swimmers       | Moderate     | PS      | No      | No       |
| Ramirez-Campillo et al. (2014) | Yes   | 17   | F/M    | 22.1         | 60.0     | NR         | No    | Runners        | High         | IS      | No      | No       |
| Redondo et al. (2014)         | Yes   | 6    | M      | 24.8         | 70.4     | 173        | Yes   | Fencers        | High         | IS      | Yes     | No       |
| Salonikidis & Zafeiridis (2008) | Yes   | 16   | M      | 21.1         | 71.7     | 174        | Yes   | Tennis         | Normal-moderate | NR      | NR      | NR       |
| Saunders et al. (2006)        | Yes   | 7    | M      | 23.4         | 67.6     | NR         | No    | Runners        | High         | NR      | No      | No       |
| Sedano et al. (2013)          | Yes   | 6    | M      | 24.1         | 68.5     | 181        | No    | Runners        | High         | PS      | Yes     | No       |
| Turner, Owings & Schwane (2003) | Yes   | 10   | F/M    | 31.0         | 65.4     | 170        | No    | Runners        | Normal       | NA      | No      | No       |
| Vlachopoulos et al. (2018)    | Yes   | 19   | M      | 14.5         | 57.2     | 170        | NR    | Swimmers       | Normal-high  | NR      | NR      | Yes      |
|                          | 14    | 14.1  | 57.7   | 168          |          |            |       | Cyclists       |              |         |         |          |
| Wilson et al. (1993)          | Yes   | 13   | NR     | 22.1         | 71.6     | 174        | NR    | Recreational    | Normal       | NA      | No      | No       |

Notes:
* Mean values for groups.

Abbreviations descriptions ordered alphabetically. Fitness was classified as in the recent review by Ramirez-Campillo et al. (2020d); BM, body mass; F, female; IS, in-season; M, male; NA, not applicable; NR, not reported; OS, off-season; PS, pre-season; Ran, randomised; SPT, indicates if the participants had previous systematic experience with plyometric jump training; TP, training period.
Methodological quality

Using the PEDro checklist, 4 studies achieved 4–5 points and were classified as being of “moderate” quality, while 22 studies achieved 6–10 points and were therefore considered as being of “high” methodological quality (Table 4).

Meta-analysis results

Jump performance

Twenty-two studies provided data for jump (vertical) performance, involving 23 experimental and 23 control groups (pooled n = 567). There was a significant effect of PJT on vertical jump performance (ES = 0.49; 95% CI [0.32–0.65]; p < 0.001; I² = 0.0%; Egger’s test p = 0.117; Fig. 2). The relative weight of each study in the analysis ranged from 1.9% to 9.0%.

Linear sprint performance

Twelve studies provided data for sprint (linear) performance, involving 12 experimental and 12 control groups (pooled n = 401). There was a significant effect of PJT on sprint performance (ES = 0.23; 95% CI [0.02–0.44]; p = 0.032; I² = 10.9%; Egger’s test p = 0.518; Fig. 3). The relative weight of each study in the analysis ranged from 5.1% to 13.7%.

Sprint with change of direction performance

Five studies provided data for sprint with COD performance, involving 5 experimental and 5 control groups (pooled n = 201). There was a non-significant effect of PJT on sprint with COD performance (ES = 0.34; 95% CI [−0.19 to 0.87]; p = 0.205; I² = 70.9%; Egger’s test p = 0.657; Fig. 4). The relative weight of each study in the analysis ranged from 17.6% to 21.7%.
Table 2 Characteristics of plyometric jump training (PJT) programs.

| Authors, year                  | Freq | Dur (weeks) | Int | BH (cm) | NTJ | Tply | Combined | RBS (s) | RBR (s) | RBTS (h) | Tsurf | PO |
|--------------------------------|------|-------------|-----|---------|-----|------|----------|---------|---------|----------|-------|----|
| Ache-Dias et al. (2016)        | 2    | 4           | Max | NA      | 1,200 | CMJ + VJ | No       | 300     | NA      | 48       | NR    | V  |
| Agostini et al. (2017)         | 2–3  | 48          | Max | NR      | NR   | Mix   | No       | NR      | NR      | NR       | NR    | NR |
| Alvarez et al. (2012)          | 2    | 18          | NR  | NA      | 720  | Hurdles | RT + SS  | 240     | NR      | 48–120   | No    |    |
| Behringer et al. (2013)        | 2    | 8           | NR  | NA      | NR   | Mix   | No       | 20–60   | 0–1     | 55–78    | NR    | Comb|
| Berryman, Maurel & Bosquet (2010) | 1    | 8           | Max | 20–60   | 240  | DJ    | No       | 180     | NR      | 168      | NR    | Comb|
| Bishop et al. (2009)           | 2    | 8           | NR  | 43–64   | 1,768 | Mix   | No       | 60–90   | NR      | NR       | NR    | Comb|
| Blagrove et al. (2018)         | 2    | 10          | NR  | NR      | 868 + 540 | Mix | RT + sprint | 90      | NR      | 48–96    | NR    | Comb|
| Bogdanis et al. (2019)         | 2    | 8           | NR  | 20–30   | 2,464 | Mix   | No       | 30–300  | NR      | 48–120   | Gymnastics carpet | Comb|
| Chelly, Hermassi & Shephard (2015) | 3    | 10          | Max | 30–40   | 1,800 | DJ + hurdles | No       | NR      | 5       | 48     | NR    | Comb|
| Cossor, Blanksby & Elliot (1999) | 3    | 20          | NR  | NR      | 18,000–27,000 | NR | No       | NR      | NR      | 48–72    | Land | T  |
| Fernandez-Fernandez et al. (2016) | 2    | 8           | Max | NR      | 1,199 | Mix   | No       | 15–90   | NR      | NR       | NR    | Comb|
| Giovanelli et al. (2017)       | 3    | 12          | NR  | NA      | NR   | Mix   | RT + core | 0–30    | NR      | ≥48      | Stable + unstable | NR |
| Hall, Bishop & Gee (2016)      | 2    | 6           | NR  | 15–30   | 417  | Mix   | No       | 60      | NR      | NR       | Concrete | Comb|
| Li et al. (2019)               | 3    | 8           | NR  | 40–60   | 1,296 | Mix   | No       | 240–480 | NR      | 48–72    | No    |    |
| Ludstrom, Betker & Ingraham (2017) | 1    | 12          | Max | NR      | 1,075 | Mix   | Sprints  | ≥60     | NR/NA   | 168      | NR    | Comb|
| Park Lee & Lee (2014)          | 3    | 12          | NR  | NA      | 25,200 | Mix | No       | NR      | NR      | NR       | V     |     |
| Pellegrino, Ruby & Dumke (2016) | 2–3  | 6           | Max | NR      | 900–3,420 | Mix | No       | NR      | NR      | NR       | NR    | Comb|
| Potdevin et al. (2011)         | 2    | 6           | NR  | 40      | 2,146 | Mix   | No       | NR      | NR      | NR       | NR    | Comb|
| Ramirez-Campillo et al. (2014) | 2    | 6           | Max | 20–60   | 720  | DJ    | No       | 120     | 15      | ≥48      | Wood | No |
| Redondo et al. (2014)          | 2    | 6           | Max | NA      | 432  | VJ    | RT       | 180     | NR      | ≥48      | NR    | No |
| Salonikidis & Zafeiridis (2008) | 3    | 9           | NR  | 20–40   | NR   | Mix (unilateral) | No       | 180–240 | 60–120  | NR       | NR    | NR |
| Saunders et al. (2006)         | 2–3  | 9           | Max | NR      | 852 + 2,700 | Mix | RT       | NR      | NR      | NR       | Mix   | Comb|
| Sedano et al. (2013)           | 2    | 12          | NR  | NA      | 2,880 | Mix   | RT       | 25–300  | NR      | ≥48      | Hard synthetic | NR |
| Turner, Owings & Schwane (2003) | 3    | 6           | Max | NA      | 1,287 | Mix   | No       | NR      | NR      | Inclined (6–8%) + flat | V |
| Vlachopoulos et al. (2018)     | 3–4  | 36          | NR  | NA      | 8,880 | CMJ   | No       | NA      | NA      | Hard Surface | Comb|
| Wilson et al. (1993)           | 2    | 10          | Max | 20–80   | 288–480 | DJ | No       | 180     | NR      | NR       | NR    | Comb|

Note:
Abbreviations descriptions ordered alphabetically. BH, box height; CMJ, countermovement jump; DJ, drop jump; Dur, duration (weeks); Freq, training frequency (days/week); Int, intensity; Max, maximal, involving either maximal effort to achieve maximal height, distance, reactive strength index, velocity (time contact or fast stretch-shortening cycle), or another marker of intensity; Mix, mixed PJT involved a combination of two or more of the following jumping drills: vertical, horizontal, bilateral, unilateral, repeated, non-repeated, lateral, cyclic, sport-specific (SS), slow stretch-shortening cycle, fast stretch-shortening cycle, NA, non-applicable; NR, non-clearly reported; NTJ, number of total jumps (usually counted as jumps per each leg); PO, progressive overload, in the form of either volume (i.e., V), intensity (i.e., I), type of drill (i.e., T), or a combination of these (Comb); PS, pre-season; PJT, plyometric jump training; RBR, rest time between repetitions (only when the PJT programme incorporated non-repeated jumps); RBS, rest time between sets; RBTS, rest between training sessions; Repl, replace, denoting if the athletes replace some common drills from their regular training with PJT drills. If not, the PJT load was added to their regular training load; RT, resistance training; Surf, type of surface used during the intervention; TP, training period; Tply, type of PJT drills used; Tsurf, type of surface; VJ, vertical jump.
Table 3 Study groups and their physical fitness.

| Author (year) | Test | PJT, before<sup>a</sup> | Control, before | PJT, after | Control, after |
|---------------|------|-------------------------|-----------------|------------|----------------|
|               |      | Mean | SD  | n     | Mean | SD  | n     | Mean | SD  | n     | Mean | SD  | n     |
| Ache-Dias et al. (2016) | Jump (CMJ, cm) | 37.74 | 5.24 | 9 | 40.02 | 6.52 | 9 | 39.52 | 5.06 | 9 | 39.37 | 6.65 | 9 |
| | Strength (KE, concentric; N.m) | 173.77 | 39.73 | 9 | 180.03 | 66.28 | 9 | 178.97 | 37.92 | 9 | 175.44 | 66.88 | 9 |
| | Endurance (vVO2peak, k.h<sup>−1</sup>) | 13.68 | 1.9 | 14 | 13.33 | 9 | 14.06 | 1.57 | 9 | 14.12 | 9 |
| Agostini et al. (2017) | Jump (CMJ; cm) | 35.8 | 6.97 | 9 | 31.7 | 4.29 | 9 | 39.94 | 2.05 | 9 | 33.06 | 3.56 | 9 |
| | CODS (square agility test; s) | 7.32 | 0.36 | 9 | 7.29 | 0.34 | 9 | 6.58 | 0.27 | 9 | 6.96 | 0.32 | 9 |
| Alvarez et al. (2012) | Jump (CMJ; cm) | 35.55 | 1.66 | 5 | 31.7 | 4.29 | 5 | 39.94 | 2.05 | 9 | 33.06 | 3.56 | 9 |
| | Strength (1-RM Barbell squat; kg) | 131.3 | 30.31 | 5 | 100.26 | 8.37 | 5 | 177.12 | 28.59 | 5 | 102.48 | 9.11 | 5 |
| Behringer et al. (2013) | Strength (10RM Leg press; kg) | 122.7 | 26.12 | 12 | 109.3 | 22.2 | 12 | 142.3 | 19.3 | 12 | 121.3 | 23.5 | 12 |
| Berryman, Maurel & Bosquet (2010) | Jump (CMJ; cm) | 33.3 | 4 | 11 | 34.27 | 6.08 | 9 | 50.93 | 7.47 | 9 | 44 | 7.64 | 9 |
| | CODS (square agility test; s) | 7.32 | 0.36 | 9 | 7.29 | 0.34 | 9 | 6.58 | 0.27 | 9 | 6.96 | 0.32 | 9 |
| Bishop et al. (2009) | Sprint (performance time to 5.5 m; s) | 3.88 | 0.48 | 11 | 3.94 | 0.39 | 11 | 3.29 | 0.47 | 11 | 3.82 | 0.38 | 11 |
| Blagrove et al. (2018) | Jump (CMJ; cm) | 58.7 | 2.3 | 9 | 60.7 | 5.9 | 9 | 62.3 | 6.9 | 9 | 60.2 | 9.3 | 9 |
| | Sprint (20-m sprint; s) | 2.79 | 0.22 | 9 | 2.64 | 0.24 | 9 | 2.69 | 0.19 | 9 | 2.62 | 0.23 | 9 |
| | Strength (MVC isometric squat; N.kg) | 159.3 | 28 | 9 | 159.4 | 25.7 | 9 | 183.9 | 26.5 | 9 | 161.5 | 37.1 | 9 |
| Bogdanis et al. (2019) | Jump (CMJ; cm) | 18.1 | 3.2 | 33 | 17 | 4.5 | 17 | 20.1 | 2.9 | 33 | 17.2 | 4.6 | 17 |
| | Sprint (10-m sprint; s) | 2.77 | 0.26 | 33 | 2.74 | 0.24 | 17 | 2.51 | 0.22 | 33 | 2.65 | 0.25 | 17 |
| Chelly, Hermassi & Shephard (2015) | Sprint (50-m time swimming; s) | 38.46 | 3.36 | 19 | 39.1 | 3.39 | 19 | 37.51 | 2.9 | 19 | 37.57 | 3.35 | 19 |
| | CODS (5-m RTT; s) | 7.45 | 0.72 | 19 | 7.63 | 0.64 | 19 | 6.94 | 0.67 | 19 | 6.89 | 0.65 | 19 |
| Fernandez-Fernandez et al. (2016) | Jump (CMJ; cm) | 30.1 | 4.3 | 24 | 30.3 | 4.2 | 27 | 28.9 | 4.1 | 24 | 20.9 | 4.2 | 27 |
| | Sprint (5-m sprint; s) | 1.17 | 0.1 | 24 | 1.16 | 0.1 | 27 | 1.11 | 0.1 | 24 | 1.15 | 0.1 | 27 |
| | CODS (Agility 505 test; s) | 2.95 | 0.2 | 24 | 2.93 | 0.1 | 27 | 2.86 | 0.2 | 24 | 2.92 | 0.1 | 27 |
| Giovanelli et al. (2017) | Jump (CMJ; cm) | 43.8 | 7.4 | 13 | 42.3 | 6.72 | 12 | 48.9 | 8.6 | 13 | 42.7 | 6.8 | 12 |
| Hall, Bishop & Gee (2016) | Jump (CMJ; cm) | 43.5 | 6.1 | 10 | 45.1 | 5.8 | 10 | 45.3 | 5.8 | 10 | 45.3 | 5.5 | 10 |
| Li et al. (2019) | Jump (CMJ; cm) | 31.06 | 3.41 | 10 | 33.46 | 4.27 | 9 | 34.51 | 3.85 | 10 | 34.26 | 4.22 | 9 |
| | Sprint (50-m time; s) | 6.25 | 0.19 | 10 | 5.94 | 0.21 | 9 | 6.11 | 0.24 | 10 | 5.92 | 0.3 | 9 |
| | Strength (1 RM; kg) | 60.25 | 8.03 | 10 | 63.33 | 9.35 | 9 | 70.5 | 11.17 | 10 | 64.44 | 8.82 | 9 |
| Ludstrom, Betker & Ingraham (2017) | Endurance (5 km time; s) | 953.7 | 12.3 | 10 | 954.11 | 6.75 | 9 | 926.9 | 9.92 | 10 | 947.33 | 10.03 | 9 |
| | Jump (CMJ; cm) | 51.3 | 12.7 | 11 | 57.6 | 19.6 | 11 | 50.3 | 11.4 | 11 | 55.4 | 14.2 | 11 |
| | Sprint (200-m sprint run; s) | 36.52 | 6.24 | 11 | 34.28 | 5.39 | 11 | 34.64 | 6.46 | 11 | 33.78 | 4.89 | 11 |
| | Endurance (2 mile time trial; min) | 14.7 | 2.4 | 11 | 14 | 2.3 | 11 | 13.3 | 1.7 | 11 | 13.3 | 1.7 | 11 |
| Pellegrino, Ruby & Dumke (2016) | Jump (CMJ; cm) | 44.7 | 4.1 | 11 | 48.8 | 4.2 | 11 | 44.4 | 4 | 11 | 45.5 | 4.6 | 11 |
| | Endurance (3-km time trial; s) | 780.9 | 29.9 | 11 | 830.4 | 35.6 | 11 | 760.8 | 29.1 | 11 | 817.2 | 39.8 | 11 |

(Continued)
Eleven studies provided data for strength (maximal) performance, involving 11 experimental and 11 control groups (pooled n = 202). There was a significant effect of PJT on strength performance (ES = 0.50; 95% CI [0.23–0.77]; p < 0.001; I² = 0.0%; Egger’s test p = 0.004 Fig. 5). After adjusting according to the Duval and Tweedie’s method ES = 0.38 (95% CI [0.08–0.68]). The relative weight of each study in the analysis ranged from 3.8% to 16.0%.
Nine studies provided data for endurance performance, involving 10 experimental and 10 control groups (pooled \( n = 233 \)). There was a significant effect of PJT on strength performance (ES = 0.30; 95% CI [0.03–0.57]; \( p = 0.028 \); \( I^2 = 11.1\% \); Egger’s test \( p = 0.119 \), Fig. 6). The relative weight of each study in the analysis ranged from 6.1% to 15.2%.

### Table 4 Physiotherapy evidence database (PEDro) scale ratings.

| Study                                      | N⁰ 1 | N⁰ 2 | N⁰ 3 | N⁰ 4 | N⁰ 5 | N⁰ 6 | N⁰ 7 | N⁰ 8 | N⁰ 9 | N⁰ 10 | N⁰ 11 | Total (from a possible maximal of 10) |
|--------------------------------------------|------|------|------|------|------|------|------|------|------|-------|-------|-------------------------------------|
| Ache-Dias et al. (2016)                    | 1    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 0     | 1     | 6                                  |
| Agostini et al. (2017)                     | 1    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Alvarez et al. (2012)                      | 1    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 7                                  |
| Behringer et al. (2013)                    | 1    | 1    | 1    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 8                                  |
| Berryman, Maurel & Bosquet (2010)          | 1    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 7                                  |
| Bishop et al. (2009)                       | 0    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Blagrove et al. (2018)                     | 1    | 1    | 1    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 8                                  |
| Bogdanis et al. (2019)                     | 1    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 7                                  |
| Chelly, Hermassi & Shephard (2015)         | 1    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Cossor, Blanksby & Elliot (1999)           | 0    | 0    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 5                                  |
| Fernandez-Fernandez et al. (2016)         | 1    | 0    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Giovannelli et al. (2017)                  | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 7                                  |
| Hall, Bishop & Gee (2016)                  | 1    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Li et al. (2019)                           | 1    | 0    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 5                                  |
| Ludstrom, Betker & Ingraham (2017)         | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 7                                  |
| Pellegrino, Ruby & Dumke (2016)            | 1    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Potdevin et al. (2011)                     | 0    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Ramirez-Campillo et al. (2014)             | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 7                                  |
| Redondo et al. (2014)                      | 0    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Salonikidis & Zafeiridis (2008)            | 0    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 0    | 1     | 1     | 5                                  |
| Saunders et al. (2006)                     | 0    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Sedano et al. (2013)                       | 1    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Turner, Owings & Schwane (2003)            | 0    | 1    | 0    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 6                                  |
| Vlachopoulos et al. (2018)                 | 1    | 1    | 1    | 1    | 0    | 0    | 0    | 1    | 1    | 1     | 1     | 7                                  |
| Wilson et al. (1993)                       | 1    | 1    | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 0     | 1     | 4                                  |

Note: * A detailed explanation for each PEDro scale item can be accessed at https://www.pedro.org.au/english/downloads/pedro-scale (access for this review: 27 May 2020).

**Endurance**

Nine studies provided data for endurance performance, involving 10 experimental and 10 control groups (pooled \( n = 233 \)). There was a significant effect of PJT on strength performance (ES = 0.30; 95% CI [0.03–0.57]; \( p = 0.028 \); \( I^2 = 11.1\% \); Egger’s test \( p = 0.119 \), Fig. 6). The relative weight of each study in the analysis ranged from 6.1% to 15.2%.

**Subgroup analyses**

Regarding vertical jump performance, similar improvements were noted for male (ES = 0.48; 11 studies), female (ES = 0.51; three studies) and mixed male-female (ES = 0.42; 7 studies) athletes (\( p = 0.931 \)). In addition, similar improvements were noted for youth (ES = 0.47; nine studies) and adult (ES = 0.50; 14 studies) athletes (\( p = 0.857 \)). Further, similar improvements (\( p = 0.657 \)) were noted for gymnasts (ES = 0.51; three studies), runners (ES = 0.40; 12 studies), and athletes from other (i.e., golf; tennis; swimming; fencing; cycling; resistance training) sports (ES = 0.57; eight studies).
Regarding linear sprint performance, similar improvements were noted for male (ES = 0.28; three studies) and mixed male-female (ES = 0.06; five studies) athletes (p = 0.394). Of note, only one study reported data for female linear sprint performance (not included in the analyses). In addition, similar improvements were noted for youth.
and adult (ES = 0.13; five studies) athletes (p = 0.473). Further, similar improvements (p = 0.837) were noted for swimmers (ES = 0.22; three studies), runners (ES = 0.17; five studies) and athletes from other (i.e., tennis; gymnasts; resistance training) sports (ES = 0.33; four studies).

![Figure 4](ftp://ftp.elsevier.com/doi/10.7717/peerj.11004/fig-4)

**Figure 4** Forest plot of changes in sprint with change of direction performance. Forest plot of changes in sprint with change of direction performance, in athletes participating in plyometric jump training compared to controls. Values shown are effect sizes (Hedges’s g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. Full-size DOI: 10.7717/peerj.11004/fig-4

| Study name            | Hedges's g | Standard error | Variance | Lower limit | Upper limit | Z-Value | p-Value |
|-----------------------|------------|----------------|----------|-------------|-------------|---------|---------|
| Agostini et al. 2017  | 1.347      | 0.386          | 0.156    | 0.572       | 2.123       | 3.406   | 0.001   |
| Bogdanski et al. 2019 | 0.457      | 0.297          | 0.088    | -0.126      | 1.040       | 1.537   | 0.124   |
| Consor et al. 1999    | -0.341     | 0.320          | 0.102    | -0.968      | 0.286       | -1.066  | 0.286   |
| Fernandes-Fernandez et al. 2016 | 0.508 | 0.281          | 0.079    | -0.043      | 1.058       | 1.808   | 0.071   |
| Salomidis 2008        | -0.175     | 0.345          | 0.119    | -0.852      | 0.502       | -0.507  | 0.612   |
|                       | 0.341      | 0.269          | 0.072    | -0.186      | 0.807       | 1.268   | 0.205   |

(ES = 0.30; seven studies) and adult (ES = 0.13; five studies) athletes (p = 0.473). Further, similar improvements (p = 0.837) were noted for swimmers (ES = 0.22; three studies), runners (ES = 0.17; five studies) and athletes from other (i.e., tennis; gymnasts; resistance training) sports (ES = 0.33; four studies).

![Figure 5](ftp://ftp.elsevier.com/doi/10.7717/peerj.11004/fig-5)

**Figure 5** Forest plot of changes in strength (maximal) performance. Forest plot of changes in strength (maximal) performance, in athletes participating in plyometric jump training compared to controls. Values shown are effect sizes (Hedges’s g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. Full-size DOI: 10.7717/peerj.11004/fig-5
Regarding maximal strength performance, a reduced number of studies available precluded a subgroup analysis according to the sex and age categories. Similar improvements \( (p = 0.873) \) were noted for runners \((ES = 0.51; \text{five studies})\) and athletes from other (i.e., golfers; fencers; tennis; resistance training) sports \((ES = 0.46; \text{five studies})\).

Regarding endurance performance, similar improvements were noted for male \((ES = 0.54; \text{four studies})\) and mixed male-female \((ES = 0.21; \text{six studies})\) athletes \((p = 0.422)\). Of note, no study reported data for female endurance performance. In relation with athletes age category, similar improvements were noted for youth \((ES = 0.23; \text{four studies})\) and adult \((ES = 0.40; \text{six studies})\) athletes \((p = 0.578)\). Further, similar improvements \((p = 0.641)\) were noted for runners \((ES = 0.37; \text{seven studies})\) and athletes from other (i.e., swimming; cycling) sports \((ES = 0.23; \text{three studies})\).

Regarding type of test, similar improvements were noted for short-duration sprint tests \((ES = 0.33; \text{nine studies})\) and longer-duration tests \((ES = -0.01; \text{three studies})\) \((p = 0.124)\). In addition, similar improvements were noted for isometric maximal strength test \((ES = 0.33; \text{three studies})\) and dynamic tests \((ES = 0.56; \text{seven studies})\) \((p = 0.427)\).

**Adverse effects**

Among the included studies, none reported soreness, pain, fatigue, injury, damage or adverse effects related to the PJT intervention.

**DISCUSSION**

**Summary of main results**

Improvements in vertical jump, linear sprint, strength and endurance performance were observed in ISA after PJT compared to a control condition. However, no significant effect
was found for COD performance. These conclusions are based on studies that were generally classified as being of high methodological quality.

**Jump performance**

The main findings of this study indicate enhancements on proxies of muscle power (CMJ) among ISA, concurring with the wider strength and conditioning literature available for other sports, mainly team sports (Ramirez-Campillo et al., 2020a, 2020d; Van de Hoef et al., 2019). A recent meta-analysis (Ramirez-Campillo et al., 2020b) revealed that PJT improved CMJ height in volleyball players, regardless of players’ age and sex. Considering that volleyball players are routinely involved in jumping actions, is not surprising that ISA, such as swimmers, with a relatively low training age regarding jumping actions (thus greater ceiling for improvement) achieved a significant improvement in such actions after PJT. However, the improvement observed in the current SRMA was small (ES = 0.49). Independent of this, jumping performance improvement can generally be attributed to factors such as enhanced motor unit recruitment, greater inter-muscular coordination, enhanced neural drive to agonist muscles, better utilization of the SSC (Markovic & Mikulic, 2010; Taube, Leukel & Gollhofer, 2012), and probably selective muscle hypertrophy (Grgic, Schoenfeld & Mikulic, 2020), factor that may relate to ISA performance.

**Linear and change of direction speed**

We found small improvements in linear sprint (ES = 0.23) in response to PJT. Neuro-mechanical adaptations induced by PJT (e.g., enhanced neural drive to agonist muscles, alterations to muscle-tendon stiffness) (De Villarreal, Requena & Cronin, 2012; Haugen et al., 2019; Markovic & Mikulic, 2010) may improve SSC efficacy. Because of improvements in SSC efficacy, a greater force would be produced in the concentric phase of the movement after a rapid eccentric muscle action (Komi & Gollhofer, 1997; Markovic & Mikulic, 2010; Radnor et al., 2017), a key requirement for better sprint performance (Bishop & Girard, 2013). Furthermore, improved neuro-mechanical properties after PJT may enhance different ground reaction force (GRF) characteristics (e.g., impulse; peak force) (Markovic & Mikulic, 2010), in turn contributing to faster sprint acceleration (Lockie et al., 2014). In contrast to linear sprinting speed performance, current findings indicate that PJT interventions that lasted between 8 up to 48 weeks, with 2–3 sessions per week, induced no significant improvement in COD compared to controls. However, a small improvement (ES = 0.34) in COD in favor of the PJT groups over the controls was indeed observed, with a 95%CI that ranged between ES = −0.19 up to ES = 0.87. Considering the relevance of both vertical and horizontal force neuromuscular-generating capabilities (Young & Farrow, 2006; Young, 2006; Young, Dawson & Henry, 2015), and the relevance of unilateral performance during COD movements (Ramirez-Campillo et al., 2015; Young, James & Montgomery, 2002), the incorporation of vertical, horizontal, and unilateral drills may increase the chances for COD improvements. Overall, it seems that small COD improvements can be expected
after PJT interventions in ISA. However, if such improvement are of relevance for some ISA (e.g., endurance runners; cyclists; swimmers) is a future line of research inquiry.

Strength
Maximal strength improved after PJT, with a small magnitude (ES = 0.30). These findings support data from previous studies examining the benefits of PJT for maximal strength (De Villarreal, Requena & Newton, 2010). Improvements in strength after PJT may be related to neural adaptations, including improved motor-unit firing frequency, synchronisation, excitability and efferent motor drive (Markovic & Mikulic, 2010). This can result in the optimization of the relative force generated per each motor unit recruited (Radnor et al., 2017). However, improvements in muscle strength after PJT may also be related to muscle hypertrophy (Grgic, Schoenfeld & Mikulic, 2020). The relative contribution of the aforementioned neuro-muscular factors may vary depending on the duration of the PJT interventions, and future studies may examine such relative contributions among ISA.

Endurance
Our results demonstrated a significant (ES = 0.30) increase in endurance performance after PJT compared to controls. PJT may not induce a significant increase in underlying aerobic qualities such as maximal oxygen consumption (VO2max) (Barnes & Kilding, 2015; Blagrove, Howatson & Hayes, 2017) or lactate threshold (Blagrove, Howatson & Hayes, 2017; Gorostiaga et al., 2004), but has been shown to improve anaerobic performance qualities (Assuncao et al., 2017) related to endurance performance. Of note, this seems to be the first meta-analysis to report the positive effects of PJT on endurance performance among ISA. Improvements in explosive performance after PJT can contribute to running economy (Blagrove, Howatson & Hayes, 2017), independently from the influence on VO2max (Balsalobre-Fernandez, Santos-Concejero & Grivas, 2016) or lactate metabolism (Spurrs, Murphy & Watsford, 2003). Indeed, the improvement in jumping performance observed in this meta-analysis may reflect an improved performance to produce maximal strength in a minimal time (Flanagan & Comyns, 2008) as a consequence of improved rate-of-force development and motor unit recruitment level (Markovic & Mikulic, 2010). In turn, this may have transferred into improved running economy and enhance aerobic performance independently of others aerobic indicators (Coyle, 1995), especially considering the relevance of neuromuscular-mediated changes in the athletes’ running economy (Yamamoto et al., 2008). An increased tendon stiffness after PJT (Markovic & Mikulic, 2010), may also allow for a faster transfer of force from contracting muscles to moving bones through tendons (Legerlotz et al., 2016), positively affecting athletes’ running economy (Balsalobre-Fernandez, Santos-Concejero & Grivas, 2016; Barnes & Kilding, 2015). Direct assessment of potential mechanisms that could improve endurance performance after PJT in ISA deserves further consideration by well-controlled studies.
Subgroup analyses

Our analyses indicated that sex, age and sport background had no modulator role on the effect of PJT in the vertical jump, linear sprint, maximal strength and endurance performance of ISA. In contrast to our findings, previous studies reported that the adaptive responses to PJT may be affected by participant age (Asadi et al., 2017; Moran et al., 2019; Moran et al., 2017), sex (De Villarreal et al., 2009) and sport background (Asadi et al., 2016; De Villarreal, Requena & Cronin, 2012; Fleck & Kraemer, 2004; Izquierdo et al., 2002; Taylor et al., 2018; Vlachopoulos et al., 2018). Indeed, one of the included studies in our meta-analysis (Vlachopoulos et al., 2018) reported that ISA (i.e., swimmers; cyclists) had significant improvements in vertical jump and endurance performance, while soccer players showed no improvement. Therefore, the reduced number of studies available for some moderators in our meta-analysis may partially explain the lack of significant effect for ISA sex, age and sport background on physical fitness adaptations after PJT. Further studies would be needed to identify optimal PJT strategies according to ISA sex, age and sport background.

Regarding type of test, similar improvements were noted for short-duration (i.e., 2–7 s) and longer-duration (i.e., 21–39 s) sprint tests. In addition, similar improvements were noted for dynamic and isometric maximal strength tests. Such findings are similar to those previously reported for a mixed sample of ISA and team sport athletes (De Villarreal, Requena & Cronin, 2012; De Villarreal, Requena & Newton, 2010). Indeed, improvements of ES = 0.20-0.39 were noted for sprint distances from 10-m up to 100-m, and for maximal strength tests involving isometric and dynamic actions (De Villarreal, Requena & Cronin, 2012; De Villarreal, Requena & Newton, 2010). However, in our meta-analysis, the small improvement for shorter sprinting distances (ES = 0.33) contrast with the trivial detrimental effect (ES = −0.01) for longer distances. Moreover, different maximal strength testing protocols have reported different results (Gentil et al., 2017). Considering the short-duration and dynamic nature of PJT drills, a greater transfer of adaptations derived from PJT would be specked for short duration sprint distances and dynamic maximal strength actions (Loturco et al., 2015, 2014; Ramirez-Campillo et al., 2019). Although our findings do not support the prescription of a specific testing protocol, according to the ISA needs, specific protocols might be selected to better reflect the competitive demands of the athlete and the potential transference effects from PJT.

Methodological quality of included studies

Although all included studies in our meta-analysis were classified as being of moderate-high quality, most scored no more than six points in the PEDro scale. Previous systematic reviews that focused on PJT (Bedoya, Miltenberger & Lopez, 2015; Johnson, Salzberg & Stevenson, 2011; Stojanović et al., 2017) and used the PEDro scale also suggested that published studies in this area are generally of medium quality. This is probably due to the difficulties in conducting studies that include blinding of participants or therapists. Relatedly, a recent PJT scoping review (Ramirez-Campillo et al., 2020c) highlighted several methodological shortcomings from 420 analysed studies, in particular an incomplete description of training intervention characteristics. Even though the
included studies in the current SRMA generally provided a clear description of the training intervention, some key elements, such as the recovery time between sets and repetitions (or even between training sessions), was not clearly reported in most studies. Future studies should strive for a more robust methodological approach.

Limitations
Firstly, the limited number of studies providing moderator data according to ISA sex, age and sport background for the outcomes vertical jump, linear and change of direction speed, maximal strength and endurance, precluded firm conclusions regarding the potential role of these moderators on the physical fitness adaptations to PJT. Secondly, the included studies did not reported adverse effects (e.g., injuries, pain). However, due to the lack of reported information, these statements must be viewed with caution. Therefore, a cautious approach is recommended, initially including moderate PJT loads and adequate progression, particularly for those unexperienced with PJT and/or with an insufficient strength and conditioning base.

In conclusion, this meta-analysis found that PJT induces small improvements on ISA physical fitness, including jumping, sprinting speed, strength and endurance. Such findings were found among ISA such as runners, weightlifters, gymnasts, golfers, swimmers, throwers, and fencers. Moreover, the PJT programmes lasted a median of 8.5 weeks. For most studies, the neuromechanically mechanisms underlying the physical fitness improvements were not addressed. Therefore, further studies are needed to clarify the optimal dose of PJT according to the particular sport practiced by ISA. In addition, more long-term studies (i.e., >12 weeks) are needed in order to clarify the effects of PJT embedded in comprehensive multidimensional long-term training programs for ISA. Finally, future studies must sought to clarify the underlying mechanisms responsible for the physical fitness improvements noticed after PJT in ISA.

ADDITIONAL INFORMATION AND DECLARATIONS

Funding
The authors received no funding for this work.

Competing Interests
Rodrigo Ramírez-Campillo is an Academic Editor for PeerJ.

Author Contributions
- Silvia Sole conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Rodrigo Ramírez-Campillo conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
• David C. Andrade conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
• Javier Sanchez-Sanchez conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.

Data Availability
The following information was supplied regarding data availability:
Raw measurements are available in Table 3.

Supplemental Information
Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.11004#supplemental-information.

REFERENCES
Abt G, Boreham C, Davison G, Jackson R, Nevill A, Wallace E, Williams M. 2020. Power, precision, and sample size estimation in sport and exercise science research. Journal of Sports Sciences 38(17):1–3 DOI 10.1080/02640414.2020.1776002.

Ache-Dias J, Dellagrana RA, Teixeira AS, Dal Pupo J, Moro AR. 2016. Effect of jumping interval training on neuromuscular and physiological parameters: a randomized controlled study. Applied Physiology, Nutrition and Metabolism 41:20–25.

Agostini BR, de Godoy Palomares EM, de Almeida Andrade R, Macêdo Uchôa FN, Alves N. 2017. Analysis of the influence of plyometric training in improving the performance of athletes in rhythmic gymnastics. Motricidade 13(2):71–80.

Alvarez M, Sedano S, Cuadrado G, Redondo JC. 2012. Effects of an 18-week strength training program on low-handicap golfers’ performance. The Journal of Strength and Conditioning Research 26(4):1110–1121.

Andrade DC, Beltran AR, Labarca-Valenzuela C, Manzo-Botarelli O, Trujillo E, Otero-Farias P, Alvarez C, Garcia-Hermosa A, Toledo C, Del Rio R, Silva-Urra J, Ramirez-Campillo R. 2018. Effects of plyometric training on explosive and endurance performance at sea level and a high altitude. Frontiers in Physiology 9:9 DOI 10.3389/fphys.2018.01415.

Asadi A, Arazi H, Ramirez-Campillo R, Moran J, Izquierdo M. 2017. Influence of maturation stage on agility performance gains after plyometric training: a systematic review and meta-analysis. Journal of Strength and Conditioning Research 31(9):2609–2617 DOI 10.1519/JSC.0000000000001994.

Asadi A, Arazi H, Young WB, De Villarreal ES. 2016. The effects of plyometric training on change-of-direction ability: a meta-analysis. International Journal of Sports Physiology and Performance 11(5):563–573 DOI 10.1123/ijspp.2015-0694.

Assuncao AR, Bottaro M, Cardoso EA, PDD S D, Ferraz M, Vieira CA, Gentil P. 2017. Effects of a low-volume plyometric training in anaerobic performance of adolescent athletes. Journal of Sports Medicine and Physical Fitness 58(5):570–575 DOI 10.23736/s0022-4707.17.07173-0.

Aughey RJ, Buchheit M, Garvican-Lewis LA, Roach GD, Sargent C, Billaut F, Varley MC, Bourdon PC, Gore CJ. 2013. Yin and yang, or peas in a pod? Individual-sport versus
team-sport athletes and altitude training. *British Journal of Sports Medicine* 47(18):1150–1154
DOI 10.1136/bjsports-2013-092764.

Balsalobre-Fernandez C, Santos-Concejero J, Grivas GV. 2016. Effects of strength training on running economy in highly trained runners: a systematic review with Meta-Analysis of Controlled Trials. *Journal of Strength and Conditioning Research* 30(8):2361–2368
DOI 10.1519/JSC.0000000000001316.

Barnes KR, Kilding AE. 2015. Strategies to improve running economy. *Sports Medicine* 45(1):37–56 DOI 10.1007/s40279-014-0246-y.

Bazyler CD, Abbott HA, Bellon CR, Taber CB, Stone MH. 2015. Strength training for endurance athletes: theory to practice. *Strength and Conditioning Journal* 37(2):1–12
DOI 10.1519/SSC.0000000000000131.

Bedoya AA, Miltenberger MR, Lopez RM. 2015. Plyometric training effects on athletic performance in youth soccer athletes: a systematic review. *Journal of Strength and Conditioning Research* 29(8):2351–2360
DOI 10.1519/JSC.0000000000000877.

Behringer M, Neuerburg S, Matthews M, Mester J. 2013. Effects of two different resistance-training programs on mean tennis-serve velocity in adolescents. *Pediatric Exercise Science* 25(3):370–384.

Berryman N, Maurel DB, Bosquet L. 2010. Effect of plyometric vs. dynamic weight training on the energy cost of running. *Journal of Strength and Conditioning Research* 24(7):1818–1825.

Bobbert MF. 1990. Drop jumping as a training method for jumping ability. *Sports Medicine* 9(1):7–22 DOI 10.2165/00007256-199009010-00002.

Bobbert MF, Huijing PA, Van Ingen Schenau GJ. 1987. Drop jumping: I—the influence of jumping technique on the biomechanics of jumping. *Medicine & Science in Sports & Exercise* 19:332–338.

Bogdanis GC, Donti O, Papia A, Donti A, Apostolidis N, Sands WA. 2019. Effect of plyometric training on jumping, sprinting and change of direction speed in child female athletes. *Sports* 7(5):116 DOI 10.3390/sports7050116.

Chelly MS, Hermassi S, Shephard RJ. 2015. Effects of in-season short-term plyometric training program on sprint and jump performance of young male track athletes. *Journal of Strength and Conditioning Research* 29(8):2128–2136.

Chu D, Myer G. 2013. *Plyometrics*. Champaign: Human Kinetics.

Cossor JM, Blanksby BA, Elliot BC. 1999. The influence of plyometric training on the freestyle tumble turn. *Journal of Science and Medicine in Sport* 2(2):106–116.
Coyle EF. 1995. Integration of the physiological factors determining endurance performance ability. Exercise and Sport Sciences Reviews 23:25–63 DOI 10.1249/00003677-199500230-00004.

De Villarreal ES, Kellis E, Kraemer WJ, Izquierdo M. 2009. Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. Journal of Strength and Conditioning Research 23(2):495–506 DOI 10.1519/JSC.0b013e318196b7c6.

De Villarreal ES, Requena B, Cronin JB. 2012. The effects of plyometric training on sprint performance: a meta-analysis. Journal of Strength and Conditioning Research 26(2):575–584 DOI 10.1519/JSC.0b013e318220fd03.

De Villarreal ESS, Requena B, Newton RU. 2010. Does plyometric training improve strength performance? A meta-analysis. Journal of Science and Medicine in Sport 13(5):513–522 DOI 10.1016/j.jsams.2009.08.005.

Deeks JJ, Higgins JP, Altman DG. 2008. Analysing data and undertaking meta-analyses. In: Higgins JP, Green S, eds. Cochrane Handbook for Systematic Reviews of Interventions. London: The Cochrane Collaboration, 243–296.

Duval S, Tweedie R. 2000. Trim and fill: a simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. Biometrics 56(2):455–463 DOI 10.1111/j.0006-341X.2000.00455.x.

Ebben WP, Hintz MJ, Simenz CJ. 2005. Strength and conditioning practices of major league baseball strength and conditioning coaches. Journal of Strength and Conditioning Research 19(3):538–546 DOI 10.1519/00003908-000041.

Egger M, Davey Smith G, Schneider M, Minder C. 1997. Bias in meta-analysis detected by a simple, graphical test. BMJ 315(7109):629–634 DOI 10.1136/bmj.315.7109.629.

Fernandez-Fernandez J, Saez de Villarreal E, Sanz-Rivas D, Moya M. 2016. The effects of 8-week plyometric training on physical performance in young tennis players. Pediatric Exercise Science 28(1):77–86.

Flanagan EP, Comyns TM. 2008. The use of contact time and the reactive strength index to optimize fast stretch-shortening cycle training. Strength and Conditioning Journal 30(5):32–38 DOI 10.1519/SSC.0b013e318187e25b.

Fleck SJ, Kraemer WJ. 2004. Designing resistance training programs. Champaign: Human Kinetics.

Garcia-Hermoso A, Ramirez-Campillo R, Izquierdo M. 2019. Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies. Sports Medicine 49(7):1079–1094 DOI 10.1007/s40279-019-01098-6.

Gentil P, Del Vecchio FB, Paoli A, Schoenfeld BJ, Bottaro M. 2017. Isokinetic dynamometry and 1RM tests produce conflicting results for assessing alterations in muscle strength. Journal of Human Kinetics 56(1):19–27 DOI 10.1515/hukin-2017-0019.

Giovanelli N, Taboga P, Rejc E, Stefano L. 2017. Effects of strength, explosive and plyometric training on energy cost of running in ultra-endurance athletes. European Journal of Sport Science 17(7):805–813.

Girard O, Mendez-Villanueva A, Bishop D. 2011. Repeated-sprint ability—part I: factors contributing to fatigue. Sports Medicine 41(8):673–694 DOI 10.2165/11590550-000000000-00000.

Gorostiaga EM, Izquierdo M, Ruesta M, Iribarren J, Gonzalez-Badillo JJ, Ibanez J. 2004. Strength training effects on physical performance and serum hormones in young soccer players. European Journal of Applied Physiology 91(5–6):698–707 DOI 10.1007/s00421-003-1032-y.

Grgic J, Schoenfeld BJ, Mikulic P. 2020. Effects of plyometric vs. resistance training on skeletal muscle hypertrophy: a review. Journal of Sport and Health Science 40:859 DOI 10.1016/j.jshs.2020.06.010.
Hall E, Bishop DC, Gee TI. 2016. Effect of plyometric training on handspring vault performance and functional power in youth female gymnasts. *PLOS ONE* 11(2):e0148790 DOI 10.1371/journal.pone.0148790.

Haugen T, Seiler S, Sandbakk O, Tønnessen E. 2019. The training and development of elite sprint performance: an integration of scientific and best practice literature. *Sports Medicine—Open* 5(1):44 DOI 10.1186/s40798-019-0221-0.

Higgins JP, Deeks JJ, Altman DG. 2008. Special topics in statistics. In: Higgins JP, Green S, eds. *Cochrane Handbook for Systematic Reviews of Interventions*. London: The Cochrane Collaboration, 481–529.

Hopkins WG, Marshall SW, Batterham AM, Hanin J. 2009. Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise* 41(1):3–13 DOI 10.1249/MSS.0b013e31818cb278.

Izquierdo M, Häkkinen K, Gonzalez-Badillo JJ, Ibáñez J, Gorostiaga EM. 2002. Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. *European Journal of Applied Physiology* 87(3):264–271 DOI 10.1007/s00421-002-0628-y.

Johnson BA, Salzberg CL, Stevenson DA. 2011. A systematic review: plyometric training programs for young children. *Journal of Strength and Conditioning Research* 25(9):2623–2633 DOI 10.1519/JSC.0b013e318204caa0.

Komi PV. 2003. Stretch shortening cycle. In: Komi PV, ed. *Strength and power in sport*. Oxford: Blackwell Science.

Komi PV, Gollhofer A. 1997. Stretch reflex can have an important role in force enhancement during SSC-exercise. *Journal of Applied Biomechanics* 13(4):451–459 DOI 10.1123/jab.13.4.451.

Kontopantelis E, Springate DA, Reeves D. 2013. A re-analysis of the cochrane library data: the dangers of unobserved heterogeneity in meta-analyses. *PLOS ONE* 8(7):e69930 DOI 10.1371/journal.pone.0069930.

Kovacs MS. 2006. Applied physiology of tennis performance. *British Journal of Sports Medicine* 40(5):381–385 DOI 10.1136/bjsm.2005.023309.

Li F, Wang R, Newton RU, Sutton D, Shi Y, Ding H. 2019. Effects of complex training versus heavy resistance training on neuromuscular adaptation, running economy and 5-km performance in well-trained distance runners. *PeerJ* 25(7):e6787 DOI 10.7717/peerj.6787.

Legerlotz K, Marzilger R, Bohm S, Arampatzis A. 2016. Physiological adaptations following resistance training in youth athletes—a narrative review. *Pediatric Exercise Science* 28(4):501–520 DOI 10.1123/pes.2016-0023.

Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JPA, Clarke M, Devereaux PJ, Kleijnen J, Moher D. 2009. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *BMJ* 339:b2700 DOI 10.1136/bmj.b2700.

Lockie RG, Murphy AJ, Callaghan SJ, Jeffriess MD. 2014. Effects of sprint and plyometrics training on field sport acceleration technique. *Journal of Strength and Conditioning Research* 28(7):1790–1801 DOI 10.1519/JSC.000000000000297.

Lohse KR, Sainani KL, Taylor JA, Butson ML, Knight EJ, Vickers AJ. 2020. Systematic review of the use of magnitude-based inference in sports science and medicine. *PLOS ONE* 15(6):e0235318 DOI 10.1371/journal.pone.0235318.

Loturco I, Pereira LA, Kobal R, Zanetti V, Kitamura K, Abad CCC, Nakamura FY. 2015. Transference effect of vertical and horizontal plyometrics on sprint performance of high-level
U-20 soccer players. *Journal of Sports Sciences* **33**(20):2182–2191
DOI 10.1080/02640414.2015.1081394.

Loturco I, Tricoli V, Roschel H, Nakamura FY, Cal Abad CC, Kobal R, Gil S, Gonzalez-Badillo JJ. 2014. Transference of traditional versus complex strength and power training to sprint performance. *Journal of Human Kinetics* **41**(1):265–273
DOI 10.2478/hukin-2014-0054.

Ludstrom CJ, Betker MR, Ingraham SJ. 2017. Effects of plyometric and explosive speed training on recreational marathoners. *Journal of Sport Sciences* **5**:1–13.

Markovic G, Mikulic P. 2010. Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Medicine* **40**(10):859–895
DOI 10.2165/11318370-000000000-00000.

Moran J, Clark CCT, Ramirez-Campillo R, Davies MJ, Drury B. 2019. A meta-analysis of plyometric training in female youth: its efficacy and shortcomings in the literature. *Journal of Strength and Conditioning Research* **33**(7):1996–2008 DOI 10.1519/JSC.0000000000002768.

Moran J, Ramirez-Campillo R, Granacher U. 2018. Effects of jumping exercise on muscular power in older adults: a meta-analysis. *Sports Medicine* **48**(12):2843–2857
DOI 10.1007/s40279-018-1002-5.

Moran J, Sandercock G, Ramirez-Campillo R, Meylan C, Collison J, Parry D. 2017. Age-related variation in male youth athletes’ countermovement jump after plyometric training: a meta-analysis of controlled trials. *Journal of Strength and Conditioning Research* **31**(2):552–565
DOI 10.1519/JSC.0000000000001444.

Park GD, Lee JC, Lee J. 2014. The effect of low extremity plyometric training on back muscle power of high school throwing event athletes. *Journal of Physical Therapy Science* **26**(1):161–164.

Pellegrino J, Ruby BC, Dumke CL. 2016. Effect of plyometrics on the energy cost of running and MHC and titin isoforms. *Medicine and Science in Sports and Exercise* **48**(1):49–56.

Pigott T. 2012. *Advances in meta-analysis*. New York: Springer-Verlag.

Potdevin FJ, Alberty ME, Chevutschi A, Pelayo P, Sidney MC. 2011. Effects of a 6-week plyometric training program on performances in pubescent swimmers. *Journal of Strength and Conditioning Research* **25**(1):80–86.

Radnor JM, Oliver JL, Waugh CM, Myer GD, Moore IS, Lloyd RS. 2017. The influence of growth and maturation on stretch-shortening cycle function in youth. *Sports Medicine* **48**(1):57–71
DOI 10.1007/s40279-017-0765-0.

Ramirez-Campillo R, Alvarez C, Garcia-Hermoso A, Keogh JWL, Garcia-Pinillos F, Pereira LA, Loturco I. 2020a. Effects of jump training on jumping performance of handball players: a systematic review with meta-analysis of randomised controlled trials. *International Journal of Sports Science & Coaching* **15**(4):584–594 DOI 10.1177/1747954120928932.

Ramirez-Campillo R, Alvarez C, Garcia-Hermoso A, Ramirez-Velez R, Gentil P, Asadi A, Chaabene H, Moran J, Meylan C, Garcia-de-Alcaraz A, Sanchez-Sanchez J, Nakamura FY, Granacher U, Kraemer W, Izquierdo M. 2018. Methodological characteristics and future directions for plyometric jump training research: a scoping review. *Sports Medicine* **48**(5):1059–1081 DOI 10.1007/s40279-018-0870-z.

Ramirez-Campillo R, Alvarez C, Garcia-Pinillos F, Gentil P, Moran J, Pereira LA, Loturco I. 2019. Effects of plyometric training on physical performance of young male soccer players: potential effects of different drop jump heights. *Pediatric Exercise Science* **31**(3):306–313
DOI 10.1123/pes.2018-0207.

Ramirez-Campillo R, Alvarez C, Henriquez-Olguin C, Baez EB, Martinez C, Andrade DC, Izquierdo M. 2014. Effects of plyometric training on endurance and explosive strength
performance in competitive middle- and long-distance runners. *Journal of Strength and Conditioning Research* **28**(1):97–104 DOI 10.1519/JSC.0b013e3182a1f44c.

**Ramirez-Campillo R, Andrade DC, Nikolaidis PT, Moran J, Clemente FM, Chaabene H, Comfort P. 2020b.** Effects of plyometric jump training on vertical jump height of volleyball players: a systematic review with meta-analysis of randomized-controlled trial. *Journal of Sports Science and Medicine* **19**:489–499.

**Ramirez-Campillo R, Burgos CH, Henriquez-Olguin C, Andrade DC, Martinez C, Alvarez C, Castro-Sepulveda M, Marques MC, Izquierdo M. 2015.** Effect of unilateral, bilateral, and combined plyometric training on explosive and endurance performance of young soccer players. *Journal of Strength and Conditioning Research* **29**(5):1317–1328 DOI 10.1519/JSC.0000000000000762.

**Ramirez-Campillo R, Moran J, Chaabene H, Granacher U, Behm DG, Garcia-Hermoso A, Izquierdo M. 2020c.** Methodological characteristics and future directions for plyometric jump training research: a scoping review update. *Scandinavian Journal of Medicine & Science in Sports* **30**(6):983–997 DOI 10.1111/sms.13633.

**Ramirez-Campillo R, Sanchez-Sanchez J, Romero-Moraleda B, Yanci J, Garcia-Hermoso A, Manuel Clemente F. 2020d.** Effects of plyometric jump training in female soccer player’s vertical jump height: a systematic review with meta-analysis. *Journal of Sports Sciences* **38**(13):1–13 DOI 10.1080/02640414.2020.1745503.

**Redondo JC, Alonso CJ, Sedano S, de Benito AM. 2014.** Effects of a 12-week strength training program on experimented fencers’ movement time. *Journal of Strength and Conditioning Research* **28**(12):3375–3384.

**Salonikidis K, Zafeiridis A. 2008.** The effects of plyometric, tennis-drills, and combined training on reaction, lateral and linear speed, power, and strength in novice tennis players. *Journal of Strength and Conditioning Research* **22**(1):182–191.

**Sánchez M, Sanchez-Sanchez J, Nakamura FY, Clemente FM, Romero-Moraleda B, Ramirez-Campillo R. 2020.** Effects of plyometric jump training in female soccer player’s physical fitness: a systematic review with meta-analysis. *International Journal of Environmental Research and Public Health* **17**(23):8911 DOI 10.3390/ijerph17238911.

**Saunders PU, Telford RD, Pyne DB, Peltola EM, Cunningham RB, Gore CJ, Hawley JA. 2006.** Short-term plyometric training improves running economy in highly trained middle and long distance runners. *Journal of Strength and Conditioning Research* **20**(4):947–954.

**Sedano S, Marín PJ, Cuadrado G, Redondo JC. 2013.** Concurrent training in elite male runners: the influence of strength versus muscular endurance training on performance outcomes. *Journal of Strength and Conditioning Research* **7**(9):2433–2443.

**Skrede T, Steene-Johannessen J, Anderssen SA, Resaland GK, Ekelund U. 2019.** The prospective association between objectively measured sedentary time, moderate-to-vigorous physical activity and cardiometabolic risk factors in youth: a systematic review and meta-analysis. *Obesity Reviews* **20**(1):55–74 DOI 10.1111/obr.12758.

**Spurrs RW, Murphy AJ, Watsford ML. 2003.** The effect of plyometric training on distance running performance. *European Journal of Applied Physiology* **89**(1):1–7 DOI 10.1007/s00421-002-0741-y.

**Stojanović E, Ristić V, McMaster DT, Milanović Z. 2017.** Effect of plyometric training on vertical jump performance in female athletes: a systematic review and meta-analysis. *Sports Medicine* **47**(5):975–986 DOI 10.1007/s40279-016-0634-6.
Taube W, Leukel C, Gollhofer A. 2012. How neurons make us jump: the neural control of stretch-shortening cycle movements. Exercise and Sport Sciences Reviews 40(2):106–115 DOI 10.1097/JES.0b013e31824138da.

Taylor JB, Ford KR, Schmitz RJ, Ross SE, Ackerman TA, Shultz SJ. 2018. Sport-specific biomechanical responses to an ACL injury prevention programme: a randomised controlled trial. Journal of Sports Sciences 36(21):2492–2501 DOI 10.1080/02640414.2018.1465723.

Turner AM, Owings M, Schwane JA. 2003. Improvement in running economy after 6 weeks of plyometric training. Journal of Strength and Conditioning Research 17(1):60–67.

Valentine JC, Pigott TD, Rothstein HR. 2010. How many studies do you need?: a primer on statistical power for meta-analysis. Journal of Educational and Behavioral Statistics 35(2):215–247 DOI 10.3102/1076998609346961.

Van de Hoef PA, Brauers JJ, Van Smeden M, Backx FJG, Brink MS. 2019. The effects of lower-extremity plyometric training on soccer-specific outcomes in adult male soccer players: a systematic review and meta-analysis. International Journal of Sports Physiology and Performance 15(1):1–15 DOI 10.1123/ijspp.2019-0565.

Vlachopoulos D, Barker AR, Ubago-Guisado E, Williams CA, Gracia-Marco L. 2018. The effect of a high-impact jumping intervention on bone mass, bone stiffness and fitness parameters in adolescent athletes. Archives of Osteoporosis 13(1):128 DOI 10.1007/s11657-018-0543-4.

Wilson GJ, Newton RU, Murphy AJ, Humphries BJ. 1993. The optimal training load for the development of dynamic athletic performance. Medicine of Science in Sports and Exercise 25(11):1279–1286.

Yamamoto LM, Lopez RM, Klau JF, Casa DJ, Kraemer WJ, Maresh CM. 2008. The effects of resistance training on endurance distance running performance among highly trained runners: a systematic review. Journal of Strength and Conditioning Research 22(6):2036–2044 DOI 10.1519/JSC.0b013e318185f2f0.

Young WB. 2006. Transfer of strength and power training to sports performance. International Journal of Sports Physiology and Performance 1(2):74–83 DOI 10.1123/ijssp.1.2.74.

Young WB, Dawson B, Henry GJ. 2015. Agility and change-of-direction speed are independent skills: implications for training for agility in invasion sports. International Journal of Sports Science & Coaching 10(1):159–169 DOI 10.1260/1747-9541.10.1.159.

Young W, Farrow D. 2006. A review of agility: practical applications for strength and conditioning. Strength and Conditioning Journal 28:24–29.

Young WB, James R, Montgomery I. 2002. Is muscle power related to running speed with changes of direction? Journal of Sports Medicine and Physical Fitness 42:282–288.