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Jump Rope Training for Health and Fitness in School-age Participants: Secondary Analyses from a Systematic Review

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ABSTRACT

Background: Altering moderator variables during a jump rope training (JRT) program can provide a novel training modification that can be used to modify the specific training outcomes. JRT is commonly implemented as a traditional game activity in many countries as an old culture of physical activity in school-age participants (SAP). However, strength and conditioning professionals need to know how JRT moderator variables affect these health- and physical fitness outcomes. Thus, an evidence-gap map (EGM) could provides a clearer picture of the design of an appropriate JRT based on scientific evidence. **Objective:** the purpose of this systematic review secondary analysis was to assess the moderator variables related to JRT effectiveness for health and physical fitness-related outcomes in SAP. **Method:** literature searches were conducted in the following electronic databases: PubMed, Web of Science and SCOPUS. The PICOS (participants, intervention, comparators, outcomes, and study design) approach was used to rate studies for eligibility. An EGM was constructed to graphically represent the body of evidence and the current research gaps. **Results:** 10,546 records were initially identified and finally, 8 studies were considered. A total of 186 participants were analysed in the intervention groups (16 groups). Five of Eight studies measured health-related parameters and five of eight included fitness-related parameters. **Conclusion:** rope weight (e.g., weighted rope i.e. 695 g), adequate post-exercise recovery strategies (e.g., dark chocolate supplementation), type of jump (e.g., freestyle), and total number of jumps, can be manipulated into JRT programs to optimise health and physical related capacities among SAP.

Key words: Plyometric Exercise, Musculoskeletal And Neural Physiological Phenomena, Human Physical Conditioning, Movement, Muscle Strength, Resistance Training

INTRODUCTION

The World Health Organization is primarily concerned with promoting the health and well-being of school-age children by encouraging their participation in regular physical activities (Chaput et al., 2020). Along with fitness, health conditions can be improved through planned, structured and repetitive form of physical activity (Caspersen et al., 1985) which in turn, could provide school aged participants (SAP) with a competitive edge during sporting activities (Faigenbaum & Myer, 2010; Zwolski et al., 2017). For example, a study by Arnason et al. (2004) showed that football teams with higher heights during countermovement jumps (CMJ) were most successful within divisions (Arnason et al., 2004). Therefore, coaches and practitioners usually use different methods to improve sports-related physical fitness. However, access to the required facilities to the participants might be limited due to several factors such as limited availability of equipment, space, or time. This problem was futher exacerbated during the pandemic where people were asked to stay indoors and train home (Gentil et al., 2020). For these reasons, scientists are exploring various training modalities that will help SAP maintain their respective health and good physical fitness during these tough situations (Anand, 2021). Thus, training methods that prioritize jump exercises offer certain benefits over other approaches, as they are cheaper, can be done in a

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limited physical area, and are often viewed as funnier (Chu & Myer, 2013; Gentil et al., 2020; Ward et al., 2007).

Jump rope training (JRT) has been demonstrated to be safe, efficient and accessible form of exercise that is accessible to everyone. In fact, JRT is also a traditional game in many countries as part of their old culture of physical activity in SAP (Goodwin, 1985). Many benefits such as improved cardiovascular fitness, endurance tests, balance, motor control, bone health-related markers, etc are attributed to JRT programs (García-Pinillos, F., Lago-Fuentes, C., Latorre-Román, P. A., Pantoja-Vallejo, A., & Ramirez-Campillo, R., 2020; Hamid et al., 2016). Literature has shown the various methods in which SAP with intellectual impairments could use JRT and reap the above-mentioned benefits (Chen, Chao-Chien & Chen, C. C., & Lin, Y. C, 2012). Consequently, JRT could be effective in incorporating all types of populations, from children to older adults (Singh, U., Ramachandran, A. K., Ramirez-Campillo, R., Perez-Castilla, A., Afonso, J., Manuel Clemente, F., & Oliver, J., 2022; Sortwell et al., 2021). Even well-trained individuals can significantly improve their fitness by 10-20 minutes of JRT per week (García-Pinillos, F., Lago-Fuentes, C., Latorre-Román, P. A., Pantoja-Vallejo, A., & Ramirez-Campillo, R., 2020). Furthermore, 12 weeks of JRT seems to be effective in improving health markers (e.g., body fat percent, waist circumference, systolic blood pressure, blood glucose, insulin levels, and homeostatic model assessment of insulin resistance) in obese adolescent girls (Kim, J., Son, W. M., Headid III, R. J., Pekas, E. J., Noble, J. M., & Park, S. Y., 2020). In addition, simulating jumping without a rope for eight weeks, three sessions per week, have shown to improve the lower extremity strength and punching performance of amateur-level school boxers (Chottidao, M., Kuo, C. H., Tsai, S. C., Hwang, S., Lin, J. J., & Tsai, Y. S., 2022). However, the training factors to consider for programming JRT such as training intensity or volume are not well described in the literature (Krzysztofik et al., 2019). Thus, it would be interesting to investigate further for more robust JRT recommendations due to the different characteristics of this type of training.

Because of these factors, a wide array of JRT moderator variables are available to physical conditioning coaches to facilitate the optimization of training. Although there is a reasonable amount of scientific literature regarding the effects of the JRT (Jahromi & Gholami, 2015; Singh, et al., 2022; Trecroci et al., 2015), considering the myriad of JRT moderator variables, likely, a majority of the JRT variables that could be incorporated into a training programme have not been properly investigated. Further, most JRT studies involved only small samples of participants (i.e., n = 10) or did not involve enough JRT in their training method (i.e., less than 50%) (Ache-Dias et al., 2015; Albers & Lewis, 2020; Sekhon & Maniazhagu, 2018). In this sense, an alternative research approach to better analyse the effect of moderator variables around JRT may involve a systematic literature review.

A recent systematic review with meta-analysis regarding JRT effects on the physical fitness of young participants identified 21 moderate to high-quality studies involving 1,021 participants (Singh et al., 2022). However, to the best of the authors' knowledge, no systematic review has yet endeavoured to provide a summary of the current literature available on the JRT moderator variables among SAP. A systematic review may provide more evidence and help coaches to prescribe JRT on evidence-based information. In addition, the systematic review could also detect gaps in the literature about JRT methodologies. Specifically, scoping reviews perform a systematic mapping of existing evidence not focusing on results or comparisons (Peters et al., 2022). These scoping reviews provide a suitable and systematic approach to build an evidence-gap map (EGM). EGMs graphically represent the body of evidence, conveying an intuitive visual interpretation of research efforts allocation, indicating where are more or less scientific evidence (Miake-Lye et al., 2016). A systematic review with EGM will provide a clearer picture of what is known and unknown about JRT moderator variables. In addition, a systematic review could provide a determination of pooled results or analytical comparisons to measure how each moderator variable was beneficial. Therefore, the main objective of this systematic review secondary analysis was to evaluate the moderator variables related to JRT effectiveness for health and physical fitness-related outcomes in SAP.

METHODS

Procedures

This systematic review secondary analysis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009), and adapted *a posteriori* (Page et al., 2021). This study was registered in PROSPERO with the number CRD42021273198.

Literature Search

The method (code line) used to search in each database and the search history are described in Electronic Supplementary Material Table S1. The electronic databases utilized were: PubMed, Web of Science and SCOPUS. Initially, a search was conducted in April 2017. One of the authors (RRC) created an account in each database to receive updates through he received automatically generated email updates regarding the search terms used. The search was refined in May 2019, June 2021, and August 2021, with daily updates if available, and studies were eligible for inclusion up to September 2021. The same author (RRC) conducted the initial search and removed duplicates, and subsequently, the search results were analysed based on the eligibility criteria (Table 1).

Following double screening study selection (Waffenschmidt et al., 2019), one experienced researcher (RRC) independently screened the titles, abstracts, and full texts of the retrieved studies, with a second author (ED) confirming. Potential discrepancies between the two authors regarding inclusion and exclusion criteria (e.g., intervention adequacy) were resolved through consensus with a third author (RKT) during the search and review process. Reference lists were analysed from selected articles to be included to identify any additional relevant studies.

Table 1. Selection criteria used in the systematic scoping review

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	Studies comparing different jump rope training approaches (e.g., different volume) without active or traditional control group will also be considered.	Only one experimental training 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	Single- or multi-arm, randomized [parallel, crossover, cluster, other] or non-randomized.	Observational studies, case reports, special communications, letters to the editor, invited commentaries, errata, studies with doubtful quality or unclear peer-review process from the journal, overtraining studies and detraining studies.

Thereafter, the list of included articles and the inclusion criteria were sent to two independent world experts in the physical fitness field and JRT to help identify additional relevant articles. Our search strategy was kept from the experts to prevent them from being influenced in their own searches. After completing all the aforementioned steps, the databases were reviewed again to search for any errata or retractions related to the studies included in the analysis.

Inclusion and Exclusion Criteria

The eligibility of studies was assessed using a PICOS (participants, intervention, comparators, outcomes, and study design) approach for rating them (Liberati et al., 2009). Our inclusion/exclusion criteria have been described in detail in Table 1.

To conduct our systematic scoping review, only included full-text, original studies that were peer-reviewed. Books, book chapters, congress abstracts, cross-sectional and review papers, or training-related studies that did not specifically investigate the effects of JRT exercises that use a rope and jump training without the use of a rope were excluded. The following types of studies were excluded from the analysis: retrospective studies, prospective studies with long follow-up periods, studies where the description of JRT exercise was unclear, studies with only abstract available, case reports, special communications, letters to the editor, invited commentaries, errata, studies with questionable quality or unclear peer-review process from the journal (Grudniewicz et al., 2019), overtraining studies, and detraining studies. These were considered for inclusion if involved a training period prior to a detraining period. Given 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, Spanish, German and Portuguese (e.g., authors native languages), were considered for this systematic scoping review. The Electronic Supplementary Material Table S2 provides information about exclusion reasons for studies in the preliminary qualitative synthesis.

Data Extraction

We sought to analyse the different moderator variables of JRT and how these effects may reflect on different health- and physical fitness attributes. Being a systematic scoping review, data refers to study characteristics and their outcomes but does not include the actual data results derived from specific tests-measurements. All data was coded into a specifically designed Microsoft® Excel worksheet. However, a simple extraction of measurement and the effect of experimental group of each study was reported with the aim to show the potential of each moderator variable effect. If relevant data or contextual information was missing, an email was sent to the studies' authors to get in touch with them, and a three-week waiting period was granted for the response (including a reminder after the first two weeks). The study was excluded if there was no response from the authors. If the missing information was not integral to the eligibility criteria, the study will be included in the review.

Data Items

The following information was retrieved from the included studies

1) Participant-related information: sample size, age, sex, sport, fitness level, body mass, height and previous experience with JRT.
2) Intervention-related information: focused on chronic adaptations; intervention length, JRT moderator variables (e.g., frequency, duration, rope weight, type of jumps, total dose, rest between sets and sessions, progressive overload, shoes and nutrition).

3) Comparators: two JRT groups, with the only difference between groups being a training prescription variable (e.g., number of total jumps; training intensity).
4) Outcomes: all outcomes that showed studies included were analysed: health parameters (e.g., bone mineral density, calcaneus stiffness index, etc.) and fitness related, (e.g., CMJ height, anaerobic power, agility, strength, etc). Considering the goal of providing a systematic review secondary analysis with EGM, outcomes will be registered, but their results will only show as a simple synthesis.

Data extraction was carried out by a single author (RRC) while the other author (RKT) verified the data, and if there were any differences, they were resolved through agreement with a third author (ED).

Data Management and Synthesis Methods

A narrative synthesis was performed along with data summaries (e.g., number, percentage) for the previously defined data items in order to provide an overview of the existing body and the corresponding gaps in research. An EGM will be constructed to graphically represent the body of evidence and intuitively convey an overview of the existing evidence and the current research gaps (Schuller-Martínez et al., 2021; Snilstveit et al., 2016). Table 2 presents a provisional EGM with the characteristics of moderator variables of JRT, which may be subject to changes during the review process.

RESULTS

Study Selection

Figure 1 provides a graphical schematisation of the study selection process carried out following the PRISMA guidelines of the current secondary analysis from a systematic review. A total of 10,546 records were initially found through database searching. After the qualitative synthesis process, 51 studies were included in this systematic review secondary analysis. However, out of the 51 studies, 45 full texts were eliminated (exclusion reasons in Electronic Supplementary Material Table S2). Two studies were included searching through reference lists and searching for new information. Finally, eight studies were considered for the systematic review secondary analysis (Arnett & Lutz, 2002; Colakoglu et al., 2017; Duzgun et al., 2010; Eskandari et al., 2020; Ozer et al., 2011; Reaper et al., 1996; Turgut et al., 2016; Yang et al., 2020).

Study Characteristics

The experimental participant characteristics, the JRT moderator variables, measurements and effects are summarised in Table 2. The details regarding the characteristics of control groups are provided in Table 3; these were not considered for this systematic scoping review analysis.

The intervention groups were composed of a total of 186 participants (16 groups). Two studies used a male sample (n = 50) (Eskandari et al., 2020; Hooshmand Moghadam et al., 2021), five used female participants (n = 96) (Arnett & Lutz, 2002; Colakoglu et al., 2017; Duzgun et al., 2010; Ozer et al., 2011; Turgut et al., 2016) and only one included participants of both genders (n = 40) (Yang et al., 2020). The participants' chronological ages were between 13 years and 17 years. Two studies were carried out by overweight subjects (87.7kg – 89.7kg) (Eskandari et al., 2020; Hooshmand Moghadam et al., 2021), while the rest used regular young participants weighted between 57.1kg

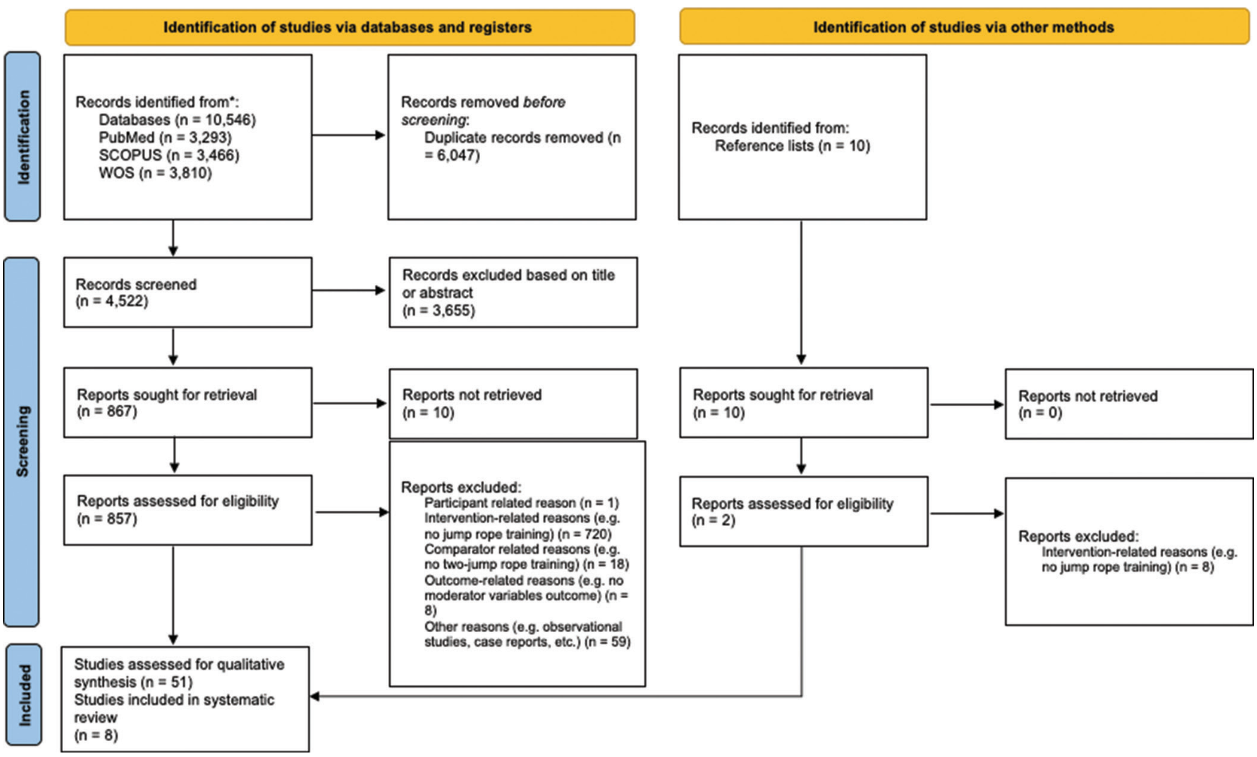

Figure 1. Flow chart illustrating the study selection process

Table 2. Description of studies included

Study	Sample (gender, nº, age, weight, height)	Freq	Dur (weeks)	Rope weight	Type of jumps	Total dose	Between-set rest (s)	Between-sessions rest (h)	Progressive overload	Supplementation	Measurement	Effect
(Arnett & Lutz, 2002)	F/13/14.9/57.1kg/ 164.3cm	4	16	NR	Jump rope	320 min	NA	NR	Int (weighted vest)	NR	Calcaneus stiffness index, body mass, body fat, bone mineral content and peak torque	→←
	F/12/14.6/58,7kg/ 164.5cm	4	16	NR	Jump rope	640 min	NA	NR	Int (weighted vest)	NR		↑
(Colakoglu et al., 2017)	F/9/14.6/59.3kg /166cm	3	12	160 g	Jump rope	1620 s	30-60	NR	V	NR	Body composition, strength, medicine ball test, sit-up and push-up tests	↑
	F/8/15/60.1kg/ 166.4cm			695 g	Jump rope	1620 s	30-60	NR	V	NR		↑↑
(Duzgun et al., 2010)	F/9/15/59.4kg/ 166cm	3	12	160 g	Jump rope	3105 s	30-60	NR	V	NR	Shoulder isokinetic strength	↑
	F/10/14,1/57.7kg/ 165cm	3	12	695 g	Jump rope	3105 s	30-60	NR	V	NR		↑↑
(Eskandari et al., 2020)	M/12/15.4/87.7kg/ 165.9cm	5	6	NR	Jump rope	11,190 jumps	30	24	V, Int (jump rate)	White chocolate	Inflammatory Adipokine, Cytokine Concentrations, and Body Composition	↑
	M/12/15.4/89.7kg/ 165.9cm	5	6	NR	Jump rope	11,190 jumps	30	24	V, Int (jump rate)	Dark chocolate		↑↑
(Hooshmand Moghadam et al., 2021)	M/13/15/87.7kg/ 165.5cm	5	6	NR	Jump rope	11,190 jumps	30	24	V, Int (jump rate)	White chocolate	Antioxidant markers, body mass, and body mass index	↑
	M/13/15/89.7kg/ 166.2cm	5	6	NR	Jump rope	11,190 jumps	30	24	V, Int (jump rate)	Dark chocolate		↑↑
(Ozer et al., 2011)	F/9/15/59.4kg/ 166cm	3	12	695g	Jump rope	3240s	30-60	NR	V	NR	Strength, coordination and proprioception	↑↑
	F/9/14.1/57.7kg/ 165cm	3	12	160g	Jump rope	3240s	30-60	NR	V	NR		↑
(Turgut et al., 2016)	F/8/15/59.4kg/ 167cm	3	12	600-695g	Jump rope	5490s	30-60 (1:1 work/ rest ratio)	NR	V	NR	Vertical jump, speed, agility and flexibility	↑↑
	F/9/14.1/57.7kg/ 165cm	3	12	100-160g	Jump rope	5490s	30-60 (1:1 work/ rest ratio)	NR	V	NR		↑
(Yang et al., 2020)	Mix/20/13.4/ NR/ NR	3	12	NR	Jump rope-freestyle	2460- 2640 steps	NR	48-72	Technique	NR	Strength, flexibility, body composition and BMD	↑↑
	Mix/20/13.5/ NR/ NR	3	12	NR	Jump rope-traditional	2460- 2640 steps	NR	48-72	Technique	NR		↑

F: female; M: male; Mix: male and female; ↑: improvement; ↑↑: improvement with respect to the other EG; →←: no improvement with respect to control group; BMD: bone mineral density; NR: not reported; NA: not applicable; PJT; plyometric jump training; * included only variables that improved with JRT

Table 3. Characteristics of control groups

Study	n	Sex	Age (y)	Body mass (kg)	Height (cm)	Activity
(Arnett & 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.
(Colakoglu et al., 2017)	8	F	14.4	50.6	161.2	Technical training program for three days a week for twelve weeks.
(Duzgun et al., 2010)	7	F	14.4	50.0	161.0	Volleyball training only.
(Eskandari et al., 2020)	12	M	15.4	90.2	165.9	Not mentioned.
(Hooshmand Moghadam et al., 2021)	12	M	15.0	90.2	164.3	Maintained normal lifestyle.
(Ozer et al., 2011)	7	F	14.4	50.0	161	Volleyball training program only.
(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.

and 60.1kg. Only one study did not report the height and weight of participants (Yang et al., 2020). Four of the eight studies samples were in volleyball players (Colakoglu et al., 2017, 2017; Duzgun et al., 2010; Ozer et al., 2011; Turgut et al., 2016), two were healthy participants without involvement in sports (Arnett & Lutz, 2002; Yang et al., 2020) and two samples were overweight (Eskandari et al., 2020; Hooshmand Moghadam et al., 2021).

Five of seven studies measured health-related parameters (calcaneus stiffness index, inflammatory adipokine, cytokine concentrations, body composition, bone mineral density and antioxidant markers) (Arnett & Lutz, 2002; Colakoglu et al., 2017; Eskandari et al., 2020; Hooshmand Moghadam et al., 2021; Yang et al., 2020) and five of eight included fitness-related parameters (shoulder isokinetic strength, hand grip strength, medicine ball javelin test, sit-up, push-ups, motor coordination, proprioception, strength and endurance of lower extremities, speed, anaerobic power, flexibility and standing long jump) (Colakoglu et al., 2017; Duzgun et al., 2010; Ozer et al., 2011; Turgut et al., 2016; Yang et al., 2020).

Moderator Variables

Figure 2 provides an EGM of JRT variables moderators analysed in the scientific literature. Not one literature study compared different experimental groups on training frequency, training duration, rest between sets, rest between sessions, or progressive overload during training.

Rope weight

Four studies provided data on rope weight (Colakoglu et al., 2017; Duzgun et al., 2010; Ozer et al., 2011; Turgut et al., 2016). The total experimental sample was 71 female volleyball players sampled in 8 different groups. Three studies compared 160g versus 695g rope weight (Colakoglu et al., 2017; Duzgun et al., 2010; Ozer et al., 2011), and another one used a 100 or 160g versus 600 or 695g depending on the length of the rope (Turgut et al., 2016). The training frequency and the duration of the intervention were the same in all studies, three and 12, respectively. The health-related measure was body composition (Colakoglu et al., 2017) and the physical fitness measures were hand-grip strength, 30 seconds sit-ups, 30 seconds push-ups, standing long jump, sergeant jump and medicine ball javelin test (Colakoglu et al., 2017), 180 and 60°/s on external and internal rotators, supraspinatus peak torque, total work of the dominant shoulder (Duzgun et al., 2010), motor coordination, proprioception, strength and endurance of lower extremities (Ozer et al., 2011), vertical jump test, 30-meter sprint test, hexagonal obstacle test, zigzag test and sit and reach test (Turgut et al., 2016).

Supplementation

Two studies provided data about the nutrition supplementation during JRT, comparing white chocolate versus dark chocolate supplementation during mid-afternoon snack (Eskandari et al., 2020). The total experimental sample was 50 overweight young males (87.7kg – 89.7kg). The measures were health-related about inflammatory adipokine, cytokine concentrations, serum concentrations of superoxide dismutase, total antioxidant capacity, glutathione peroxidase, thiobarbituric acid reactive substances and body composition.

Type of jumps

One study provided data about the type of jumps, comparing traditional JRT with freestyle JRT (Yang et al., 2020). The total experimental sample was 40 non-athlete middle school children. The total dose, training frequency and the rest of the moderator variables were same for both the groups. The conventional JRT approach prioritized individual frequency and speed, while the freestyle JRT approach emphasized team performance and the enjoyment of participating with peers. The health-related measures were body composition and bone mineral density and the physical fitness measures were standing long jump, hand grip and toe-touch test.

Total dose

One study provided data about the total training dose of JRT, comparing a total of 320 minutes versus 640 minutes

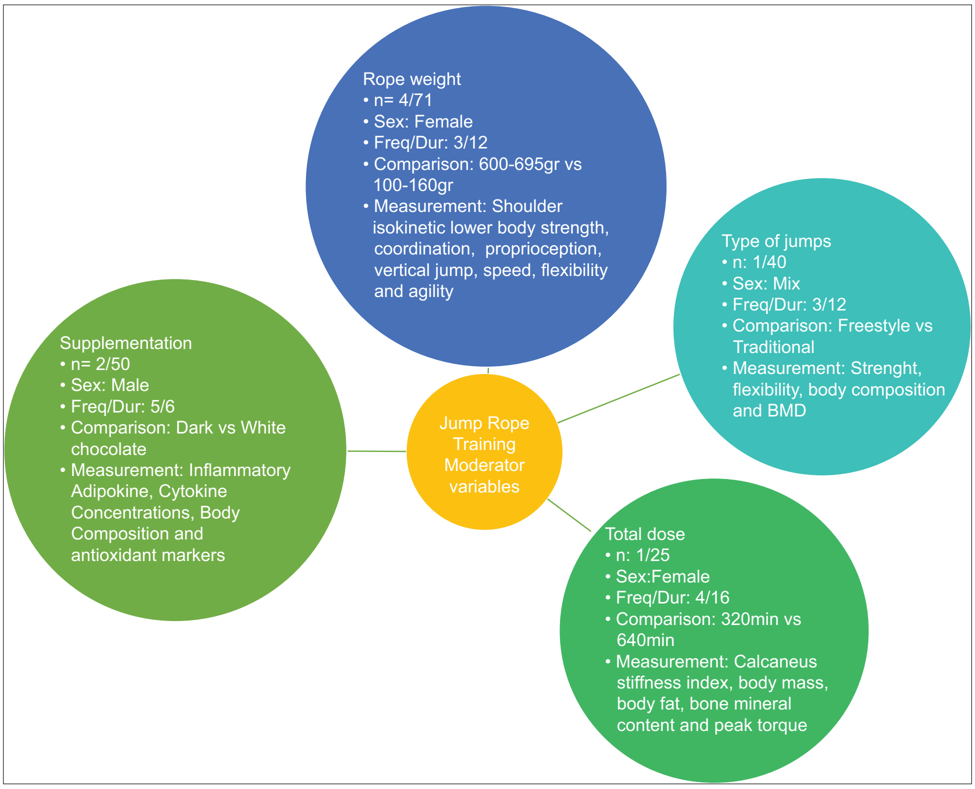

Figure 2. Overview of available experimental literature analysing relevant jump rope training programming factors in school-age participants. Note: bubble sizes are relative to total sample size (n = number of studies/total sample size)

(Arnett & Lutz, 2002). The total experimental sample was 25 young non-athletic females. The rest of the moderator variables were the same for both groups. Training frequency was 4 days per week for 16 weeks with a rate of 50 jumps per minute for 5 or 10 minutes. The measures of health-related were: calcaneus stiffness index, body mass, body fat and bone mineral content. The unique measure of physical fitness was the peak muscle torque of the right knee extensors.

DISCUSSION

This systematic review's primary secondary analysis aimed to assess the moderator variables related to JRT effectiveness for health and physical fitness-related outcomes in SAP. From analysis of 8 studies and 186 participants, scientific literature about JRT provides quality information about four moderator variables namely: jump rope weight (4 studies), supplementation (2 studies), type of jumps (1 study) and total dose (1 study). Our results showed that two of eight studies only showed health-related outcomes, three only physical fitness outcomes and three measured both health and physical fitness-related effects.

Rope Weight

Our systematic review secondary analysis revealed four studies that compared the rope weight as a moderator variable for JRT. This comprises 50% of the studies and 38.2% of the sample analysed in this study. The primary comparison was between 160g and 696g in majority of the studies included. Only the Turgut et al. (2016) study varied the rope weight between 100 and 160g or 600 and 695g depending on the length of the rope (Turgut et al., 2016). The sample of the four studies were homogeneous and was conducted in female volleyball players between 13 and 16 years old. The training frequency and program duration were 3 days/week for 12 weeks respectively. Thus, the conclusions about rope weight could be a lot of precise for this type of population.

Body composition was assessed by Colakoglu et al. (2017), decrease in the body was reported for the JRT groups compared to the control group, but not between the weighted and non-weighted rope jump groups. In spite of JRT providing significant health benefits through a reduction in body fat (Kim, J., Son, W. M., Headid III, R. J., Pekas, E. J., Noble, J. M., & Park, S. Y., 2020; Singh, U., Ramachandran, A. K., Ramirez-Campillo, R., Perez-Castilla, A., Afonso, J., Manuel Clemente, F., & Oliver, J., 2022; Sung et al., 2019), rope weight seems ineffective to moderate such an effect.

Regarding physical-fitness-related related to rope weight, each study assessed different abilities. With respect to strength, Duzgun et al. (2010) concluded that weighted JRT program potentially increase the effectiveness the strength levels in shoulder external for volleyball players (Duzgun et al., 2010). These results are in line with Lee (2003), who suggested that weighted JRT would improve upper body strength (Lee, 2003). In addition, Masterson and Brown (1993) showed that increased rope weight during training weeks improves lower and upper body strength, assessed by leg press and bench press one repetition maximum (Masterson & Brown, 1993). However, only a few differences were found between weighted JRT versus non-weighted JRT. For example, Colakoglu et al. (2017) reported no significant differences between JRT programs with 695g versus 160g rope in push-ups, sit-ups, handgrip strength or medicine ball javelin test, but the weighted group improved more respect to the control group (Colakoglu et al., 2017). Likewise, Ozer et al. (2011) reported no significant differences for lower limb strength in weighted group (Ozer et al., 2011). However, they found advantages in favour of the weighted JRT group for coordination and eccentric endurance parameters measured by the monitored squat system. Thus, because the strength and movements seem to be a task-specific (Boettcher et al., 2010; Travis et al., 2020), the JRT seems to be the same way. In a study by Turgut et al. (2016), weighted JRT resulted in higher improvements in CMJ and agility (measured by the zigzag test) (Turgut et al., 2016). However, the agility results could be affected by the type of test, because the same sample exhibited no differences when the hexagonal obstacle test was performed to assess agility. From a biomechanical perspective, weighted rope provides more mechanical load, demands, and muscular work than standard rope. Thus, 695g of rope weight may not be enough to improve supraspinatus muscle strength or hypertrophy (Duzgun et al., 2010), but seems to be more effective than 160g rope in enhancing lower limb coordination, vertical jump and shoulder external rotation in young female volleyball players.

Supplementation

Our systematic review secondary analysis revealed two studies that compared the supplementation weight moderator variable of JRT. This comprises 25% of the studies and 26.9% of the sample analysed in this study. The main comparison was between dark chocolate and white chocolate in obese young children. The sample of the two studies was homogeneous: males with obesity, between 13 to 17 years old. The two studies used a training frequency of 5 days/week for 6 weeks (Eskandari et al., 2020; Hooshmand Moghadam et al., 2021).

These two studies analysed the health-related markers but not the physical fitness related outcomes. For instance, Eskandari et al. (2020) showed how dark chocolate supplementation when is combined with JRT could be beneficial in reducing obesity-induced inflammation in obese young children. They reported a reduction in parameters like inflammatory cytokines, adipokines, and body composition with respect to the white chocolate group. Knowing this Mogadham et al. (2021) compared three groups, JRT + white chocolate, JRT + dark chocolate and only dark chocolate consumption. They concluded that JRT + dark chocolate group obtained better results in improving antioxidant capacity over the other groups. In addition, body mass decreased more in this group than in the others. Thus, as suggested in literature, the JRT decreased body mass index (Bellver et al., 2021; Kim, J., Son, W. M., Headid III, R. J., Pekas, E. J., Noble, J. M., & Park, S. Y., 2020; Singh, U., Ramachandran, A. K., Ramirez-Campillo, R., Perez-Castilla, A., Afonso, J., Manuel Clemente, F., & Oliver, J., 2022; Sung et al., 2019). Furthermore, adding dark chocolate supplementation for obese adolescents could be beneficial (Eskandari et al., 2020; Hooshmand Moghadam et al., 2021).

Type of Jumps

Our systematic review secondary analysis revealed one study that compared the type of jump weight moderator variable of JRT. This comprises 12.5% of studies and 21.1% of samples analysed in this study. This study compared adolescents, an average of 13.5 years old, that were randomised on freestyle JRT or traditional JRT for 12 weeks, training three days/per week. Freestyle JRT consisted of various rope skipping techniques both individually and as part of team performance (single freestyle, long rope freestyle Chinese wheel freestyle double dutch freestyle, single + long rope freestyles and Chinese wheel + double dutch freestyle) and traditional JRT focused on individual frequency and speed (basic rope skills, single rope speed, double under speed, triple under speed, basic rope skills + single rope speed and double + triple under speed).

Regarding physical fitness measures, the freestyle JRT showed greater significant improvement in flexibility (toe touch test) than the traditional JRT; the hand-grip strength and standing long jump observed greater improvements in favour to freestyle JRT with no significant differences. The difference between groups for flexibility might have been because freestyle JRT integrates more movements, such as hand rolls, flips, flying feet, and various steps (Yang et al., 2020). This justification could explain the differences for the standing long jump test; freestyle JRT incorporated more specific jumps (e.g. horizontal vector involved jumps, etc.) pertaining to the test, which might have been better for adolescent development (Hernandez et al., 2009).

Regarding health-related outcomes, this study showed that freestyle JRT was the unique group that increased bone mineral density (Yang et al., 2020). This might be due to the short intervention period (12 weeks) and how fast adolescents grow depending on the maturity stage. However, other studies demonstrated considerable changes in bone mineral density among female college students after six months of jump training (Kato et al., 2006). Thus, these changes are challenging to consider in adolescents in the maturity stage.

Total Dose

Our systematic review secondary analysis revealed one study that compared the total dose weight moderator variable of JRT. This comprises 12.5% of studies and 13.9% of the sample analysed in this study. This study compared high-volume JRT (10 minutes of 50 jumps per minute) with low-volume JRT (5 minutes of 50 jumps per minute) in post-pubescent females average of 14.7 years old. One strength of this study is that intervention comprised of 16 weeks of training, four days/per week.

Regarding physical fitness measures, the peak muscle torque of the right knee extensors was measured using an isokinetic dynamometer. Still, no differences between high-volume and low-volume JRT were found with respect to the control group.

The primary analysis of this study was on health-related measures, calcaneus stiffness index, body mass, body fat and bone mineral content. The high volume of JRT showed significant differences in calcaneus stiffness index and bone mineral content on femoral neck and greater trochanter compared to the control group. Thus, according to this study and other studies that used jumping interventions, bone formation is significant due to impact and seems dose-dependent.

CONCLUSION

As an alternative to traditional plyometric jump training, JRT can offer meaningful improvements in health and fitness measures in SAP. Manipulation of JRT moderator variables can be a novel training guide to strength and conditioning coaches for designing and implementing their training programs. If appropriately used, rope weight (e.g., weighted rope i.e. 695 g), adequate post-exercise recovery strategies (e.g., dark chocolate supplementation), type of jump (e.g., freestyle), and total number of jumps, can be manipulated into JRT programs to optimise health, and physical capacities among SAP. However, due to the limited number of high-quality (e.g., randomised-controlled trials) studies currently available in relation to the effects of JRT programming variables (e.g., intensity; duration), a robust recommendation regarding its optimal prescription to SAP is precluded. Nonetheless, the current systematic review offers valuable insights regarding EGM-related future lines of research in this field.

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SUPPLEMENTARY MATERIALS

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 S 2

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

Study	Reason
(Ache-Dias et al., 2015)	Exercise interventions not involving jump rope training (e.g., intermittent bouts of 30 s of maximal continuous jumps; i.e., no rope was used).
(Albers & Lewis, 2020)	Only one experimental rope jump training group.
(Hamid et al., 2016)	Compared jump rope training with traditional running group.
(Barahona-Fuentes et al., 2019)	Only one experimental rope jump training group.
(Cinar-Medeni et al., 2015)	Only one experimental rope jump training group.
(Behringer et al., 2013)	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, countermovement jump, countermovement jump to box, cycled split squat jump, push-ups with and without clapping hands, etc.).
(Bellver et al., 2021)	Not included two experimental jumping groups.
(Buchheit et al., 2014)	Only one experimental rope jump training group.
(Chen & Lin, 2011)	Only one experimental rope jump training group.
(Chen, Chao-Chien & Chen, C. C., & Lin, Y. C, 2012)	Only one experimental rope jump training group.
(Ciacci & Bartolomei, 2017)	Compared two different training protocols (hang clean+jump rope vs half squat+speed ladder).
(de Souza et al., 2020)	Only one experimental rope jump training group.
(Dimarucot & Soriano, 2020)	Only one experimental rope jump training group.
(Eler & Acar, 2018)	Only one experimental rope jump training group.
(Engelke et al., 2006)	Only one experimental rope jump training group.
(Fernandes & Hans, 2022)	Only one experimental rope jump training group.
(Formenti et al., 2021)	Only one exercise intervention involved jump rope training (compared sport specific training vs balance, speed, agility, quickness and jump rope training)
(García-Pinillos, F., Lago-Fuentes, C., Latorre-Román, P. A., Pantoja-Vallejo, A., & Ramirez-Campillo, R., 2020)	Not included two experimental jumping groups.
(Ghorbanian et al., 2013)	Only one experimental rope jump training group.
(Ha & Ng, 2017)	Only one experimental rope jump training group.

(*Contd...*)

Table S2. (*Continued*)

Study	Reason
(Jahromi & Gholami, 2015)	Only one experimental rope jump training group.
(Kemmler et al., 2002)	Only one experimental rope jump training group.
(Kemmler et al., 2003)	Only one experimental rope jump training group.
(Kemmler et al., 2004)	Only one experimental rope jump training group.
(Kim et al., 2007)	Only one experimental rope jump training group.
(Kim, J., Son, W. M., Headid III, R. J., Pekas, E. J., Noble, J. M., & Park, S. Y., 2020)	Only one experimental rope jump training group.
(Kramer et al., 2019)	Only one experimental rope jump training group.
(Kusuma, A. I., Setijonob, H., & Mintartoc, E., 2020)	Compared jump rope training with high jump experimental group.
(Masterson & Brown, 1993)	Compared jump rope training with countermovement abalakov experimental group.
(Miyaguchi et al., 2015)	Only one experimental rope jump training group.
(Mullur & Jyoti, 2019)	Only one experimental rope jump training group.
(da Silva et al., 2017)	Only one experimental rope jump training group.
(Nogueira et al., 2014)	Only one experimental rope jump training group.
(Partavi, 2013)	Only one experimental rope jump training group.
(Pérez-Castilla et al., 2018)	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.).
(PraveenA et al., s. f.)	Only one experimental rope jump training group.
(Reaper et al., 1996)	Exercise interventions involving jump rope training programs representing less than 50% of the total training load when delivered in conjunction with other type of jumps (e.g., skipping, lateral cone jumps, bounding, box jumps and accelerations)
(Sandstedt et al., 2013)	Only one experimental rope jump training group.
(Sankar & Thanalakshmi, s. f.)	Only one experimental rope jump training group.
(Sekhon & Maniazhagu, 2018)	Doubtful quality or peer-review process unclear from the journal.
(Seo, 2017)	Doubtful quality or peer-review process unclear from the journal.
(Sung et al., 2019)	Only one experimental rope jump training group.
(Trecroci et al., 2015)	Only one experimental rope jump training group.
(S. V. Stengel et al., 2005)	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).
(S. von Stengel et al., 2007)	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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