Jump rope training effects on health- and sport-related physical fitness in young participants: A systematic review with meta-analysis

Short title: A meta-analysis on jump rope training

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ABSTRACT

The aim of this systematic review with meta-analysis was to assess the available body of published peer-reviewed articles related on the effects of jump rope training (JRT) compared with active/passive controls on health- and sport-related physical fitness outcomes. Searches were conducted in three databases, including studies that satisfied the following criteria: i) healthy participants; ii) a JRT program; iii) active or traditional control group; iv) at least one measure related to health- and sport-related physical fitness; v) multi-arm trials. The random-effects model was used for the meta-analyses. Twenty-one fair-good quality (i.e., PEDro scale) studies were meta-analysed, involving 1,021 participants (male, 50.4%). Eighteen studies included participants with a mean age <18 years old. The duration of the JRT interventions ranged from 6-40 weeks. Meta-analyses revealed improvements (i.e., $p= 0.048$ to <0.001; ES= 0.23-1.19; $I^2= 0.0$-76.9%) in resting heart rate, body mass index, fat mass, cardiorespiratory endurance, lower- and upper-body maximal strength, jumping, range of motion, and sprinting. No significant JRT effects were noted for systolic-diastolic blood pressure, waist-hip circumference, bone or lean mass, or muscle endurance. In conclusion, JRT, when compared to active and passive controls, provides a range of small-moderate benefits that span health- and sport-related physical fitness outcomes.

Key words: plyometric exercise, musculoskeletal and neural physiological phenomena, human physical conditioning, movement, muscle strength, resistance training.

1. Introduction

The ability to carry out daily tasks and perform physical activities in a highly functional state (i.e., physical fitness) is an important marker of current and future health status (Cadenas-Sanchez et al., 2021; Garcia-Hermoso, Ramirez-Campillo, & Izquierdo, 2019). A meta-analysis (Garcia-Hermoso, et al., 2019) involving 30 studies (n = 21,686 participants) evidenced a prospective association ($p<0.05$, moderate-large effect size [ES]) between muscular fitness (e.g., standing long jump) in children/youths aged 3–18 years and future (i.e., follow-up period of ≥1 year) health status (e.g., adiposity, insulin resistance, bone mineral density). Although a causality is difficult to be established (e.g., greater muscular fitness improves perceived competence, stimulating exercise, thus further developing muscular fitness), well-developed muscular fitness remains important. Further, optimal physical fitness in sporting contexts (e.g., jumping, sprinting) may offer competitive advantage (Arnason et al., 2004; Lemos et al., 2020; Slimani and Nikolaidis, 2019) and reduced risk of injury (Arnason, et al., 2004; de la Motte, Gribbin, Lisman, Murphy, & Deuster, 2017; de la Motte, Lisman, Gribbin, Murphy, & Deuster, 2019; Lisman et al., 2017). For instance, a retrospective study noted that soccer teams with players achieving greater vertical jump height performance and having fewer days missed through injury had a better final league standing (Arnason, et al., 2004). Therefore, participants usually engage in different training methods in order to improve health- and sport-related physical fitness. However, opportunities to exercise are often limited by external factors such as access to facilities, equipment and limited availability of time or space. For example, there is a need for access to simple and effective ways to provide children at schools the opportunity to exercise (Blažević, Benassi, & Šterpin, 2020; Osborne, Belmont, & Peixoto, 2016). Therefore, there is a need to seek training methods that might help people stay active at an adequate level (e.g., intensity) despite of being restricted at home due to the above-mentioned external factors (Lopez et al., 2020; Mustapa, Justine, Latir, & Manaf, 2021; Vidal-Almela et al., 2020).

Jump rope training (JRT) may provide a mode of exercise that is accessible to all as it has been shown to be an effective, safe, and time-efficient training method. This form of training can be easily adapted for populations based on sex, age, health, and physical fitness status (Aagaard, 2012; Ache-Dias, Dellagrana, Teixeira, Dal Pupo, & Moro, 2016; Arnett and Lutz, 2002; Chen and Lin, 2011; Garcia-Pinillos, Lago-Fuentes, Latorre-Roman, Pantoja-Vallejo, & Ramirez-Campillo, 2020). Indeed, JRT may overcome common barriers such as low-income, bad weather, reduced safety in outdoor conditions which makes it difficult for a large proportion of the population to engage in physical activity programs (Withall, Jago, & Fox, 2011). A JRT program can be readily implemented in schools, with a positive impact on students perceptions regarding physical activity (A. Ha, Sum, Chan, & Ng, 2014). Moreover, JRT might be equally or even more effective compared to other training methods (e.g., running, high-intensity interval training) to stimulate cardiorespiratory fitness and endurance time-trial events (Arazi, Jalali-Fard, & Abdinejad, 2016; Ducrocq, Hureau, Meste, & Blain, 2019; Garcia-Pinillos, et al., 2020; Kramer, Poppendieker, & Gruber, 2019; Laurson, Brown, Dennis, & Cullen, 2008; Racil et al., 2015). Further, JRT resembles the neuro-musculoskeletal effects of traditional *more intense* plyometric-jump training methods (Markovic and Mikulic, 2010). For example, JRT may favour improvements in bone health-related markers such as bone mineral content (Arnett and Lutz, 2002), and neuromuscular-related outcomes such as reactive strength and stiffness (Garcia-Pinillos, et al., 2020). Even trained individuals may achieve meaningful physical fitness improvements with 5-min JRT sessions applied two-four times per week (Garcia-Pinillos, et al., 2020). Furthermore, jump training in general (Ward, Hodges, & Williams, 2007) and JRT in particular (Aagaard, 2012), is usually considered a pleasant training method. Additionally, due to its intensity-related effects (Arazi, et al., 2016; Ducrocq, et al., 2019; Garcia-Pinillos, et al., 2020; Kramer, et al., 2019; Racil, et al., 2015), JRT may be particularly effective to increase the effectiveness of intervention for larger groups of individuals such as in school settings (García-Hermoso et al., 2020) as it requires reduced physical space and low-budget equipment.

A quick search on PubMed database using the term "physical fitness" retrieved 51,047 articles (PubMed, 2021), with ~5,000 publications per year in the few last years. Relatedly, a recent jump training (including JRT) scoping review noted that the number of jump training-related publications has increased 25-fold between 2000 and 2017 (Ramirez-Campillo et al., 2018; Ramirez-Campillo, Moran, et al., 2020). However, to our knowledge, no review has attempted to summarize the large amount of currently available literature regarding the potential effects of JRT on health- and sport-related physical fitness. Although previous intervention studies have evidenced the effectiveness of JRT on health- and sport-related physical fitness, most published studies have included relatively small sample sizes (i.e., n <10), a common issue in the sport-science literature (Abt et al., 2020). A meta-analysis would allow the sample size from different studies to be aggregated, and may provide not only high-quality evidence, but also new insights to practitioners that may help them to take more evidence-based informed decisions regarding JRT implementation (Murad, Asi, Alsawas, & Alahdab, 2016). Additionally, a systematic review with meta-analysis may help to detect gaps and limitations in the JRT scientific literature, providing valuable information for researchers and practitioners. Therefore, the primary aim of this systematic review with meta-analysis was to assess the available body of published peer-reviewed articles related on the effects of JRT compared with active/passive controls on health- and sport-related physical fitness outcomes in apparently healthy participants.

2. Methods

2.1. Procedures

A meta-analysis was conducted following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009), and adapted *a posteriori* (Page et al., 2021).

2.2. Literature search

The search strategy (code line) for each database and background of search history is described in Electronic Supplementary Material Table S1. Briefly, computerized literature searches were conducted in the electronic databases PubMed, Web of Science and SCOPUS. After an initial search in April 2017, an account was created for one of the authors (RRC) in each of the respective databases, through which he received automatically generated email updates regarding the search terms used. The search was refined in May 2019, June 2021, and August 2021, with updates received daily (if available). Studies were eligible for inclusion up to September 2021. The same author (RRC) conducted the initial search and removed duplicates. Thereafter, the search results were analysed according to the eligibility criteria (Table 1).

*****Table 1*****

Two authors (US and AKR) independently screened the titles, abstracts, and full-text versions of retrieved studies. During the search and review process, potential discrepancies between the same two authors regarding inclusion and exclusion criteria (e.g., type of control group, intervention adequacy) were resolved through consensus with a third author (RRC). From selected articles to be included, reference lists were analysed to identify any additional relevant studies.

Thereafter, the list of included articles and the inclusion criteria were sent to two independent world experts in the field of physical fitness and JRT to help identify additional relevant articles. The experts were not provided with our search strategy, to avoid biasing their own searches. Upon completion of all these steps, the databases were again consulted in search for errata or retractions of any included study.

2.3. Inclusion and exclusion criteria

A PICOS (participants, intervention, comparators, outcomes, and study design) approach was used to rate studies for eligibility (Liberati, et al., 2009). The Table 1 indicates our inclusion/exclusion criteria.

Additionally, only full-text, peer-reviewed, original studies were considered for the present meta-analysis. Excluded were books, book chapters, and congress abstracts, as well as cross-sectional and review papers, and training-related studies that did not focus on the effects of JRT exercises, such as jump training without the use of a rope. Also excluded were retrospective studies, prospective studies (e.g., relationship between bone density at the end of JRT, and at several years of follow-up), studies in which the use of JRT exercises was not clearly described, studies for which only the abstract was available, case reports, special communications, letters to the editor, invited commentaries, errata, studies with doubtful quality or unclear peer-review process from the journal (Grudniewicz et al., 2019), overtraining studies, and detraining studies. In view of the potential difficulties of translating articles written in different languages, and the fact that 99.6% of the jump training literature is published in English (Ramirez-Campillo, et al., 2018), only articles written in English, as well as in Spanish and Portuguese (e.g., authors native languages), were considered for this meta-analysis.

2.4. Data extraction

We sought to analyse the effects of JRT on different health- and sport-related physical fitness attributes, as these effects may reflect different physiological and biomechanical indicators relevant to participants health and performance (Ben Abdelkrim, El Fazaa, & El Ati, 2007; Delextrat and Cohen, 2008; García-Hermoso, et al., 2020; Garcia-Hermoso, et al., 2019; Garcia-Hermoso, Ramirez-Velez, Ramirez-Campillo, Peterson, & Martinez-Vizcaino, 2018; Reilly, Bangsbo, & Franks, 2000). Therefore, outcome measures such as (but not limited to) jumping (e.g., countermovement jump height), linear sprinting (e.g., 10-m sprint time), maximal oxygen consumption), body composition and cardiovascular (e.g., heart rate, blood pressure) measures were extracted as dependent variables from included studies. The above-mentioned tests examining the chosen health- and sport-related physical fitness attributes (e.g., jump, linear sprint, change-of-direction speed, balance, endurance, and strength) usually present very high test-retest reliability (with an intraclass correlation coefficient of >0.9) (Altmann, Ringhof, Neumann, Woll, & Rumpf, 2019; Bangsbo, Iaia, & Krustrup, 2008; Grgic, Lazinica, Schoenfeld, & Pedisic, 2020; Slinde, Suber, Suber, Edwen, & Svantesson, 2008), which is essential to ensure strong consistency between analysed studies within a meta-analysis (Liberati, et al., 2009).

The means and standard deviation of dependent variables were extracted at pre- and post-JRT time points from included studies using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). In cases where the required data were not clearly or completely reported, the authors of the study were contacted for clarification. Two authors (US and AKR) performed data extraction independently, and any discrepancies between them (e.g., mean value for a given outcome, total number of participants in a group) were resolved through consensus with a third author (RRC).

2.5. Methodological quality of the included studies

The Physiotherapy Evidence Database (PEDro) scale was used to assess the methodological quality of the included studies, which were rated from 0 (lowest quality) to 10 (highest quality). The validity and reliability of the PEDro scale has been established previously (de Morton, 2009; Maher, Sherrington, Herbert, Moseley, & Elkins, 2003; Yamato, Maher, Koes, & Moseley, 2017). Additionally, its agreement with other scales (e.g., Cochrane risk of bias tool) has been reported (Moseley et al., 2019). Moreover, the PEDro scale is probably the most frequently used scale in the jump training literature (including JRT) (Asadi, Arazi, Young, & Saez de Villarreal, 2016; Ramirez-Campillo, Moran, et al., 2020; Stojanović, Ristić, McMaster, & Milanović, 2017). Accordingly, it helps to make comparisons between meta-analyses. According to cut-off scores, the methodological quality was rated as ‘poor’ (<4), ‘fair’ (4-5), ‘good’ (6-8), and ‘excellent’ (9-10). If trials were already rated and listed in the PEDro database, the respective scores were adopted. The methodological quality for each included study was assessed independently by two authors (US and AKR), and any discrepancies between them were resolved via consensus with a third author (RRC).

2.6. Summary measures, synthesis of results, and publication bias

Although meta-analyses can be done with as few as two studies (Valentine, Pigott, & Rothstein, 2010), considering the fact that reduced sample sizes are common in the sport-science literature (Pigott, 2012), including JRT studies (Abt, et al., 2020; Arnett and Lutz, 2002; Ramirez-Campillo, et al., 2018; Ramirez-Campillo, Moran, et al., 2020), meta-analysis was only conducted in the present case when $\geq$3 studies were available (Garcia-Hermoso, et al., 2019; Moran, Ramirez-Campillo, & Granacher, 2018; Skrede, Steene-Johannessen, Anderssen, Resaland, & Ekelund, 2019). Effect sizes (ES, i.e., Hedge's *g*) for each health- and sport-related physical fitness attribute in the JRT and control/comparator groups were calculated using pre-training and post-training mean and standard deviation for each dependent variable. Data were standardized using post-intervention standard deviation values. The random-effects model was used to account for differences between studies that might affect the JRT effect (Deeks, Higgins, & Altman, 2008; Kontopantelis, Springate, & Reeves, 2013). The ES values are presented with 95% confidence intervals (95% 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, Marshall, Batterham, & Hanin, 2009). In studies including more than one intervention group, the sample size in the control group was proportionately divided to facilitate comparisons across multiple groups (Higgins, Deeks, & Altman, 2008). The impact of heterogeneity was assessed using the I^2 statistic, with values of <25%, 25–75%, and >75% representing low, moderate, and high levels of heterogeneity, respectively (Higgins and Thompson, 2002). The risk of publication bias was explored for continuous variables (≥10 studies per outcome) (Egger, Davey Smith, Schneider, & Minder, 1997; Higgins et al., 2019; Sterne et al., 2011) using the extended Egger's test (Egger, et al., 1997). To adjust for publication bias, a sensitivity analysis was conducted using the trim and fill method (Duval and Tweedie, 2000), with L0 as the default estimator for the number of missing studies (Shi and Lin, 2019). All analyses were carried out using the Comprehensive Meta-Analysis software (version 2, Biostat, Englewood, NJ, USA). Statistical significance was set at $p \leq 0.05$.

3. RESULTS

3.1. Study selection

The search process in the databases identified 10,569 studies. Figure 1 provides a flow chart illustrating the study selection process.

*****Figure 1 here*****

Duplicate studies were removed (n = 6,047). After study titles and abstracts were screened, 3,655 studies were removed and 867 full-text studies were screened. Fifty-one studies were included in qualitative synthesis and their reference list screened, with 10 records identified through the reference lists screening process. Thereafter, 40 full-text studies were excluded (exclusion reasons in Electronic Supplementary Material Table S2), and 21 considered eligible for meta-analysis (Arazi, et al., 2016; Arnett and Lutz, 2002; Bellver et al., 2021; Chen and Lin, 2011, 2012; Çınar-Medeni, Turgut, Colakoglu, & Baltaci, 2019; Colakoglu, Karacan, Guzel, & Baltaci, 2017; Duzgun, Baltaci, Colakoglu, Tunay, & Ozer, 2010; Eler and Acar, 2018; Eskandari et al., 2020; Garcia-Pinillos, et al., 2020; Ghorbanian, Ravassi, Kordi, & Hedayati, 2013; Ha and Ng, 2017; Kim et al., 2007; Kim et al., 2020; Kusuma, Setijonob, & Mintartoc, 2020; Masterson and Brown, 1993; Orhan, 2013; Sung, Pekas, Scott, Son, & Park, 2019; Turgut, Çolakoğlu, Güzel, Kapacan, & Baltaci, 2016; Yang, Lee, Gu, Zhang, & Zhang, 2020).

3.2 Methodological appraisal of the included studies

According to the PEDro checklist, the median (i.e., non-parametric) score was 6, with six studies attaining fair quality (5 points), and 15 studies were of good quality (6-7 points; no study scored above 7 points) (Table 2). The two independent reviewers that performed methodological appraisal of the included studies achieved a Spearman correlation (i.e., data non-parametric) agreement of 0.95.

*****Table 2 here*****

3.3 Study characteristics

The participant characteristics and the JRT programs of the included studies are detailed in Tables 3 and 4, respectively.

***** Table 3 here*****

*****Table 4 here*****

A total of 527 participants were analyzed in the intervention arms (27 groups) and 494 participants were assessed in the control groups (21 groups); of those, n=120 (7 groups) were active controls (e.g., regular volleyball training group), 363 (13 groups) were passive controls (e.g., youths maintaining their regular non-training activities), and n=11 (1 group) were alternative training-intervention controls (i.e., performed countermovement jumps as training). Of note, 18 studies included participants with a mean age <18 years old (n=878) and 3 studies included participants with a mean age >18 years old (n=143). From the total 1,021 participants, 171 participants were mixed in male-female groups, the sex of 25 participants was unidentified, and the remained involved 416 male and 409 female participants (see Table 3 and Electronic Supplementary Material Table S5). Considering the number of identified male and female participants, the included studies recruited an equal distribution of participants according to sex (i.e., male, 50.4%; female, 49.6%).

The duration of the training programs in the intervention and control groups ranged from 6 to 40 weeks and the frequency of weekly training sessions ranged from 2 to 5 (Table 4). Methods to report training intensity (Table 4) included maximal effort intensity (i.e., maximal reactive strength; minimal ground-contact time), jumping rate (i.e., 35-109 jumps/min), rating of perceived exertion (i.e., 11-16, using a 20-points maximal scale), heart rate (i.e., 60-75% maximal heart rate; 40-70% heart rate reserve). Some studies, in addition to jumping rate, also included a minimal height (i.e., 3 to 8.5 cm), vertical ground reaction force (i.e., 3.97 times-body mass), or impact load rate (i.e., 41 body mass/s) per jump (as a mean value). Some studies indicated only a qualitative description for intensity (i.e., intermediate-advanced jumps; explosive tempo). Six studies did not provide any details regarding intensity. Relatedly, only 4 studies reported the characteristics of the rope used during JRT (Colakoglu, et al., 2017; Duzgun, et al., 2010; Orhan, 2013; Turgut, et al., 2016) (Electronic Supplementary Material Table S3).

The testing, measurement and assessment protocols for each of the included health- and sport-related physical fitness outcomes in the meta-analysis are detailed in Electronic Supplementary Material Table S4.

3.4 Results from meta-analysis

Figure 2 depicts the overall results for each of the included health- and sport-related physical fitness outcomes in the meta-analyses. Overall, significant small-moderate (ES = 0.23 - 1.19) improvements were observed in resting heart rate, body mass index, fat mass, cardiorespiratory endurance performance, lower-body maximal strength performance, upper-body maximal strength performance, jump performance, range of motion, and sprint performance. No significant JRT effects (ES = 0.1 – 0.79) were noted for systolic blood pressure, diastolic blood pressure, waist and waist-hip circumference, bone mass, lean mass, and localized muscle endurance performance.

*****Figure 2*****

A detailed presentation of the results for each of the health- and sport-related physical fitness outcomes are presented in the following paragraphs.

3.4.1 Health-related physical fitness outcomes

There was a significant moderate effect of JRT, compared to controls, on resting heart rate (ES = 1.19; I^2= 57.0%) (Electronic Supplementary Material Figure S1), body mass index (ES = 0.67; I^2= 43.1%) (Electronic Supplementary Material Figure S4), and fat mass (ES = 0.55; I^2= 37.9%; Egger's test p=0.517) (Electronic Supplementary Material Figure S8). There was a non-significant moderate effect of JRT, compared to controls, on systolic blood pressure (ES = 0.79; I^2= 96.1%) (Electronic Supplementary Material Figure S2), diastolic blood pressure (ES = 0.31; I^2= 95.6%) (Electronic Supplementary Material Figure S3), waist and waist-hip circumference (ES = 0.39; I^2= 69.2%) (Electronic Supplementary Material Figure S5), bone-related body composition (ES = 0.16; I^2= 0.0%) (Electronic Supplementary Material Figure S6), and on lean mass (ES = 0.10; I^2= 0.0%) (Electronic Supplementary Material Figure S7).

3.4.2 Sport-related physical fitness outcomes

There was a significant small effect of JRT, compared to controls, on endurance performance (ES = 0.48; I^2= 76.9%) (Electronic Supplementary Material Figure S9), lower-body maximal strength performance (ES = 0.23; I^2= 0.0%) (Electronic Supplementary Material Figure S11), upper-body maximal strength performance (ES = 0.89; I^2= 28.5%) (Electronic Supplementary Material Figure S12), jump performance (ES = 0.53; I^2= 0.0%) (Electronic Supplementary Material Figure S13), range of motion (ES = 0.51; I^2= 4.0%) (Electronic Supplementary Material Figure S14), and sprint performance (ES = 0.44; I^2= 0.0%)

(Electronic Supplementary Material Figure S15). There was a non-significant small effect of JRT, compared to controls, on local endurance performance (ES = 0.49; I^2= 41.1%) (Electronic Supplementary Material Figure S10).

4. DISCUSSION

The primary aim of this systematic review with meta-analysis was to assess the available body of published peer-reviewed articles related on the effects of JRT compared with active/passive controls on health- and sport-related physical fitness outcomes in apparently healthy participants. From 21 moderate-high quality studies, involving 1,021 participants, JRT provides a range of small to moderate (ES = 0.23 - 1.19) significant benefits when compared to control (active and passive) conditions, that span health- and sport-related physical fitness outcomes.

4.1. Jump rope training and health-related physical fitness

Our meta-analysis revealed that there is a significant moderate (ES = 1.19) effect of JRT on resting heart rate. Such a decrease is consistent with the result of a recent meta-analysis on the effects of endurance training (Reimers, Knapp, & Reimers, 2018). The American Heart Association recommends JRT (AHA, 2018; Breslow, 1996), which is supported by the findings of this review as JRT reduced resting HR and such a reduction is associated with improved life expectancy (Huang et al., 2005). However, our results provide only provisional evidence (e.g., a single new study may alter current findings), requiring further studies for more robust conclusions regarding the effects of JRT on resting heart rate.

With regards to systolic and diastolic blood pressure, our meta-analysis showed non-significant moderate effect of JRT on systolic (ES = 0.79) or diastolic (ES = 0.31) blood pressure in young individuals (age <19 years). The included studies demonstrated systolic blood pressure reduction by 6-7 mmHg, which is clinically significant, as the reduction by 2 mmHg reduce mortality from stroke by 6%, coronary heart disease by 4% (Chobanian et al., 2003), and cardiovascular disease manifestations (Wong and Wright, 2014). Therefore, JRT seems to be an effective, inexpensive, and easily accessible training modality to reduce blood pressure.

Of note, body mass index in adolescence is associated with systolic and diastolic blood pressure in both genders (Chorin et al., 2015). Our meta-analysis showed a significant moderate (ES = 0.67) effect of JRT on body mass index, contributing to participants health status. Nonetheless, of the 9 meta-analysed studies for body mass index, only 4 provided dietary control data (Bellver, et al., 2021; Eskandari, et al., 2020; Kim, et al., 2020; Sung, et al., 2019). Therefore, dietary control may be considered in future large randomized-controlled trials to elucidate the independent effect of JRT on body mass index.

Regarding waist and waist-hip circumference, as indirect markers for individual's fatness (Snijder, van Dam, Visser, & Seidell, 2006), the meta-analysis revealed a non-significant change after JRT. However, the effects may have been non-significant due to poor statistical power (few studies, small samples). Accordingly, regardless of findings being non-significant, a small reduction effect (ES = 0.39) was noted in favour of JRT. Of the five included studies, four reported reduced waist circumference, involving overweight and obese participants (Eskandari, et al., 2020; Kim, et al., 2007; Kim, et al., 2020; Sung, et al., 2019), whereas the study without reduced waist circumference values (Yang, et al., 2020) involved participants with the lower basal waist circumference (i.e., <69 cm). JRT might be effective in improving waist circumference, but only in participants who are overweight or obese. However, dietary intake was not controlled in the study that reported no changes in waist circumference (Yang, et al., 2020), whereas intakes were controlled in three of the four studies that reported improvements after JRT (Eskandari, et al., 2020; Kim, et al., 2020; Sung, et al., 2019).

Our meta-analysis revealed a trivial effect for JRT on bone-related body composition (ES = 0.16). The potential main reasons for the trivial effect are two-fold. Firstly, the median duration of the meta-analysed studies was 16 weeks, a reduced period considering that meaningful detectable changes in bone-related body composition may require more prolonged training periods (e.g., 6- 9-months) (Kato et al., 2006; McWhannell, et al., 2008; Witzke and Snow, 2000). Secondly, the lack of appropriate control for overload progression may have precluded optimal bone-related body composition improvements (Ha and Ng, 2017).

With regards to lean mass, a non-significant trivial (ES = 0.10) effect of JRT was found. From the four included studies, two (Arnett and Lutz, 2002; Bellver, et al., 2021) did not report lean body mass changes among healthy high school girls and Olympic artistic female swimmers, while the remaining two studies (Kim, et al., 2020; Sung, et al., 2019) reported increased lean body mass among young girls with pre-hypertension (120–140 mmHg systolic blood pressure; 80–90 mmHg diastolic blood pressure) and abdominal obesity (waist >80 cm). Therefore, JRT might not produce lean body mass changes among young healthy-athletic individuals, although may be effective for non-athletes. However, further research is needed as limited evidence is available on this topic.

Exercise is a potent non-pharmacological agent against body fat accretion (Kelley and Kelley, 2013). A recent meta-analysis reported a reduction in body fat (1.3-1.5%) after resistance training (Wewege et al., 2021) or both aerobic and resistance training (Chen et al., 2021). Indeed, our meta-analysis revealed that JRT reduced body fat when compared to controls (ES = 0.55), providing a low-cost training strategy, with potential for implementation in large groups of participants.

4.2. Jump rope training and sport-related physical outcomes

JRT involving high jumping frequency (up to 110 jumps/min) (Bellver, et al., 2021), may induce significant metabolic activation during exercise (e.g., ≥90% of maximal oxygen consumption), comparable to interval running (Ducrocq, et al., 2019; Kramer, et al., 2019). Relatedly, our meta-analysis found a significant small effect of JRT on cardiorespiratory endurance (ES = 0.48), one of the most important markers for both health- and sport-related physical fitness (Coyle, 1995; Laukkanen et al., 2016; Mohr, Krustrup, & Bangsbo, 2003; J. R. Ruiz et al., 2011; Jonatan R. Ruiz et al., 2006). Therefore, JRT may be considered especially well-suited to improve both neuromuscular (e.g., strength-power [jump]), as well and cardiorespiratory endurance, key aspects of both health- and sport-related physical fitness. Moreover, as JRT can involve significant metabolic activation (Ducrocq, et al., 2019; Kramer, et al., 2019), from a health perspective, and considering international guidelines (Bull et al., 2020), this mode of exercise could contribute to accumulation of daily moderate to vigorous physical activity. Also, there was a non-significant small effect (ES = 0.49) of JRT on local endurance performance, although performance was measured in terms of number of sit-ups performed. Therefore, further research is required to determine the effects of JRT on muscular endurance, using a valid testing approach (e.g., lower-body muscles), and in larger samples, through randomized-controlled trials.

A small significant improvement (ES = 0.23) was noted in lower body strength after JRT, in line with the results of previous meta-analyses related to traditional plyometric jump training (de Villarreal, Requena, & Newton, 2010; Oxfeldt, Overgaard, Hvid, & Dalgas, 2019), although with slightly lower effects compared to the aforementioned study (ES = 0.33 - 0.97). We also observed a significant moderate (ES = 0.89) effect of JRT on upper-body maximal strength. Greater upper-body strength improvements have been noted after weighted rope training compared to normal (i.e., non-weighted) JRT (Colakoglu, et al., 2017; Duzgun, et al., 2010). Weighted rope may increase mechanical load on the upper-body muscles, facilitating increased upper body maximal strength. Therefore, JRT can be used to improve upper body maximal strength, with weighted rope being particularly effective to this purpose.

Considering the benefit of increased strength on current and future health status (Garcia-Hermoso, et al., 2019; J. R. Ruiz, et al., 2009), and its relationship with athletic performance (Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004), JRT may also be considered as an adequate intervention to achieve such benefits. However, most of the aforementioned outcomes were based on the findings across <5 studies. Further research is required to provide more robust conclusions.

We found a significant small effect (ES = 0.53) of JRT on jump performance, a marker that may be considered important for both sport-related and health-related purposes (J. R. Ruiz, et al., 2011; Jonatan R. Ruiz, et al., 2006). However, some considerable differences were noted on the jump performance improvement between JRT studies (ES = 0.31 to 0.94), which may have been affected by the type of rope used (e.g., standard compared to weighted rope) (Colakoglu, et al., 2017; Turgut, et al., 2016). Ropes come in different sizes, weights and widths (Lee, 2003), with such factors potentially impacting on the intensity of the exercises and, indirectly, on the number of repetitions performed, and/or on the speed of execution. Indeed, there is evidence to suggest that optimal hand-held weights should be individualized (McKenzie, Brughelli, Gamble, & Whatman, 2014; McKenzie, Brughelli, Whatman, & Brown, 2016; Rosas et al., 2016). Nonetheless, there is no robust evidence related to the optimal rope characteristics to be used according to the participant's characteristics. Further, from the 21 studies included in this meta-analysis, only 4 reported the characteristics of the rope used during JRT (Colakoglu, et al., 2017; Duzgun, et al., 2010; Orhan, 2013; Turgut, et al., 2016). Proper reporting of rope characteristics is needed in future studies.

We found a significant small effect (ES = 0.51) of JRT on range of motion. Greater range of motion improvement was noted after freestyle rope jumping compared to traditional JRT (Yang, et al., 2020), as well as after weighted JRT compared to standard JRT (Turgut, et al., 2016). The underlying mechanisms responsible for range of motion improvement after JRT need further investigation. However, a recent meta-analysis indicated that traditional plyometric jump training programs involving >500 jumps per week may reduce stiffness (Moran et al., 2021). The 6 studies included in our range of motion meta-analysis involved a large number of jumps (~456 to 7,380 per week). Therefore, if stiffness reduction occurred, this may entail a more compliant muscle-tendon unit and related elastic behaviour of joint sub-components (Markovic and Mikulic, 2010), potentially aiding toward greater range of motion. Such potential adaptations would not only be compatible with greater range of motion, but also with greater SSC performance (e.g., greater jump height) (De Ste Croix, Lehnert, Maixnerova, Ayala, & Psotta, 2021), allowing the muscle fibres to operate at a more optimal length over the first part of their shortening range (Markovic and Mikulic, 2010; Wilson, Elliott, & Wood, 1992).

Vertical jumping and linear sprinting are performed in different planes of motion but there seems to be a cross-over between the two (Singh, Ramachandran, Baxter, & Allen, 2021). Indeed, JRT improved (small ES = 0.42) sprint performance. Similar effects were noted after traditional plyometric jump training (Lockie, Murphy, Callaghan, & Jeffriess, 2014; Oxfeldt, et al., 2019; Sáez de Villarreal, Requena, & Cronin, 2012). High level sprint performance is considered to be an essential fundamental skill in many sports among youth and adults (Faude, Koch, & Meyer, 2012). Nonetheless, further research is needed to examine the effects of programming JRT variables on sprinting performance.

4.3. Adverse effects

Jump rope exercise has been indicated as one of the most popular physical activities in some countries (e.g., China) (Yang, et al., 2020), highlighting its potential to be accessible to a broad portion of the population, helping them to improve their health- and sport-related physical fitness. Nonetheless, potential adverse effects should be minimized and acknowledged. In our meta-analysis, two studies (Bellver, et al., 2021; Eskandari, et al., 2020) reported no adverse health effects due to JRT. However, a participant in one of the aforementioned studies (Bellver, et al., 2021) reported an episode of tibia periostitis, although the participant successfully continued the JRT protocol. Furthermore, one study (Eskandari, et al., 2020) reported a drop out owing to health and unwillingness reasons. The remaining studies included in the meta-analysis failed to report any specific information pertaining to adverse health effects. Nonetheless, too much JRT may produce unwarranted adverse effects.

4.4. Methodological quality

All included studies were of moderate-to-high quality, although 20 studies scored ≤6 points on the PEDro scale and only one study scored 7 points, thus reducing confidence in the existence evidence. A possible reason for this could be due to the difficulties in conducting studies that include blinding of participants, therapists and assessors and due to this reason, all the included studies scored zero for the PEDro scale items 5, 6 and 7 (Table 2). Although most of the included studies in our meta-analysis reported comprehensive description of the training interventions, some potentially important programming parameters (e.g., recovery time between-sessions) were neglected in most studies. Therefore, future JRT studies should attempt to provide robust methodological approaches (e.g., large randomized-controlled trials), including appropriate description of the programming training factors.

4.5. Limitations and road map for future studies

Despite our systematic review with meta-analysis making a novel and significant contribution to the existing literature and highlights the benefits of JRT to improve both health- and sport-related physical fitness outcomes, some limitations should be discussed, in line with recommendations for future studies in this field.

4.5.1. Reduced number of studies per outcome, and reduced number of participants per study group

For some outcomes (systolic and diastolic blood pressure; waist and waist-hip circumference; bone mass; lean mass; local muscle endurance) non-significant differences were noted between JRT and control condition. Although non-significant, most results attained an ES >0.2 (range, ES = 0.1 to 0.79) in favour of JRT. These findings may be explained by the small number of studies (i.e., 3-4 studies available per each outcome), and the small sample sizes (~12 participants per group) in most studies. Therefore, true differences may have been masked due to inadequate sample sizes. Future studies may provide *a priori* sample size power analysis (Abt, et al., 2020), to recruit a sufficient number of participants, therefore increasing the likelihood of small differences being detected instead of being undetected due to reduced statistical power. Additionally, most non-significant meta-analyses had moderate-high impact of heterogeneity (mean I2 = 50%). In contrast, most significant meta-analyses had low impact of heterogeneity (mean I2 = 28%). Moreover, publication bias analysis was precluded (aside from body fat) as less than 10 studies were available for most comparisons. Large randomized-controlled trials should be encouraged in future efforts to address the effects of JRT.

4.5.2. Reduced number of studies in adults

Of note, 18 studies included participants with a mean age <18 years old (n=878) and 3 studies included participants with a mean age >18 years old (n=143, i.e., 14%). Therefore, several meta-analyses (i.e., systolic blood pressure; diastolic blood pressure; waist circumference; range of motion; local endurance) involved results mainly arising from youth populations. This may limit the transferability of current findings toward adult population. This gap in the literature should be solved by efforts in future research focused with adult groups of participants.

4.5.3. Jump rope training programming variables

Of note, only one study (Garcia-Pinillos, et al., 2020) reported the surface type were JRT was performed. The surface type can affect acute and long-term responses to jump exercises (Bobbert, 1990; Markovic and Mikulic, 2010; Ramirez-Campillo, Andrade, & Izquierdo, 2013). Moreover, the type of shoe midsole hardness can affect lower extremity biomechanics during jump rope (Yu et al., 2021). Similarly, none of the 21 included studies in meta-analyses reported using a taper. This is considered an important programming variable for jump training (Ramirez-Campillo, Pereira, et al., 2020) and competitive performance (Bosquet, Montpetit, Arvisais, & Mujika, 2007; Mujika, 1998, 2009), particularly after interventions involving large number of repetitions (e.g., *loads*), which in the case of JRT interventions, most of the included studies in meta-analyses involved large number of foot contacts, some achieving ~100,000 total jumps (Yang, et al., 2020). Additionally, although rope jumping is a common component of general conditioning methods and athletes become generally quickly proficient (Buchheit, Rabbani, & Beigi, 2014), due to its technical demand (particularly for complex rope jump drills, e.g., may be used for progression and overload), experimental studies may include familiarization sessions before pre-intervention testing. Future large-scale randomized-controlled trials should properly report these factors and their potential impact on adaptations after JRT.

5. Conclusion

The majority of available evidence comes from young male and female populations (<18 y) and indicates that JRT, when compared to active and passive controls, provides a range of small-moderate significant benefits, that span health- and sport-related physical fitness outcomes.

6. Registration

This study was registered in PROSPERO with the number CRD42021273198.

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Competing interests

None of the authors declares competing financial interests.

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Table 1. Selection criteria used in the meta-analysis.

Category	Inclusion criteria	Exclusion criteria
Population	Healthy participants, with no restrictions on their fitness level, sex, or age.	Participants with health problems (e.g., injuries, recent surgery), precluding participation in a jump rope training program.
Intervention	A jump rope training program, which included unilateral and/or bilateral jumps, which commonly utilize a pre-stretch or countermovement stressing the stretch-shortening cycle.	Exercise interventions not involving jump rope training (e.g., traditional drop jump training) or exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., high-load resistance training).
Comparator	Active or traditional control group. Studies comparing different jump rope training approaches (e.g., different volume) without active or traditional control group will also be considered.	Absence of control group.
Outcome	At least one measure related to sport-health-related physical fitness before and after the training intervention.	Lack of baseline and/or follow-up data.
Study design	Multi-arm trials.	Single arm trials/observational studies.

Table 2. Methodological quality of the included studies using the PEDro rating scale.

Study N°	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Score***	**Study quality**
Arazi et al. 2016	0	1	0	1	0	0	0	1	1	1	1	6	Good
Arnett and Lutz 2002	1	1	0	1	0	0	0	1	1	1	1	6	Good
Bellver et al. 2021	1	0	0	1	0	0	0	1	1	1	1	5	Fair
Chen and Lin 2011	1	1	0	1	0	0	0	1	1	1	1	6	Good
Chen and Lin 2012	1	1	0	1	0	0	0	1	1	1	1	6	Good
Cınar-Medeni et al. 2019	1	1	0	0	0	0	0	1	1	1	1	5	Fair
Colakoglu et al. 2017	1	1	0	1	0	0	0	1	1	1	1	6	Good
Duzgun et al. 2010	1	1	0	1	0	0	0	1	1	1	1	6	Good
Eler and Acar 2018	0	1	0	1	0	0	0	1	1	1	1	6	Good
Eskandari et al. 2020	1	1	0	1	0	0	0	1	1	1	1	6	Good
Garcia-Pinillos et al. 2020	1	1	1	1	0	0	0	1	1	1	1	7	Good
Ghorbanian et al. 2013	1	1	0	1	0	0	0	0	1	1	1	5	Fair
Ha and Ng 2017	1	0	0	1	0	0	0	1	1	1	1	5	Fair
Kim et al. 2007	1	1	0	0	0	0	0	1	1	1	1	5	Fair
Kim et al. 2020	1	1	0	1	0	0	0	1	1	1	1	6	Good
Kusuma et al. 2020	1	0	0	1	0	0	0	1	1	1	1	5	Fair
Masterson and Brown 1993	1	1	0	1	0	0	0	1	1	1	1	6	Good
Orhan 2013	1	1	0	1	0	0	0	1	1	1	1	6	Good
Sung et al. 2019	1	1	0	1	0	0	0	1	1	1	1	6	Good
Turgut et al. 2016	1	1	0	1	0	0	0	1	1	1	1	6	Good
Yang et al. 2020	1	1	0	1	0	0	0	1	1	1	1	6	Good

A detailed explanation for each PEDro scale item can be accessed at https://www.pedro.org.au/english/downloads/pedro-scale.

*From a possible maximal score of 10.

Table 3. Participant's characteristics in the experimental groups from the included studies.

Study N°	n	Sex	Age (y)¶	Body mass (kg)	Height (cm)	SPT	Sport	Fitness*
Arazi et al. 2016	12	M	11.3	40.5	151.4	No	NA	Normal
Arnett and Lutz 2002	13, high volume 12, low volume	F	15.0	57.9	164.4	No	NA	Normal
Bellver et al. 2021	16	F	19.0	56.3	170.3	No	Artistic swimmers	High
Chen and Lin 2011	6	NR	14.0	43.4	148.0	NR	NA	Low
Chen and Lin 2012	8	NR	16.0	62.4	164.5	NR	NA	Low
Cınar-Medeni et al. 2019	18	F	16.0	63.0	173.6	NR	Volleyball	Moderate
Colakoglu et al. 2017	8, weighted rope 9, standard rope	F	14.8	59.7	166.2	NR	Volleyball	Moderate
Duzgun et al. 2010	9, weighted-rope 8, standard rope	F	14.5	58.6	165.5	NR	Volleyball	High
Eler and Acar 2018	120	M	11.0	34.2	138.4	No	NA	Normal
Eskandari et al. 2020	12 white chocolate supplement 12 dark chocolate supplement	M	15.0	88.7	165.9	No	NA	Low
Garcia-Pinillos et al. 2020	51	Mix	27.2	66.0	172.0	No	Runners (endurance)	Moderate-normal
Ghorbanian et al. 2013	15	M	17.0	87.2	175.8	No	NA	Low
Ha and Ng 2017	66	F	13.0	43.6	151.0	Yes	NA	Normal
Kim et al. 2007	14	M	17.0	89.7	173.9	No	NA	Low
Kim et al. 2020	24	F	15.0	70.8	158.9	No	NA	Low
Kusuma et al. 2020	11	M	16.0	NR	NR	NR	Badminton	Moderate
Masterson and Brown 1993	10	Mix	20.0	67.6	NR	No	NA	Low
Orhan 2013	20	M	17.5	80.8	189.6	NR	Basketball	Moderate
Sung et al. 2019	20	F	15.0	69.0	160.0	No	NA	Low-normal
Turgut et al. 2016	8, weighted rope 9, standard rope	F	14.5	58.6	165.5	NR	Volleyball	Moderate-high
Yang et al. 2020	20, freestyle rope skipping 20, traditional jump rope	Mix	13.5	NR	NR	No	NA	Normal

*Fitness was classified here as: **(i)** NR; **(ii)** high encompasses professional/elite athletes with regular enrolment in national and/or international competitions, or highly trained participants with 10 training hours per week or 6 training sessions per week and a regularly scheduled official or friendly competition; **(iii)** moderate encompasses non-elite/professional athletes with a regular attendance in regional and/or national competitions, between 5.0-9.9 training hours per week or 3-5 training sessions per week and a regularly scheduled official or friendly competition; **(iv)** normal encompasses recreational athletes with <5 training hours per week with sporadic or no participation in competition; and **(v)** low, for healthy but sedentary participants, healthy older adults, and participants under medical treatment (e.g., overweight).

¶: The age, body mass, and height have been mentioned for experimental groups. However, some studies reported mean values combining control and experimental groups.

Abbreviations ordered alphabetically: **F,** female; **M,** male; **NA,** not applicable; **NR**, not reported; **SPT,** systematic experience with plyometric jump training.

Table 4. Characteristics of jump rope training interventions the included studies.

Study n°	Freq (sessions/ week)	Dur (weeks)	Intervention	Total dose	Combined	Between-set rest (s)	Between-sessions rest (h)	Progressive overload	Training period	Replaced
Arazi et al. 2016	3	8	65-85 jump/min (60-75% heart rate max)	729 min	No	90-150	NR	Int, V	NA	No
Arnett and Lutz 2002	4	16	50 jump/min (8.5 cm each)	320-640 min	No	NA	NR	Int (weighted vest)	NA	Yes
Bellver et al. 2021	2	22	Vertical reaction forces = 3.97 body mass; impact load rate of 41 body mass/s; 1.82 jump/s	264 min	Yes (whole-body vibration)	0-90	NR	V	IS	No
Chen and Lin 2011	3	10	RPE 11-15	480 min	No	120	NR	No	NA	NR
Chen and Lin 2012	3	12	RPE 11-15	576 min	No	120	24-72	No	NA	NR
Cınar-Medeni et al. 2019	NR	12	NR	≥1,200 jumps	No	NR	NR	Technique, V	NR	No
Colakoglu et al. 2017	3	12	NR	3,240 s	Yes	30-60	NR	V, Int	NR	Yes
Duzgun et al. 2010	3	12	NR	3,105 s	No	30-60	NR	V	NR	No
Eler and Acar 2018	3	10	35-60 jump/min (3-5 cm each)	600 min	No	30	NR	V	NA	No
Eskandari et al. 2020	5	6	60-90 jump/min	11,190 jumps	No	30	24	V, Int (jump rate)	NA	NA
Garcia-Pinillos et al. 2020	2-4	10	Max (RSI-time contact)	160 min	No	20-30	24-48	V	NA	Yes
Ghorbanian et al. 2013	4	8	60-90 jump/min	59,868 jumps	No	30	NR	Int, V	NA	No
Ha and Ng 2017	NR	40	Intermediate to advanced	NR	No	NR	NR	No	NA	NA
Kim et al. 2007	5	6	60-90 jump/min	1,200 min	No	30	24-72	Int	NA	No
Kim et al. 2020	5	12	RPE 11-16 (HRR 40-70%)	2,400 min	No	NR	24-72	Int	NA	Yes
Kusuma et al. 2020	3	8	Heart rate-based	NR	NR	1:1 work/rest ratio	48-72	NR	NR	NR
Masterson and Brown 1993	3	10	Max (RSI)	23-90 min	No	180	NR	V + Int (rope mass)	NA	NA
Orhan 2013	3	8	Explosive tempo	12,000 – 38,400 jumps	No	1:1 work/rest ratio	NR	NR	NR	NR
Sung et al. 2019	5	12	RPE and heart rate-based	NR	No	NR	24-72	Int	NA	NA
Turgut et al. 2016	3	12	NR	5,490 s	No	30-60 (1:1 work/rest ratio)	NR	V	NR	Yes
Yang et al. 2020	3	12	82–88 jump/min	88,560-95,040 jumps	No	NR	48-72	Technique	NA	Yes

Abbreviations ordered alphabetically: **Dur,** duration; **Freq,** frequency of training; **HRR:** heart rate reserve; **Int,** intensity; **IS,** in-season; **NA,** not-applicable; **NR,** not reported; **Replaced**, denoting if the athletes replace some common drills from their regular training with jump rope training drills. If not, the jump rope training load was added to their regular training load; **RPE:** rating of perceived exertion; **RSI:** reactive strength index; **V**, volume (i.e., in this context, usually referred as the number of repetitions or minutes).

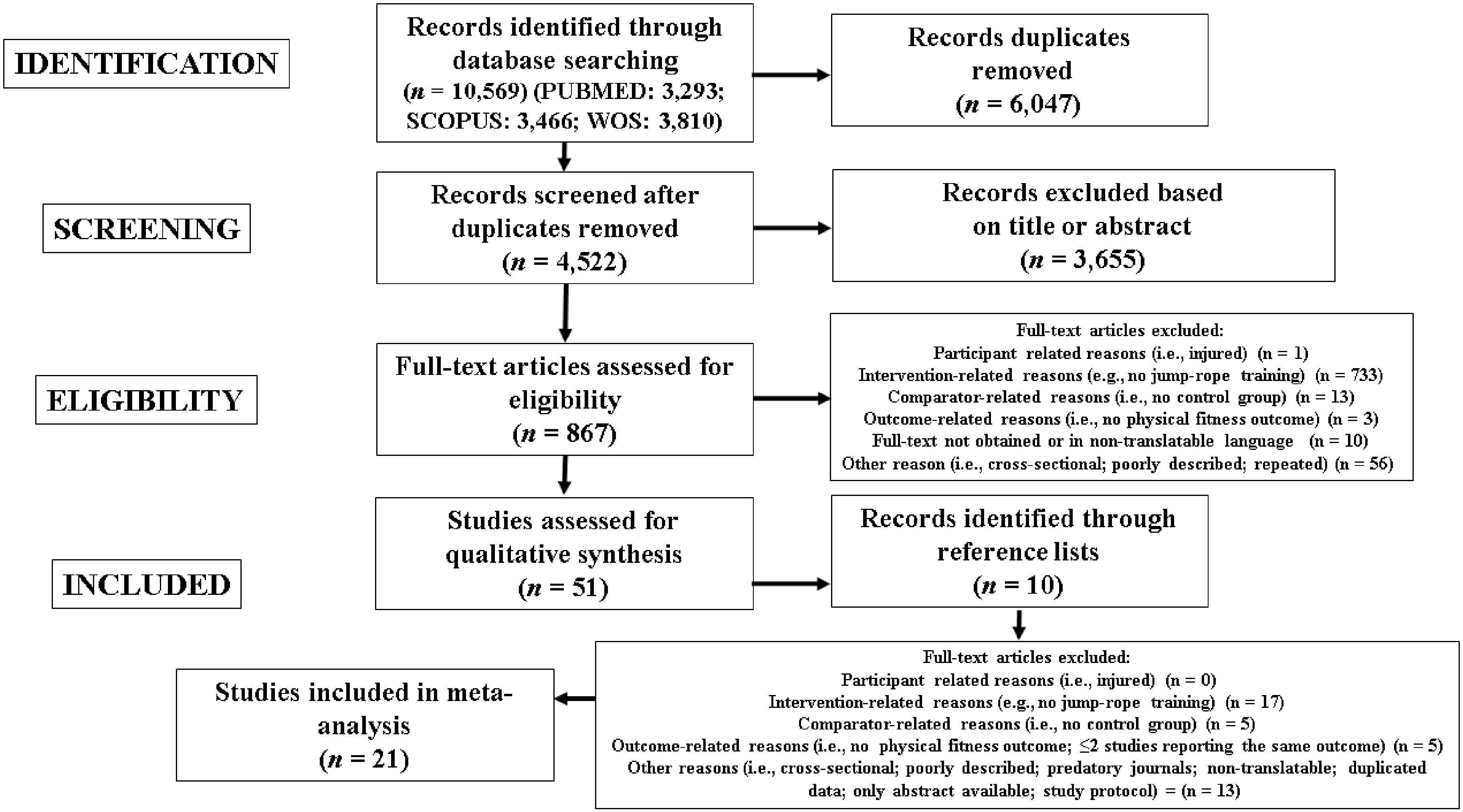

Figure 1. Flow chart illustrating the study selection process.

	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Heart rate	1.187	0.324	0.105	0.552	1.822	3.663	0.000
Systolic blood pressure	0.790	1.140	1.301	-1.446	3.025	0.692	0.489
Diastolic blood pressure	0.309	1.043	1.087	-1.735	2.352	0.296	0.767
Body mass index	0.645	0.180	0.032	0.292	0.998	3.583	0.000
Waist circunference	0.391	0.262	0.069	-0.123	0.905	1.493	0.136
Bone mass	0.155	0.126	0.016	-0.093	0.402	1.223	0.221
Lean mass	0.112	0.158	0.025	-0.198	0.422	0.707	0.479
Fat mass	0.545	0.124	0.015	0.302	0.788	4.391	0.000
Endurance (cardiorespiratory)	0.437	0.218	0.048	0.010	0.865	2.004	0.045
Endurance (local)	0.493	0.317	0.100	-0.127	1.114	1.557	0.119
Strength, lower-body	0.230	0.116	0.013	0.002	0.457	1.979	0.048
Strength, upper-body	0.891	0.201	0.041	0.497	1.286	4.428	0.000
Jump	0.529	0.127	0.016	0.280	0.778	4.163	0.000
Range of motion	0.507	0.183	0.033	0.148	0.865	2.770	0.006
Sprint	0.424	0.212	0.045	0.009	0.840	2.001	0.045

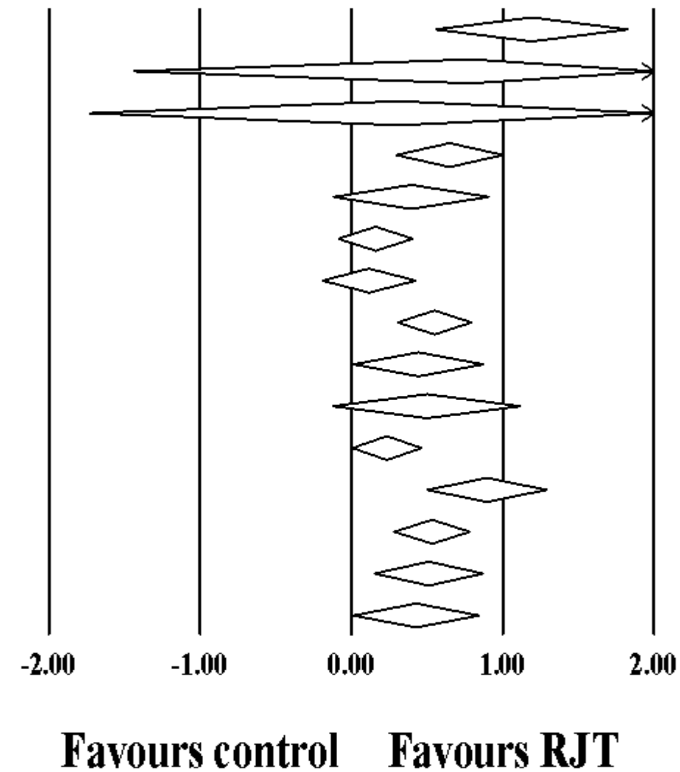

Figure 2. Forest plot of changes in health- and sport-related physical fitness outcomes, in participants that completed a rope jump training (RJT) program compared to participants allocated as controls. Forest plot values shown are effect sizes (Hedges's g) with 95% confidence intervals. The withe diamond reflects the overall result for each outcome.

Electronic Supplementary Material Table S1

Table S1. Search strategy (code line) for each database and background of search history.

Date of the search	July, 2017	July, 2019	September, 2021
Databases	PubMed	PubMed, WOS (Core Collection), Scopus	PubMed, WOS (Core Collection[a]), Scopus
Keywords	"plyometric", "training"	"ballistic", "complex", "cycle", "explosive", "force", "plyometric", "shortening", "stretch", "training", "velocity"	"ballistic", "complex", "cycle", "explosive", "force", "jump", "plyometric", "power", "shortening", "stretch", "training", "velocity"
Database fields for the search	All	PubMed: all WOS: all Scopus: title, abstract, keywords	PubMed: all [b] WOS: all [b] Scopus: title, abstract, keywords [b]
Restrictions for the search	None	None	None
Examples of search strategy code line	Pubmed: "plyometric exercise"[MeSH Terms] OR ("plyometric"[All Fields] AND "exercise"[All Fields]) OR "plyometric exercise"[All Fields] OR ("plyometric"[All Fields] AND "training"[All Fields]) OR "plyometric training"[All Fields] WOS: (ALL=(plyometric)) AND ALL=(training) SCOPUS: TITLE-ABS-KEY (plyometric AND training)		

[a]: except for the keywords "jump" and "power" searched in all WOS databases.
[b]: except for the keywords "jump" and "power" searched in the database field TITLE.

Electronic Supplementary Material Table S2

Table S2. Exclusion reasons for studies included in preliminary qualitative synthesis.

Study	Reason
[1]	Exercise interventions not involving jump rope training (e.g., intermittent bouts of 30 s of maximal continuous jumps; i.e., no rope was used).
[2]	Assessment of outcomes not includable in this systematic review (i.e., the study reported the amounts of physical activity performed at different intensities during rope jump training sessions).
[3]	Exercise interventions not involving jump rope training (e.g., the jump rope training program represented less than 50% of the total training load, as this was combined with other jump drills).
[4]	Exercise interventions not involving jump rope training (i.e., rope jumps represented less than 50% of the total training load, when delivered in conjunction with other drills, such as lateral barrier hop, box hopping, counter movement jump, counter movement jump to box, cycled split squat jump, push-ups with and without clapping hands, etc.).
[5]	Absence of control group; single arm trial (i.e., only one experimental rope jump training group).
[6]	Article in non-translatable language for the authors of this systematic review (i.e., no fund available).
[7]	Exercise interventions not involving jump rope training (e.g., the jump rope training program represented less than 50% of the total training load, as this was combined with other jump drills).
[8]	Absence of control group; single arm trial (i.e., only one experimental rope jump training group).
[9]	Absence of control group; single arm trial (i.e., only one experimental rope jump training group).
[10]	Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., running program, strength training, range of motion training).
[11]	Absence of control group; single arm trial (i.e., only one experimental rope jump training group).
[12]	Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., balance drills, speed, agility and quickness drills).
[13]	Study protocol.
[14]	Assessment of outcomes not includable in this systematic review (e.g., behavior-cognitive outcomes, such as physical activity at school and quality of life).
[15]	Assessment of outcomes not includable in this systematic review (e.g., behavior-cognitive outcomes, such as self-efficacy, and its long-term on BMI and metabolic markers).
[16]	Doubtful quality or peer-review process unclear from the journal.
[17]	Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., endurance training, strength and range of motion training).
[18]	Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., endurance training, strength and range of motion training).
[19]	Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., endurance training, strength and range of motion training).
[20]	Only abstract was available.
[21]	Single arm trials/observational studies (i.e., cross-sectional study).
[22]	Article in non-translatable language for the authors of this systematic review (i.e., no fund available).
[23]	Lack of baseline and/or follow-up data (i.e., data outcomes poorly reported, not valid, and/or indicative of ethical-related issues).
[24]	Single arm trials/observational studies.
[25]	Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., squat jumps, alternate leg bounding, static tuck jumps, diagonal obstacle jump, repeated tuck jumps, etc.).

[26] Exercise interventions not involving jump rope training (e.g., jumps, hops, squat jumps, tuck jumps, star jumps, ginga, handstands, cartwheel; i.e., no rope was used)
[27] Duplicated data (in Advances in Environmental Biology, 7(5): 945-951, 2013).
[28] Article in non-translatable language for the authors of this systematic review (i.e., no fund available).
[29] Two or less studies provided data for the same outcome measures and, therefore, was not meta-analysed.
[30] Doubtful quality or peer-review process unclear from the journal.
[31] Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., jumping jack, vertical drop jump, horizontal drop jump, countermovement jump, abdominal crunch, Romanian deadlift, etc.).
[32] Doubtful quality or peer-review process unclear from the journal.
[33] Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., 50 y accelerations, skipping 25 y, lateral cone hop jumps, bounding and box jumps).
[34] Rope skipping was combined with other exercises such as muscle strength training, core exercises and exercises with free weights for arms.
[35] Exercise interventions not involving jump rope training (i.e., the intervention was poorly described, with authors only indicting "The experimental group was subjected to the jump rope training during evening hours for three day…").
[36] Doubtful quality or peer-review process unclear from the journal.
[37] Doubtful quality or peer-review process unclear from the journal.
[38] Two or less studies provided data for the same outcome measures and, therefore, was not meta-analysed.
[39] Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., weightlifting session, gymnasium session consisting of coordination, strength, endurance, and range of motion training).
[40] Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., weightlifting session, gymnasium session consisting of coordination, strength, endurance, and range of motion training).

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Electronic Supplementary Material Table S3

Table S3. Rope characteristics.

Study	Rope characteristics
Colakoglu et al. 2017	Standard rope: cable rope (Selex) and the length of the rope, the part of the rope weight, and the total weight were 270cm, 100g and 160g; respectively; Weighted rope: weighted rope (Power rope (V-3067)) and the length of the rope, the part of the rope weight and the total weight were 260cm, 600g and 695g; respectively.
Duzgun et al. 2010	Unweighted-rope training group: Cable rope (Selex, Alexandria, VA) with a length, handle weight, and total weight of 270 cm, 100 g, and 160 g, respectively; Weighted-rope training group: (Power Rope V-3067) had a length, handle weight, and total weight of 260 cm, 600 g, and 695 g, respectively.
Orhan 2013	Weighted rope with trade mark Powerope (V- 3067) that has 260 cm length and 600 gr rope weight, and 695 gr. total weight was used for the experimental group.
Turgut et al. 2016	Weighted rope: The rope (Power Rope, V-3067) used in this group was weighted 600 grams and 695 grams, depending on the length of the rope; Standard rope: A cable rope (Selex, Alexandria, VA), which weighted between 100 grams to 160 grams, depending on the length of rope.

Electronic Supplementary Material Table S4

Table S4. Measurement protocols for studies outcomes included in meta-analysis.

Study	Outcome	Equipment	Procedure
Arazi et al. 2016	Fat mass	Skin fold	Body fat was computed from a prediction equation derived from sum of skin-fold of triceps and calf.
	Endurance	NR	Subjects were instructed to run back and forth on a 20 m course and return on the 20 m line at the same time a beep is emitted from a tape, until subjects can no longer reach the line on time, the last completed stage was the test score.
	ROM		Sit and reach test. Participants were instructed to sit on the floor with their head and upper body upright, and their legs placed together with full extension. Both feet were placed flat against the test device. Participants then inhaled and exhaled slowly while stretching the upper body, gradually bending forwarded as much as possible and pushing the measure guide with their middle fingers. Participant maintained their full-extension position for a few seconds and the distance was recorded from the measure guide. Three trials were performed with 30 seconds' rest in between. The greatest reach distance was used for the analysis.
	Endurance (local)		Maximum number of sit-ups in one minute were recorded. During the test, subjects assumed a crook lying position on a mat with both hands placed at the back of the neck. Subject's legs were stabilised by the researcher. Subjects were instructed to raise their trunk completely off the mat until it made a 60° angle with the floor
Arnett and Lutz 2002	Lean mass	DXA measurement	Lean mass was obtained from the total body scan. Fat was obtained from the total body scan. % Body fat was calculated through the ratio of total fat mass to the mass of all tissue (sum of fat, lean, and BMC). DXA measurements of the proximal femur (femoral neck and greater trochanter) and lumbar spine (L2–4) were obtained for BMC. The precision of measurements varied ~2%.
	Fat mass		
	Bone		
	Strength, lower	Isokinetic	Isokinetic dynamometer: 10 warm-up trials were given to each participant, followed by five maximal knee extensions and flexions at a speed of 180°/s (ICC = 0.92).
Bellver et al. 2021	Bone	DXA	During testing, participants wore light clothing, barefoot and without any jewellery or metal buttons. Subjects were tested in supine position, with their feet in slight internal rotation. CV: 0.87%
	Fat mass		
	Lean mass		
	BMI	NR	NR
Chen and Lin 2011	BMI	NR	NR
	ROM		Sit and reach test (NR)
	Endurance		Local endurance (NR)
Chen and Lin 2012	BMI	NR	NR
	ROM		Sit and reach test. Not explained.
	Endurance		Sit-up test. Not explained.
Cınar-Medeni et al. 2019	Jump	Field equipment	Tape measure was put on the wall. The participants were instructed to stand upright with their side to the wall. The feet was positioned flat on the ground were asked to reach up with the right hand. The point where the fingertips reached was marked and were asked to jump vertical as high as possible with both arms and touch the wall at the highest point. The score determined by taking the difference in distance between the reach height and jump height.
	Strength	Dynamometer	The grip strength was measured using hand dynamometer.
	Endurance (local)	NA	Participants were instructed to lie on the floor with knees bent, arms folded across chest and feet flat on the floor. Sit-up was initiated with back on the floor and body raised to 90 degree position and then return back again to the floor.
	Fat	Calliper	Skinfold thicknesses were taken at two sites (triceps and suprailiac). Percentage body fat and subsequent fat free mass were estimated using Sloan and Weir's equation
	BMI	Scale and stadiometer	Weight in kg divided by the square of height in meters.
Colakoglu et al. 2017	Sprint	Photocells	20-m: Subjects started from a stationary position, and performed a single timed maximum sprint.
	Endurance	Pre-recorded tape	Subject ran back and forth on a 20 m course. When a sound signal was heard from a pre-recorded tape subjects touched the block at the 20 m line. The frequency of the sound started at 8.5 km/h and increased 0.5 km/h for each minute. The test was stopped when the subjects could not continue the test. Cited previous literature for the determination of maximal VO2 uptake.

	Jump	NR	Subjects with feet flat on the ground, reached as high as possible with the dominant hand and touched the wall with fingers while the non-dominant hand stayed near the body. The height achieved was termed as the standing reach height
Duzgun et al. 2010	Strength, upper	Isokinetic dynamometer	Shoulder isokinetic strength (PT Ecc) during full can at 60 deg/sec. An Isomed 2000 program was selected to conduct the concentric–eccentric test during shoulder elevation and depression in the scapular plane by tilting the dynamometer approximately 30° from horizontal base position. The supraspinatus strength test in full-can comprised of concentric elevation followed by eccentric depression in the scapular plane. One set of 10 repetitions were performed at 60°/s.
Eler and Acar 2018	Fat	Skinfold	Measurements were taken from the calf and triceps areas (% body fat).
	Sprint	Photocells	20-m: The time was started automatically when the subject started to run, and the timer was stopped when the subject passed the finish line.
	Endurance	NR	Cardiorrespiratory (VO2max): Not explained
	Strength, lower	NR	Not explained
Eskandari et al. 2020	BMI	Bioelectrical impedance	The authors cited a previous study
	Waist hip ratio		
	Fat		
Garcia-Pinillos et al. 2020	Jump	Jump mat (infrared)	CMJ height: Participants were instructed to maximize the jump height. The height of the rise using the body's center of gravity was measured through flight time. Athletes performed 2 trials of with a 15-second recovery period between them, with the best trial being used for the statistical analysis.
	Endurance	NR	The 3-km time trial was executed on an outdoor 400-m synthetic track. The elapsed time (in seconds) for the 3-km running was recorded for the analysis. The participants were instructed to finish the race as fast as they could.
Ghorbanian et al. 2013	Fat	Calliper	Body fat was computed using skinfold calliper (sensitivity: 0.2 mm) using 3-site skinfold equations.
	BMI	Field equipment	BMI was calculated as body mass (kg) divided by the square of height in meters.
	Endurance	NR	Vo2max was estimated by Rockport fitness walking test.
Ha and Ng 2017	Bone	DXA	From DXA, an overall BMD-calcanei score was calculated as the mean of BMD values taken at the right and left calcaneus.
	Endurance	NR	Using a 15-m multi-stage shuttle-run test, participants were instructed to complete laps at a pre-recorded cadence, and stopped upon exhaustion (e.g., failure to keep cadence). Measurement considered the number of completed laps.
Kim et al. 2007	BMI	Field equipment	BMI was calculated as body mass divided by the square of height in meters.
	Waist	Tape measure	Waist circumferences was obtained in duplicate with a Gullick II tape
	Fat	BIA	Percent body fat mass was measured by foot-to-foot BIA
	SBP	NR	NR
	DBP		
Kim et al. 2020	BMI	Stadiometer and BIA scale	BMI was calculated body mass divided by the square of height in meters
	Fat	BIA	Bioelectrical impedance analysis (InBody)
	Lean mass		
	SBP	Sphygmomanometer	SBP measured using an automatic sphygmomanometer. The measurement was taken in duplicate and the average of the two measurements was recorded as the resting BP.
	DBP		DBP measured using an automatic sphygmomanometer. The measurement was taken in duplicate and the average of the two measurements was recorded as the resting BP.
	Waist	Standard tape	WC was measured using a standard tape measure to the nearest 0.1 cm.
Kusuma et al. 2020	Endurance	NR	Multistage fitness test using polar was performed
Masterson and Brown 1993	Jump	NR	The subjects were asked to jumped as high as possible without using a run or step. A natural countermovement was permissible. The subjects were given one practise jump followed by three trials. The best of the three heights were taken. The peak power was computed by the following formula (): Peak Power (W) = 61.9 + Jump Height (cm) + 36*(Body Mass in kg) - 1822
	Sprint	Handheld stopwatch	The subjects were asked to perform three trials of the 15 yard running dash. A stopwatch was used to measure the time to the nearest 0.01 second. Time for full recovery was allowed in between each trial. The subject's speed was divided by the body mass of the participant in order to make the relationship between speed and anaerobic power more acceptable.

	Strength, lower	Leg press	The seat of the leg press machine was adjusted in order to maintain similar knee (88-90 degrees) and hip (65-69 degrees) angle as measured using a flexometer. Participants performed 3 repetitions at 70% of their perceived maximal. After a 1 minute break, 1 RM test was performed followed by 30 seconds break. This process was continued till the time the participants failed to lift the next load. The final successfully executed lift was considered as the final 1-RM for the leg press.
	Strength, upper	Bench press	1RM in the bench press throw (similar method as for the leg press 1RM)
Orhan 2013	Heart rate	Hear rate monitor	Basketball players were instructed to lay position for 15 minutes and then resting rate was measured in pulse/min (Polar S720i)
Sung et al. 2019	BMI	Scale and stadiometer	The body mass was divided by the square of height (kg/m2) for calculating BMI
	Heart rate	Field equipment	Resting heart rate (bpm) was measured through radial artery palpation.
	SBP	Automatic sphygmomanometer	Resting blood pressure (mmHg) was measured in duplicate using an automatic sphygmomanometer
	DBP		
	Fat	Bioelectrical impedance	Bioelectrical impedance analysis was used, which simultaneously recorded total body mass (nearest 0.1 kg), percent body fat (nearest 0.1%), and fat-free mass (nearest 0.1 kg). CV: 0.3 - 0.8%
	Lean mass		
	Waist circumference	Standard tape	Waist circumference was recorded using a standard tape measure to the nearest 0.1 cm at the midpoint between the iliac crest and the lower rib.
Turgut et al. 2016	Jump	Field equipment	The participants were asked to stand side on to a wall and reach up with the hand closest to the wall. Keeping the feet flat on the ground, the point of the fingertips was re- corded. This was defined as the standing reach height. The participants were then asked to perform countermovement jump and to touch the wall at the highest point of the jump. The difference in distance between the standing reach height and the jump height was the score. The best of three attempts was recorded.
	Sprint		The test involves running a single maximum 30-m sprint. Participants were asked to take standard stationary position, with one foot in front of the other and to maintain the position for 2 seconds prior to start. All participants were encouraged to continue running hard through the finish line. Duration of the test was recorded in seconds.
	ROM		Sit and reach: Participants were asked to sit on the floor with legs out straight ahead. The feet were placed with the soles flat against the box and shoulder-width apart. Both knees were kept flat against the floor during test. Then, the participants were asked to reach forward as far as possible and the distance was recorded.
Yang et al. 2020	Strength, upper	Dynamometer	Both left- and right-hands grip strength (kg) were measured three times in a standing position, and the highest number was used for the final data analyses.
	Jump	Field equipment	Students stood on a line marked on the ground. They were instructed to place their feet slightly apart, swing the arms and bend the knees, and jump as far as possible. The trial was performed three times, and the longest jump distance was recorded and considered in the data analysis
	ROM	Field equipment	Toe touch test: students stood on a box bare-footed and maintained straight arms and knees during testing and bent over to try to touch the box for 10 s. The research assistants measured the distance (cm) between each students' fingers and the box. If the students' fingertips did not contact the box, the scores were negative; if the student reached it, the scores were recorded as positive.
	Waist circumference	Field equipment	Participants bare waist circumference at a standing posture was measured using a measuring tape. The research assistants started at the top of the participant's hip bone at the belly button level and wrapped the tape around the waist. The measurement was performed twice, and the mean score (cm) was recorded in this study
	Bone	Sonometer	This equipment estimated BMD (g/cm2) by measuring the transmission of high-frequency sound waves through the heel. Students were instructed to sit on the chair, and an oil-based coupling gel was applied to their heel.

Note 1: abbreviations ordered alphabetically; **Note 2:** when reliability was reported, the information was; included; **Note 3:** blinding of assessors was reported only by Arett and Lutz 2002; **List of abbreviations**: **1RM**: one repetition maximum; **BIA**: bioelectrical impedance analysis; **BMC**: bone mineral content; **BMD**: bone mineral density; **BMI:** body mass index; **CMJ:** countermovement jump; **CV:** coefficient of variation; **DBP:** diastolic blood pressure; **DXA:** dual energy X-ray absorptiometry; **FFM:** fat free mass; **ICC**: intraclass correlation coefficient; **NR:** no reported; **ROM:** range of motion

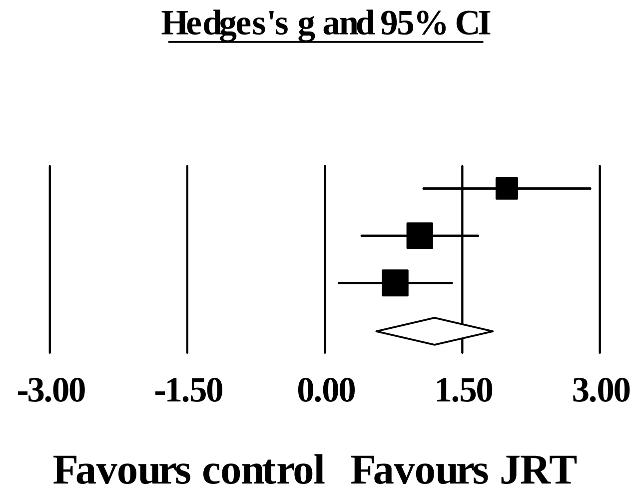
Electronic Supplementary Material Table S5

Table S5. Control groups characteristics.

Study	n	Sex	Age (y)	Body mass (kg)	Height (cm)	Activity
Arazi et al. 2016	10	M	11.3	40.6	151.5	Regular physical education classes
Arnett and Lutz 2002	12	F	14.0	57.5	162.9	Walk for 5 min and then stretched for 5 min at the beginning of the class
Bellver et al. 2021	16	F	19.0	56.3	170.3	Artistic swimming and gym sessions
Chen and Lin 2011	8	NR	16.0	63.9	165.9	Did not performed exercise
Chen and Lin 2012	3	NR	14.0	63.6	166.3	Maintained daily routine
Cınar-Medeni et al. 2019	17	F	15.6	58.2	168.5	Regular volleyball training
Colakoglu et al. 2017	8	F	14.4	50.6	161.2	Technical training only
Duzgun et al. 2010	7	F	14.4	50.0	161.0	Volleyball training only
Eler and Acar 2018	120	M	11.0	36.1	139.6	Physical education and sports lessons only
Eskandari et al. 2020	12	M	15.4	90.2	165.9	Not mentioned
Garcia-Pinillos et al. 2020	44	Mix	26.1	65.7	171.0	Maintained regular training routine
Ghorbanian et al. 2013	15	M	16.9	90.0	171.2	Regular physical education classes only
Ha and Ng 2017	97	F	12.1	42.1	149.1	Not mentioned
Kim et al. 2007	12	M	17.0	90.5	174.9	Regular physical education classes
Kim et al. 2020	24	F	15.0	70.8	157.9	Present at laboratory for the study duration but did not participate in exercise
Kusuma et al. 2020	11	M	15	NR	NR	High jump interval treatment
Masterson and Brown 1993	10	Mix	20.2	66.2	NR	No reported
Orhan 2013	20	M	17.5	81.8	187.9	Basketball technical training only
Sung et al. 2019	20	F	15.0	68.0	161.0	Did not participate in the exercise intervention, or any outside exercise
Turgut et al. 2016	8	F	14.4	50.0	161.0	Volleyball training program only
Yang et al. 2020	20	Mix	13.2	NR	NR	Free-play only

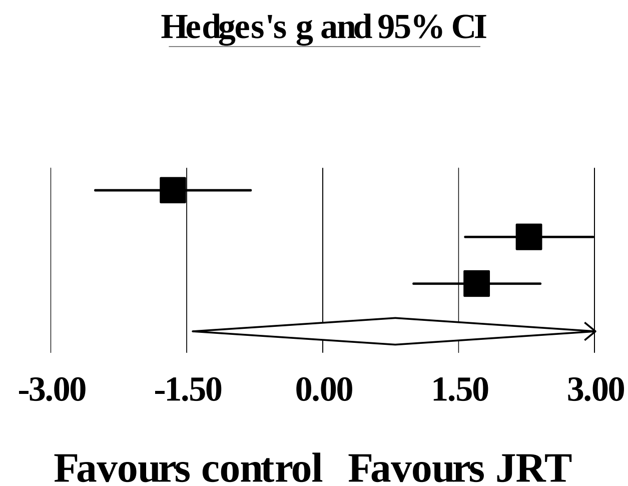
Electronic Supplementary Material Fig. S1 to S15

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Kim et al., 2007	1.987	0.470	0.221	1.065	2.908	4.225	0.000
Orhan 2013	1.037	0.331	0.110	0.388	1.685	3.133	0.002
Sung et al., 2018	0.769	0.322	0.103	0.138	1.399	2.390	0.017
	1.187	0.324	0.105	0.552	1.822	3.663	0.000



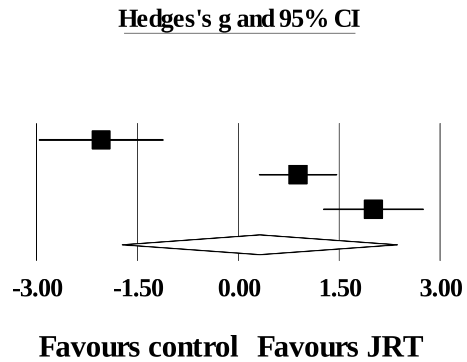
Electronic Supplementary Material Figure S1. Forest plot of resting heart rate changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Kim et al., 2007	-1.651	0.444	0.198	-2.522	-0.780	-3.715	0.000
Kim et al., 2020	2.278	0.367	0.135	1.559	2.998	6.208	0.000
Sung et al., 2018	1.702	0.364	0.132	0.989	2.415	4.680	0.000
	0.790	1.140	1.301	-1.446	3.025	0.692	0.489



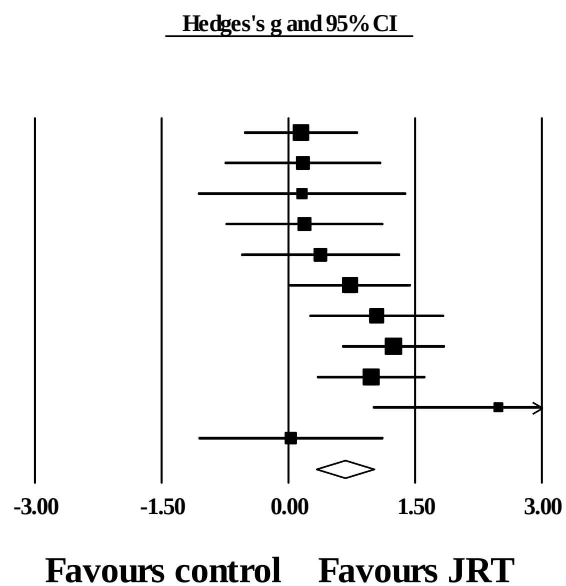
Electronic Supplementary Material Figure S2. Forest plot of resting systolic blood pressure changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Kim et al., 2007	-2.038	0.474	0.225	-2.968	-1.108	-4.297	0.000
Kim et al., 2020	0.889	0.298	0.089	0.304	1.473	2.981	0.003
Sung et al., 2018	2.010	0.383	0.147	1.260	2.760	5.250	0.000
	0.309	1.043	1.087	-1.735	2.352	0.296	0.767



Electronic Supplementary Material Figure S3. Forest plot of resting diastolic blood pressure changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Bellver et al., 2021	0.150	0.345	0.119	-0.527	0.826	0.435	0.664
Chen et al., 2011	0.172	0.474	0.224	-0.756	1.101	0.363	0.716
Chen et al., 2012	0.163	0.630	0.397	-1.072	1.397	0.258	0.796
Eskandari 2020 (Jump rope+White Chocolate	0.190	0.477	0.228	-0.745	1.126	0.399	0.690
Eskandari 2020 (Jump rope+Dark Chocolate	0.380	0.480	0.231	-0.561	1.322	0.792	0.428
Ghorbanian 2013	0.730	0.368	0.135	0.010	1.450	1.986	0.047
Kim et al., 2007	1.047	0.408	0.166	0.247	1.846	2.567	0.010
Kim et al., 2020	1.244	0.311	0.097	0.635	1.854	4.000	0.000
Sung et al., 2018	0.980	0.329	0.108	0.336	1.624	2.981	0.003
Colakoglu 2017 (Weighted Rope)	2.486	0.760	0.577	0.997	3.975	3.273	0.001
Colakoglu 2017 (Standard Rope)	0.029	0.559	0.313	-1.066	1.125	0.053	0.958
	0.665	0.174	0.030	0.324	1.007	3.816	0.000

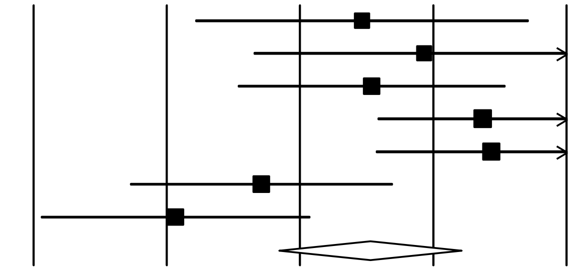


Electronic Supplementary Material Figure S4. Forest plot of body mass index changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Eskandari 2020 (White Chocolate)	0.349	0.480	0.230	-0.591	1.289	0.728	0.467
Eskandari 2020 (Dark Chocolate)	0.698	0.490	0.240	-0.262	1.659	1.425	0.154
Kim et al., 2007	0.403	0.385	0.148	-0.351	1.158	1.047	0.295
Kim et al., 2020	1.029	0.303	0.092	0.435	1.622	3.398	0.001
Sung et al., 2018	1.077	0.333	0.111	0.426	1.729	3.240	0.001
Yang et al., 2020 (Freestyle rope skipping)	-0.217	0.378	0.143	-0.958	0.523	-0.576	0.565
Yang et al., 2020 (Standard jump rope)	-0.700	0.388	0.150	-1.460	0.059	-1.807	0.071
	0.391	0.262	0.069	-0.123	0.905	1.493	0.136

Statistics for each study

Hedges's g and 95% CI

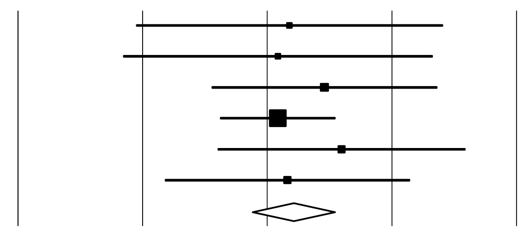


Electronic Supplementary Material Figure S5. Forest plot of waist and waist-hip circumference changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Arett and Lutz 2002 (HV)	0.134	0.472	0.223	-0.791	1.059	0.284	0.777
Arett and Lutz 2002 (LV)	0.065	0.476	0.227	-0.869	0.998	0.135	0.892
Bellver et al., 2021	0.344	0.347	0.121	-0.337	1.025	0.991	0.322
Ha and Y.Y Ng 2017	0.064	0.178	0.032	-0.286	0.413	0.357	0.721
Yang et al., 2020 (Freestyle rope skipping)	0.448	0.381	0.145	-0.299	1.195	1.175	0.240
Yang et al., 2020 (Standard jump rope)	0.122	0.377	0.142	-0.618	0.861	0.322	0.747
	0.155	0.126	0.016	-0.093	0.402	1.223	0.221

Statistics for each study

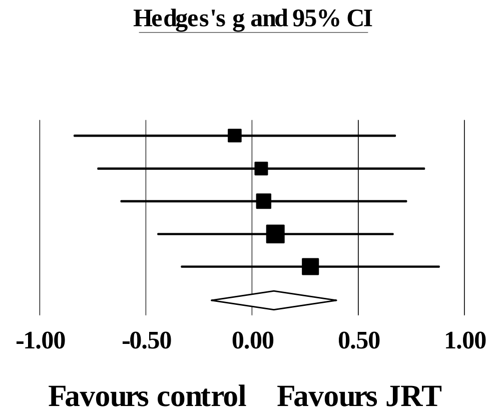
Hedges's g and 95% CI



Electronic Supplementary Material Figure S6. Forest plot of bone mass changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Arett and Lutz 2002 (HV)	-0.082	0.387	0.150	-0.841	0.677	-0.211	0.833
Arett and Lutz 2002 (LV)	0.043	0.394	0.155	-0.730	0.816	0.109	0.913
Bellver et al., 2021	0.055	0.345	0.119	-0.620	0.731	0.160	0.873
Kim et al., 2020	0.110	0.284	0.081	-0.447	0.667	0.388	0.698
Sung et al., 2018	0.275	0.311	0.097	-0.336	0.885	0.882	0.378
	0.099	0.150	0.023	-0.195	0.394	0.661	0.509

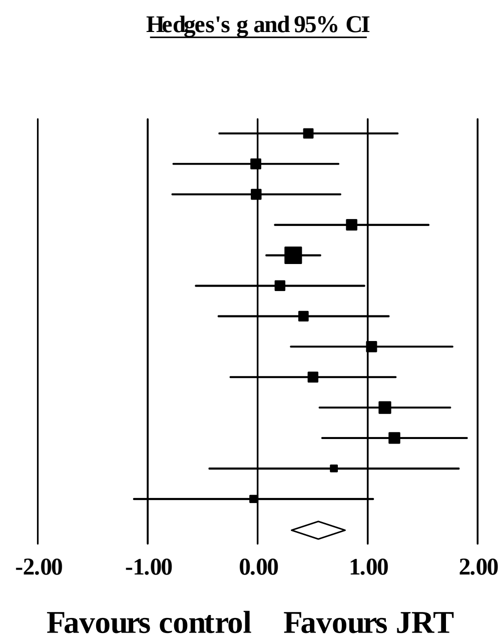
(Statistics for each study)



Electronic Supplementary Material Figure S7. Forest plot of lean mass changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

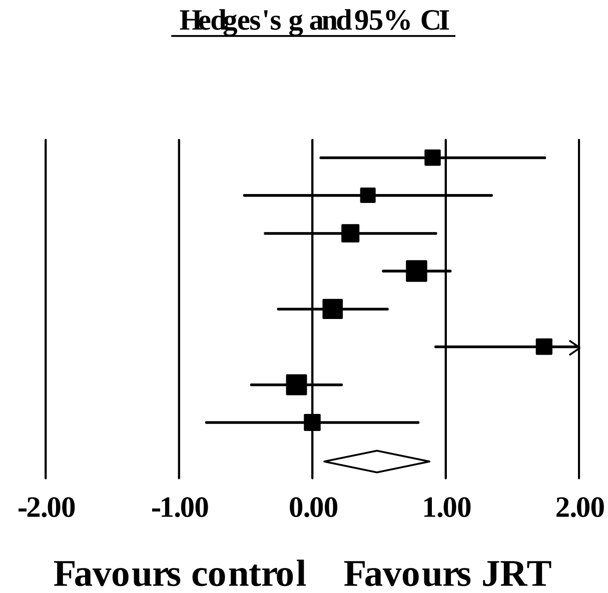
Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Arazi 2016	0.461	0.418	0.175	-0.357	1.280	1.105	0.269
Arett and Lutz 2002 (HV)	-0.016	0.387	0.150	-0.775	0.742	-0.042	0.966
Arett and Lutz 2002 (LV)	-0.013	0.394	0.155	-0.785	0.760	-0.032	0.974
Bellver et al., 2021	0.855	0.361	0.130	0.148	1.562	2.369	0.018
Eler and Acar 2018	0.323	0.130	0.017	0.069	0.577	2.495	0.013
Eskandari 2020 (White Chocolate)	0.203	0.395	0.156	-0.571	0.978	0.514	0.607
Eskandari 2020 (Dark Chocolate)	0.417	0.399	0.159	-0.364	1.199	1.047	0.295
Ghorbanian 2013	1.037	0.380	0.144	0.293	1.781	2.731	0.006
Kim et al., 2007	0.503	0.387	0.150	-0.256	1.262	1.300	0.194
Kim et al., 2020	1.157	0.308	0.095	0.554	1.760	3.762	0.000
Sung et al., 2018	1.245	0.340	0.115	0.579	1.911	3.664	0.000
Colakoglu 2017 (Weighted Rope)	0.694	0.583	0.340	-0.448	1.836	1.191	0.234
Colakoglu 2017 (Standard Rope)	-0.038	0.559	0.313	-1.134	1.057	-0.069	0.945
	0.545	0.124	0.015	0.302	0.788	4.391	0.000

(Statistics for each study)



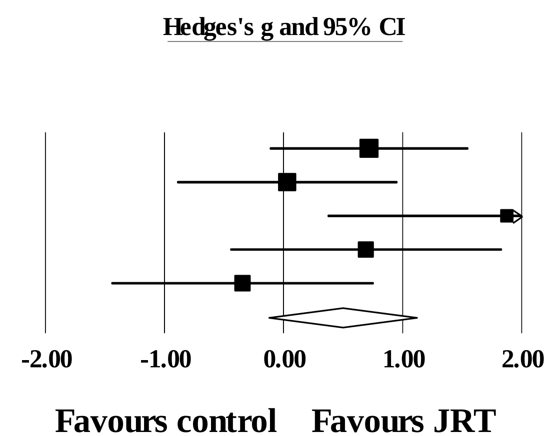
Electronic Supplementary Material Figure S8. Forest plot of body fat changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Arazi 2016	0.904	0.434	0.188	0.053	1.754	2.083	0.037
Chen et al., 2011	0.417	0.478	0.229	-0.520	1.355	0.872	0.383
Cinar Medini et al., 2019	0.287	0.332	0.110	-0.364	0.938	0.863	0.388
Eler and Acar 2018	0.783	0.134	0.018	0.522	1.045	5.865	0.000
Garcia-Pinillos 2020	0.153	0.214	0.046	-0.266	0.573	0.716	0.474
Ghorbanian 2013	1.739	0.420	0.177	0.915	2.562	4.137	0.000
Ha and Y.Y Ng 2017	-0.119	0.178	0.032	-0.468	0.231	-0.666	0.506
Kusuma et al., 2018	0.000	0.410	0.168	-0.804	0.804	0.000	1.000
	0.477	0.201	0.041	0.082	0.872	2.368	0.018



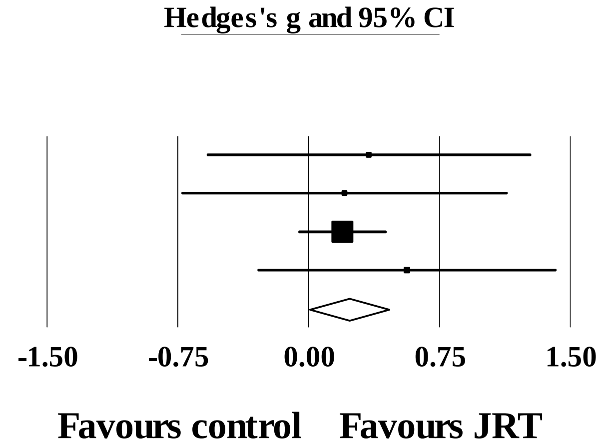
Electronic Supplementary Material Figure S9. Forest plot of endurance (cardiorespiratory) changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Arazi 2016	0.718	0.426	0.181	-0.116	1.553	1.687	0.092
Chen et al., 2011	0.031	0.473	0.224	-0.896	0.957	0.065	0.948
Chen et al., 2012	1.875	0.768	0.590	0.369	3.381	2.440	0.015
Colakoglu 2017 (Weighted Rope)	0.692	0.583	0.339	-0.450	1.834	1.188	0.235
Colakoglu 2017 (Standard Rope)	-0.345	0.563	0.317	-1.449	0.759	-0.613	0.540
	0.493	0.317	0.100	-0.127	1.114	1.557	0.119



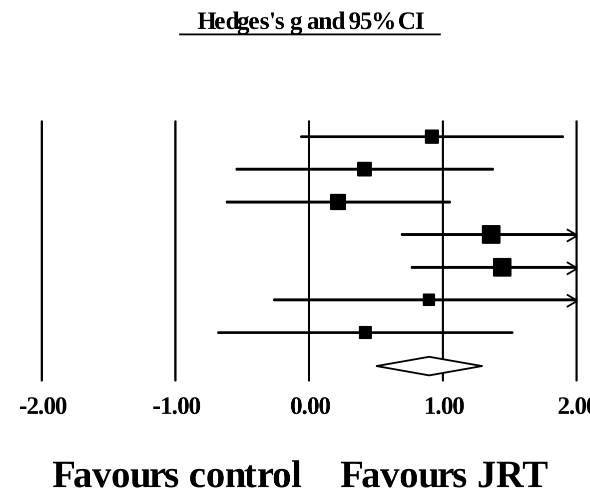
Electronic Supplementary Material Figure S10. Forest plot of endurance (local) changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Anrett and Lutz 2002 (HV)	0.345	0.475	0.225	-0.585	1.276	0.727	0.467
Arrett and Lutz 2002 (LV)	0.206	0.477	0.228	-0.730	1.142	0.432	0.666
Eler and Acar 2018	0.194	0.129	0.017	-0.059	0.447	1.504	0.133
Masterson and Brown 1993	0.564	0.437	0.191	-0.294	1.421	1.289	0.198
	0.230	0.116	0.013	0.002	0.457	1.979	0.048



Electronic Supplementary Material Figure S11. Forest plot of strength (lower-body) changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

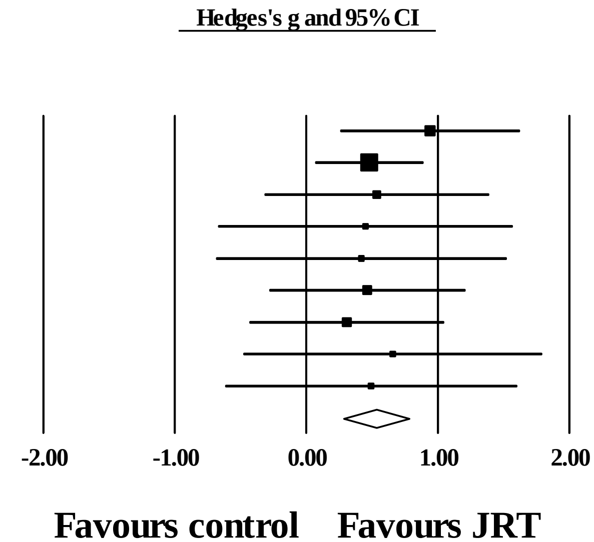
Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Duzgun 2010 (Weighted rope)	0.919	0.503	0.253	-0.068	1.906	1.826	0.068
Duzgun 2010 (Unweighted rope)	0.415	0.493	0.243	-0.551	1.381	0.842	0.400
Masterson and Brown 1993	0.218	0.430	0.185	-0.624	1.060	0.507	0.612
Yang et al., 2020 (Freestyle rope skipping)	1.362	0.345	0.119	0.685	2.039	3.944	0.000
Yang et al., 2020 (Standard jump rope skipping)	1.444	0.349	0.122	0.759	2.129	4.133	0.000
Colakoglu 2017 (Weighted Rope)	0.897	0.594	0.353	-0.268	2.061	1.509	0.131
Colakoglu 2017 (Standard Rope)	0.420	0.565	0.319	-0.688	1.527	0.743	0.457
	0.891	0.201	0.041	0.497	1.286	4.428	0.000



Electronic Supplementary Material Figure S12. Forest plot of strength (upper-body) changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Cinar Medini et al., 2019	0.941	0.349	0.122	0.257	1.625	2.695	0.007
Garcia-Pinillos et al., 2021	0.479	0.211	0.045	0.065	0.892	2.269	0.023
Masterson and Brown 1993	0.536	0.437	0.191	-0.320	1.391	1.227	0.220
Turgut et al., 2016 (Weighted jump rope)	0.450	0.573	0.328	-0.672	1.573	0.786	0.432
Turgut et al., 2016 (Standard jump rope)	0.419	0.565	0.319	-0.688	1.526	0.742	0.458
Yang et al., 2020 (Freestyle rope skipping)	0.464	0.382	0.146	-0.284	1.212	1.216	0.224
Yang et al., 2020 (Standard jump rope)	0.308	0.379	0.144	-0.435	1.051	0.813	0.416
Colakoglu 2017 (Weighted Rope)	0.657	0.581	0.338	-0.481	1.796	1.132	0.258
Colakoglu 2017 (Standard Rope)	0.493	0.567	0.322	-0.619	1.604	0.868	0.385
	0.529	0.127	0.016	0.280	0.778	4.163	0.000

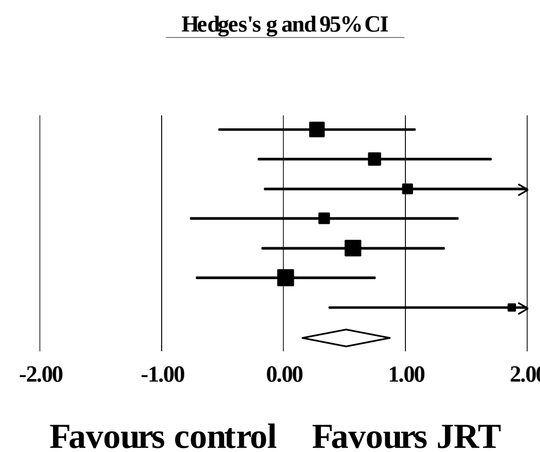
(Statistics for each study)



Electronic Supplementary Material Figure S13. Forest plot of jump performance changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

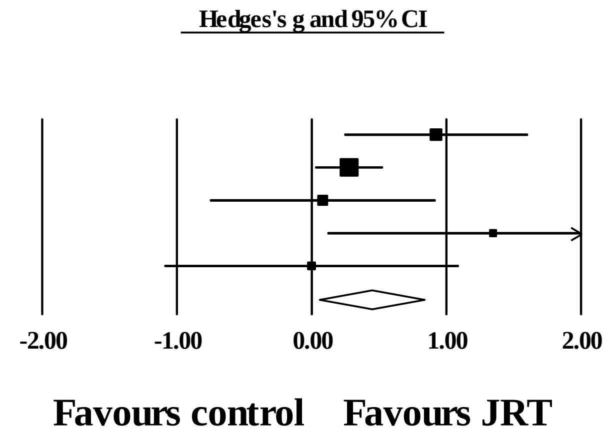
Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Arazi 2016	0.275	0.414	0.171	-0.536	1.086	0.664	0.506
Chen et al., 2011	0.749	0.491	0.241	-0.213	1.711	1.525	0.127
Turgut et al., 2016 (Weighted jump rope)	1.019	0.602	0.363	-0.162	2.199	1.692	0.091
Turgut et al., 2016 (Standard jump rope)	0.334	0.563	0.317	-0.769	1.437	0.593	0.553
Yang et al., 2020 (Freestyle rope skipping)	0.571	0.384	0.147	-0.182	1.323	1.486	0.137
Yang et al., 2020 (Standard jump rope)	0.018	0.377	0.142	-0.720	0.757	0.049	0.961
Chen et al 2012	1.875	0.768	0.590	0.369	3.381	2.440	0.015
	0.507	0.183	0.033	0.148	0.865	2.770	0.006

(Statistics for each study)



Electronic Supplementary Material Figure S14. Forest plot of range of motion changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Cinar Medini et al., 2019	0.924	0.348	0.121	0.242	1.607	2.653	0.008
Eler and Acar 2018	0.279	0.129	0.017	0.025	0.532	2.154	0.031
Masterson and Brown 1993	0.083	0.429	0.184	-0.757	0.922	0.193	0.847
Turgut et al., 2016 (Weighted jump rope)	1.348	0.629	0.395	0.116	2.580	2.144	0.032
Turgut et al., 2016 (Standard jump rope)	0.000	0.559	0.312	-1.096	1.096	0.000	1.000
	0.443	0.199	0.040	0.053	0.833	2.226	0.026



Electronic Supplementary Material Figure S15. Forest plot of linear sprint changes in participants after jump rope training (JRT) compared to controls. Forest plot values shown are effect sizes (Hedges' g) with 95% confidence intervals (CI).