ORIGINAL SCIENTIFIC PAPER

The effects of single and combined jump exercises utilizing fast and slow stretch-shortening cycle on physical fitness measures in healthy adult males: A randomized controlled trial

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Abstract

This study aimed to compare the effects of six-week volume-equated jump training using drop jump (DJ), countermovement jump (CMJ), or a combination of both (COMB) on the physical fitness of adult males. Participants were randomly assigned to DJ (n=10), CMJ (n=9), or COMB (n=10) training groups or an active control group (n=7). Performance data were collected for 10-m and 30-m sprint, DJ, CMJ, standing long jump (SLJ), triple-hop jump, change of direction speed (CODS), and maximal isometric strength. The DJ demonstrated improvements in the 10-m sprint, CMJ, and SLJ (g=0.62–1.13, %Δ=3.0–10.8). The CMJ group improved in the 10-m and 30-m sprints, CODS, CMJ and SLJ (g=0.34–1.17, %Δ=3.4–10.5). The COMB group displayed progress in CMJ and SLJ (g=0.46–0.61, %Δ=6.4–8.6). In comparison to the control and COMB groups, the DJ and CMJ groups improved the 10-m sprint (p=0.008, ηp2=0.311), and in comparison to the control group, the CMJ group improved SLJ (p=0.037, ηp2=0.220). To conclude, the findings presented here deviate from the training principle of specificity, particularly in relation to ground contact time. This suggests that the classification of jump exercises into fast- and slow-SSC categories based solely on ground contact time might oversimplify a more intricate phenomenon.

Keywords: *Plyometric exercise; human physical conditioning; resistance training; muscle strength; athletic performance*

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Introduction

Jump training (JT) is a training method that usually involves using an individual's own body mass as resistance to induce distinct physical and physiological adaptations (Ramirez-Campillo, Moran, et al., 2020). JT serves as a cost-effective training approach, providing numerous physical fitness benefits across diverse populations, including physically active adults (Singh, Kushwah, Singh, Thapa, et al., 2022). The essence of JT lies in the utilization of the "stretch-shortening cycle" (SSC), encompassing three consecutive phases during movement. These are the eccentric, the amortization, and the concentric phases (Seiberl et al., 2021). The SSC action allows the muscles and tendons to store and utilize elastic energy during a pre-stretch movement (i.e., eccentric phase) with the resultant energy being released when the muscle is shortened (i.e., concentric phase) (Bobbert et al., 1996). Furthermore, JT exercises are typically categorized as fast-SSC (<250 ms) or slow-SSC (>250 ms), based on the duration of the ground contact time of a given jump (Duda, 1988). For example, the bounce drop jump (DJ) exercise is often categorized as a fast-SSC exercise as the feet are in contact with the ground for less than 250 ms during the eccentric pre-stretch phase of the movement (Pedley et al., 2017) as are any subsequent jumps carried out in series. The countermovement jump (CMJ), on the other hand, is categorized as a slow-SSC exercise because the feet have a ground contact time of more than 250 ms during movement (McMahon et al., 2018).

Further to the above, the DJ involves jumping or dropping from a raised platform (e.g., plyometric box) and immediately performing a vertical jump upon landing (Pedley et al., 2017) so as to minimize ground contact time whilst maximizing jump height (Pedley et al., 2017). This facilitates a larger magnitude of eccentric loading and therefore training with such an exercise improves the elastic capacity of the lower limbs by increasing the stiffness of the Achilles tendon (Laurent et al., 2020). In contrast, the CMJ exercise requires an individual to be in a standing position after which a pre-stretch (i.e. downward phase of a jump) is initiated prior to a vertical jump (Asmussen & Bonde-Petersen, 1974).

When formulating specific JT interventions, coaches can prescribe a combination of jump-type exercises, such as the DJ and the CMJ, to target a broad segment of the force-velocity curve so as to enhance a wide variety of physical fitness metrics (Ramírez-Campillo, Burgos, et al., 2015; Ramírez-Campillo, Gallardo, et al., 2015; Ramirez-Campillo et al., 2022). Improvements that are obtained through the execution of JT can be partially attributed to the task-specific similarity of the selected jump and the athletic movement it is being used to improve. For example, sprinting requires utilization of the fast-SSC (~150 ms ground contact time) (Ammann et al., 2016) while change of direction (COD) movements require utilization of both fast (i.e., during straight sprinting) and slow (~500 ms ground contact time during turning movement) SSC (Dos'Santos et al., 2020). Accordingly, utilizing jumps with specific SSC-orientated characteristics may induce improvements that are closely related to those exhibited during execution of the athletic task (e.g., fast-SSC for linear sprinting; slow-SSC for turning movement in COD).

Despite the above, there are few JT studies that compare the effects of isolated JT exercises, such as the DJ (i.e., fast SSC) and CMJ (i.e., slow SSC) on physical fitness (Ruffieux et al., 2020; Thomas et al., 2009). In one study that did, Thomas & colleagues (Thomas et al., 2009) failed to report the ground contact time of the DJ exercises during executed training sessions and did not assess DJ performance as an outcome measure (e.g., jump ground contact time, height, and reactive strength index [RSI]). In addition, Ruffieux & colleagues (Ruffieux et al., 2020) used the 'countermovement' DJ and not the 'bounce' DJ in an intervention which compared DJ to CMJ over a six week period. Furthermore, previous research that focused on isolated forms of JT compared only unilateral and bilateral jumps (Bogdanis et al., 2019; Ramírez-Campillo, Burgos, et al., 2015) or horizontal and vertical jumps (Loturco et al., 2015; Ramírez-Campillo, Gallardo, et al., 2015; Talukdar et al., 2022). Moreover, previous studies compared isolated forms of JT that utilized the slow SSC exercise category alone (e.g., CMJ versus horizontal jumps) (Loturco et al., 2015) or compared JT exercises utilizing the slow SSC (e.g., horizontal jumps) versus fast combined with slow SSC (e.g., DJ combined with CMJ) (Talukdar et al., 2022).

Due the above-mentioned limitations within the existing body of literature, which might restrict practitioners' comprehension of the distinct effects of jumps utilizing fast or slow SSCs, this study was designed to assess and compare the outcomes of a six-week of JT using DJ (representing fast-SSC), CMJ (representing slow-SSC), or a combined approach (COMB), on selected measures of physical fitness in healthy adult males. Considering the common ground contact time continuum (e.g., ≤250 to >250 ms) usually observed in sprinting, jumping, and CODS exercises-tests, and the potential relevance of ground contact time during JT exercises to induce adaptations, based on the principle of training specificity (e.g., specific adaptation to imposed demands) (Ammann et al., 2016; Davies et al., 2015; Dos'Santos et al., 2020; Duda, 1988; McMahon et al., 2018; Pedley et al., 2017) we hypothesized that there would be i) greater improvements in sprinting and DJ performance after DJ training, ii) greater improvements in CMJ, SLJ, and triple hop test performance after CMJ training, and iii) greater CODS improvements after COMB training.

Methods

Experimental design

The study was designed taking into consideration international guidelines for quality-based randomized controlled trials (e.g., CONSORT). A two (within-subject; pre-post) by four (between-subject; DJ group, CMJ group, COMB group, control group) randomized controlled study design was conducted to compare the effects of the three different JT interventions on various measures of physical fitness. Baseline and post-intervention assessments were performed at similar times during the day with at least 48 hours of rest after the most recent training session. The sequence of the testing order was the same for all the participants and tests. For outdoor assessments during the pre- and post-intervention testing sessions, the temperature, humidity, and wind velocity were 31.8 – 33.1° C, 40 – 57 %, 3.8 – 6 km/h, respectively.

A total of five familiarization sessions (20 – 30 min duration each) were conducted for the DJ and CMJ exercises'

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technical execution before the intervention and group allocations were conducted. The first, second, and third sessions were focused on the correct technical execution of jumping and landing. During the same sessions, instructions related to the ground contact time were given. The focus was placed on a few important cues such as (i) [keeping] the spine erect and shoulders back, (ii) [positioning the] chest over knees, (iii) jumping straight up with no excessive side-to-side or forward-backward movement, (iv) [execute a] soft landing including toe-to-heel motion and bending of the knees and (v) [jumping as quick as possible] minimal ground contact for the concentric part of the jump (for the DJ). The fourth and fifth sessions were focused on the familiarization of a typical DJ and CMJ session (50 jumps in total were performed in each session; from low to near-maximal or maximal intensity effort) to be used during the intervention. Only participants with the ability to perform both DJ and CMJ with the correct techniques (i.e., ability to adhere to the five cues mentioned above) were finally recruited for the study. Demographic and anthropometric data were collected, and the testing procedures were also explained during the familiarization sessions. In addition, the proper use of a visual analogue scale and session rating of perceived exertion (sRPE) were explained and practiced during the familiarization sessions. Participants were asked to i) refrain from strenuous activity 24 hours before testing and ii) eat (up to 3 hours before testing) and drink habitually. The CONSORT flow diagram is provided in Figure 1.

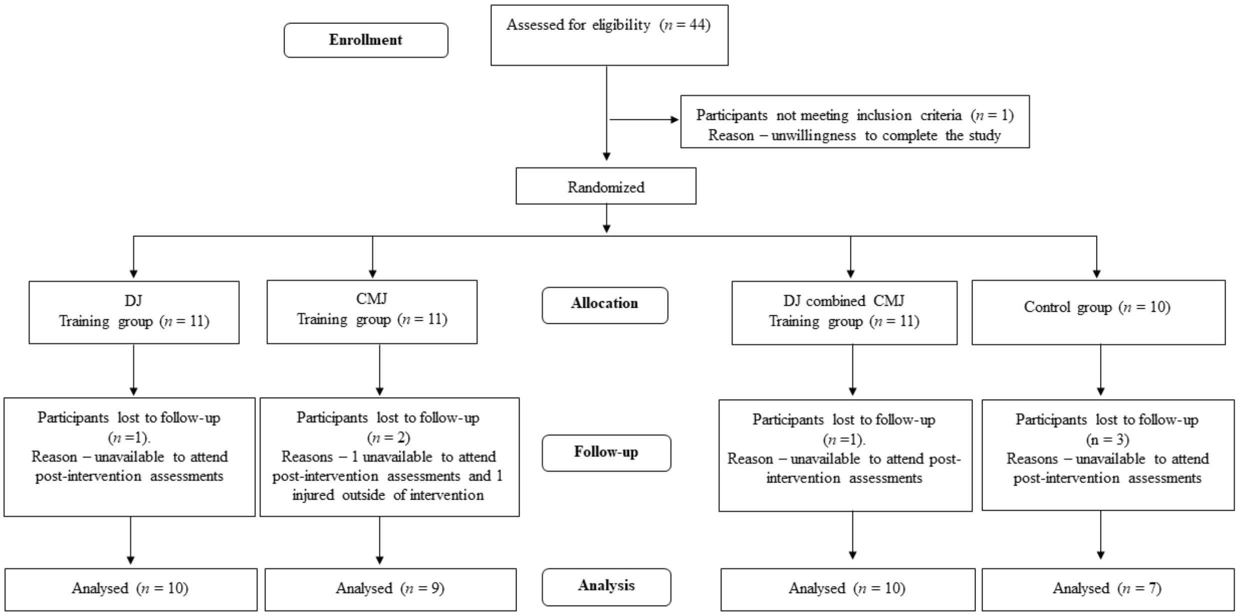

Figure 1. CONSORT flow diagram

Participants

The required sample size was estimated using statistical software (G*power; University of Düsseldorf, Düsseldorf, Germany). The following variables were included in the a priori power analysis: study design, four groups; two measurements; alpha error <0.05; nonsphericity correction =1; correlation between repeated measures = 0.7; desired power (1-ß error) = 0.80; and effect size (f) of 0.33 (i.e., large effect [Cohen d value of 0.66 reported for CMJ converted to Cohen f]), based on prior research investigating the effects of eight-weeks JT with similar study design (i.e., three experimental and one control group) in physically active young males (Ramirez-Campillo et al., 2021).

The results of the a priori power analysis indicated that a minimum of five participants would be required for each group to achieve statistical significance for the main outcome of the study (i.e., CMJ). However, due to the potential for participant attrition in such a trial, we attempted to maximize participant recruitment (n=44). Thereafter, each participant was assessed for eligibility based on the inclusion criteria that required them to be: i) physically active adults who undertook 150 – 300 minutes of moderate-intensity physical activity a week or 75 – 150 minutes of vigorous-intensity physical activity per week; ii) free from any major lower limb injury in the past six months; iii) able to perform both DJ and CMJ with correct technique (detailed information available in the experimental design section) and free from major discomfort or pain; iv) willingness to undergo twelve intervention training sessions as well as fitness tests before and after the intervention. Participants

Table 1. Demographics of the participants in the experimental and control group

	DJ	CMJ	COMB	Control	P – value*
Age	19.9 ± 1.2	20.9 ± 2.3	19.8 ± 1.2	20.4±1.4	0.435
Height	171.5 ± 6.2	176.6±10.6	174.0±6.1	177.0±6.7	0.474
Body mass	62.3 ± 8.6	63.2 ± 9.8	60.8 ± 12.1	61.7±12.5	0.968

Note: CMJ – countermovement jump training group, COMB – drop jump combined countermovement jump training group, DJ – drop jump training group. *one-way analysis of variance were not excluded based on JT compliance although attendance analysis based on categorizations were performed to explore potential effects on pre- to post-test changes. The eligible participants were randomly assigned (using an online randomization tool; www.randomizer.org) to either the DJ training group, the CMJ training group, the COMB training group, or the control group, using a 1:1:1:1 allocation ratio. The allocation sequence was concealed from those implementing the intervention. § The descriptive information of the participants in each group is presented in Table 1. The potential risks and benefits of this study were explained to the participants before they took part. Thereafter, informed consent forms were signed by the participants. The Internal Review Board of provided ethical approval to conduct the study (approval no.) following which the research protocol was prospectively registered on the OSF platform on 13/04/2023 with the doi . The study was conducted according to the guidelines of Declaration of Helsinki.

Training intervention

The experimental groups followed the JT training protocol for six weeks duration which is sufficient to assess the induced effects in a non-athlete population (Markovic & Mikulic, 2010). A weekly frequency of two sessions was selected based on previous indications that such a JT frequency is likely sufficient to induce positive adaptations (Ramirez-Campillo et al., 2018). A total of 12 sessions were completed by each experimental group. The control group did not perform any form of JT during the six-week period but did continue their normal physical activity routine of 150-300 minutes of moderate or 75-150 minutes of vigorous physical activity, as did the experimental groups. The JT exercises replaced part of the regular physical activity time. Specific instructions were given to the participants while performing DJ and CMJ. During DJ, the participants were instructed to jump as high and fast as possible while minimizing the ground contact time, and during CMJ to jump as high as possible. The participants were instructed to wear the same type of shoes during the training interventions. A soft surface (i.e., natural grass football pitch) was used in weeks 1 and 2 and, thereafter, a hard surface (i.e., concrete) in the remaining weeks to gradually increase the load on the Achillis tendons (Ramirez-Campillo, Álvarez, et al., 2020). Detailed information regarding the weekly training load and progression used is provided in Table 2. In addition, a minimum of three participants from the DJ group and COMB group were asked (at random) to perform DJ repetitions during training sessions using contact time jump platforms (Chronojump Boscosystem, Barcelona, Spain) to check jump ground contact time (i.e., <250 ms) in weeks 2, 4, and 6.

Table 2. Training load for drop jump (DJ), countermovement jump (CMJ), and DJ combined CMJ training (COMB).

	DJ group	CMJ group	COMB‡
	Repetitions × block × series		
Week 1 – 2	10 × 3 × 3	10 × 3 × 3	10 × 3 × 3
Week 3 – 4	12 × 3 × 3	12 × 3 × 3	12 × 3 × 3
Week 5 – 6	14 × 3 × 3	14 × 3 × 3	14 × 3 × 3

* Rest between repetitions, blocks, and series: 3 – 5 s, 60 s, and 180 s, respectively; ‡ The three groups completed a total of 1,296 jumps during intervention. The combined group completed 648 drop jumps and 648 countermovement jumps.

Physical fitness tests

The physical fitness tests were conducted on two separate days, with 30 m linear sprints and CODS performed on day one (i.e., outdoor assessments) and lower body power (i.e., all jump assessments) and isometric maximal strength test performed on day two (i.e., laboratory assessments) (Thapa et al., 2024). All the tests were conducted by the same research assistants who were blinded to the participants' group allocation. Prior to the tests, the participants underwent a general warm-up of ~10 minutes consisting of running at a self-selected speed and involving change of direction actions, followed by short sprints, and dynamic stretching. Thereafter, specific warm-ups were performed according to the test to be performed.

Sprint Speed

A 30 m linear sprint test was conducted with a 10m split time using a reliable dual-beam timing system (Chronojump Boscosystem, Barcelona, Spain) (Thapa, Sarmah, et al., 2023). The testing protocol was conducted on a natural grass surface. Three trials were conducted with a rest of one minute between trials. The best trial was selected for the analysis. The interclass correlation coefficient (ICC) with 95% confidence interval (CI) was 0.86 (0.80 – 0.91) and 0.89 (0.84 – 0.93) for 10 m and 30 m, respectively.

Lower body jump-related performance

Lower body jump-related performance was assessed using the CMJ, DJ, ground contact time and RSI measured from a 20 cm box, SLJ and triple hop jump test (double leg) for distance. A portable contact mat (Chronojump Boscosystem, Barcelona, Spain) was used to analyze the CMJ and DJ. The SLJ and triple hop test were conducted inside a laboratory as described in a previous study (Singh, Kushwah, Singh, Ramírez-Campillo, et al., 2022) and was measured using a tape. Three trials were conducted for all jump tests and the best trial was selected for the analysis. The ICC with 95% CI were 0.92 (0.88 – 0.94) for CMJ height, 0.93 (0.90 – 0.95) for DJ height, 0.79 (0.71 – 0.86) for DJ contact time, 0.82 (0.75 – 0.86) for DJ RSI, 0.79 (0.71 – 0.85) for SLJ distance, and 0.86 (0.78 – 0.91) for triple hop distance.

Change of direction speed

Change of direction speed was assessed using the modified T-test and was conducted with methods outlined in a previous study (Thapa, Clemente, et al., 2023). One pair of dual beam photocell timing gates (Chronojump Boscosystem, Barcelona, Spain) was used to record the time in seconds (Thapa, Sarmah, et al., 2023). Three trials were conducted, and the best trial was selected for analysis. The ICC with 95% CI for CODS time was 0.85 (0.78 – 0.90).

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Isometric maximal strength

Isometric maximal strength (i.e., isometric mid-thigh pull) was measured with a portable strain gauge (Chronojump Boscosystem, Barcelona, Spain) attached to a leg dynamometer. Briefly, the participants were asked to stand upright on the base of the dynamometer with their feet shoulder-width apart. Participants were instructed to hang their arms straight down to hold the bar at the centre with both hands, with palms facing towards the body. Flexion of knees were allowed at approximately 110 degrees, thereafter the chain was adjusted. The subjects were then asked to pull as hard as possible for a duration of ~ 5 seconds and asked to straighten the legs without bending the back. Peak and average force were recorded for each participant. Three trials were conducted with rest of three minutes between trials and the best trial was selected for analysis. The ICC with 95% CI were 0.89 (0.94 – 0.93) and 0.88 (0.81 – 0.92) for peak force and average force, respectively.

Pain analogue scale

A visual analogue scale (0 to 10 point scale) was used to assess acute pain due to the intervention training (Bijur et al., 2001). Each participant was asked to rate pain in lower limb muscles with scores ranging from 0 (i.e., no pain) to 10 (i.e., worst possible pain). The data were recorded immediately, 24 hours, and 48 hours after the first (i.e., at week 1) and last (i.e., at week 6) training session.

Statistical analyses

The normal distribution of the data was tested using the Shapiro-Wilk test. The normality assumptions were violated for DJ contact time, DJ RSI, and SLJ for CMJ group and for 30 m linear sprint time in the control group. Following the visual inspection of the histogram (i.e., data were skewed), a two-step approach method was used for the transformation of the non-normal data (to normal) to perform the parametric tests. Normally distributed data were presented as mean and standard deviation, while non-normally distributed data were presented as median and interquartile range. One-way analysis of variance and Kruskal-Wallis test were used to analyze the demographic and pain analogue data. Two (pre-post) by four (DJ, CMJ, COMB, control) mixed design analysis of variance (ANOVA) was used to find the interaction effects. Further, analysis of covariance (ANCOVA), using the baseline as a covariate was employed to detect possible between-group differences after training. Partial eta squared (ηp2) derived from the ANCOVA output were used as effect size scores. Post-hoc tests using Bonferroni corrections were conducted to detect the exact location of differences between groups. Further, paired t-test were conducted to assess within-group changes. Hedges' g (t-test effect sizes) was calculated to assess the magnitude of improvement from pre- to post-intervention in all groups. Percentage change scores were also calculated for each variable in each group using the equation in Microsoft Excel sheet: [(meanpost – meanpre)/meanpre] × 100. The magnitude of effects for ηp2 was interpreted as small (<0.06), moderate (≥0.06-0.13), and large (≥0.14) (Cohen, 1988), while Hedge's g was interpreted as trivial (<0.2), small (0.2-0.6), moderate (>0.6-1.2), or large (>1.2-2.0) (Hopkins et al., 2009). In addition, the reliability of the testing procedures was assessed using the ICC between trials and was interpreted as poor (<0.5), moderate (0.5-0.75), good (0.75-0.9), and excellent (>0.9) reliability based on the lower bound of the 95% CI (Koo & Li, 2016). Statistical significance was set at $p \leq 0.05$.

Results

Deviation from registered protocol

There were a few deviations in the current study from the original protocol published in the OSF platform with doi on 13/04/2023. Firstly, the session rating of perceived exertion (sRPE) for each training session were not included in this article. The reason for this decision was an insufficient number of sRPE data reported in each of the groups in the study. Since sRPE data collection was conducted using google forms after 30 minutes of completion of the experimental session, the researchers involved did not have control over this element of the data collection process making compliance amongst the participants less likely. Secondly, due to logistical reasons, the data for body composition could not be retrieved for all of the participants. Thirdly, the data for the rate of force development and impulse during the IMTP tests were not reliable, hence we removed this data from the current study. Lastly, the analysis of inter-individual responses to training was considered too lengthy and difficult to accommodate in this paper. To provide adequate context, a comprehensive analysis, and insightful interpretation, the results of inter-individual responses are considered for a secondary analysis manuscript.

Adverse effects

No participants were injured during the interventions. However, dropouts were observed in the experimental groups (n = 3) and control group (n = 3) due to participants' unavailability for post-test data collection. One participant in CMJ group sustained injuries outside of the intervention and couldn't complete the study.

Pain analogue scale

There were no significant differences between the experimental groups in pain analogue score immediately, 24 hours, and 48 hours after the first training session (Kruskal-Wallis p = 0.390 – 0.750). However, a significant difference between groups was observed 24 hours (Kruskal-Wallis p = 0.020) after the last training session of the intervention, with greater pain perceived with COMB compared to CMJ training (p = 0.027). No other between-group differences were observed immediately or after 48 hours (Kruskal-Wallis p = 0.552 – 0.880) of the last training session of the intervention.

Within-group changes

Outcome measures at pre- and post-intervention are presented in Table 3, and Hedges g data are presented in Table 4. Pre- to post-improvements (all p<0.05) were observed in the DJ group in 10 m sprint (g = 1.13, %Δ = 6.1), CODS (g = 0.84, %Δ = 3.0), CMJ height (g = 0.85, %Δ = 10.8), and SLJ distance (g = 0.62, %Δ = 5.1). Similarly, the CMJ group improved (all p<0.05) 10 m sprint (g = 0.89, %Δ = 5.4), 30 m sprint (g = 0.67, %Δ = 3.4), CODS (g = 0.34, %Δ = 2.1), CMJ height (g = 1.12, %Δ = 10.5), and SLJ distance (g = 0.97, %Δ = 8.9). The COMB group improved (all p<0.05) CMJ height (g = 0.46, %Δ = 8.6), and SLJ distance (g = 0.56, %Δ = 6.4). No significant within-group improvements were noted in the control group. A graphical representation of pre- to post-intervention percentage change is presented in Figure 2.

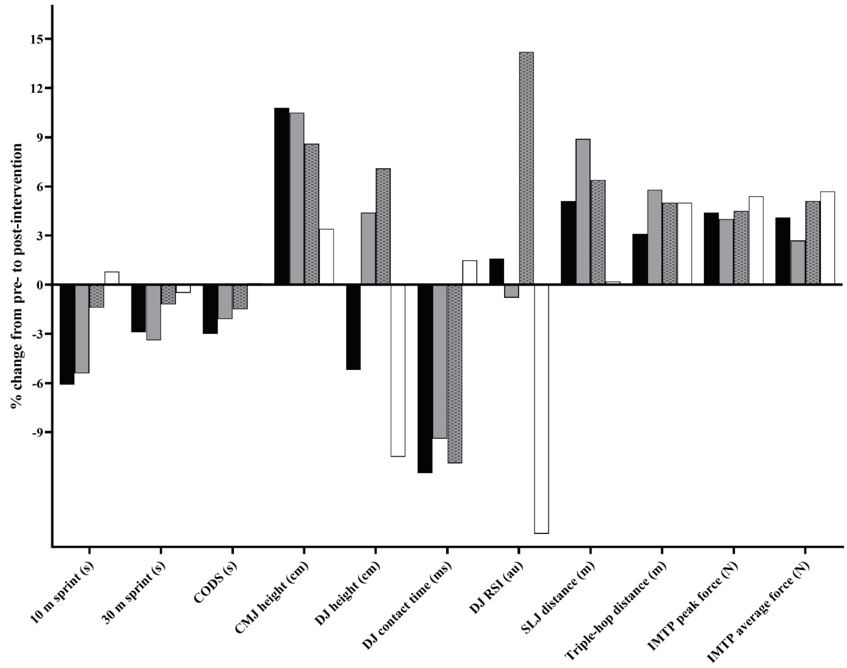

Figure 2. Graphical representation of pre- to post-intervention percentage change in outcome variables for each group. Note – black, gray, gray dotted, and white bars denote drop jump (DJ), countermovement jump (CMJ), COMB training groups, and control group, respectively. CODS – change of direction speed, RSI – reactive strength index, SLJ – standing long jump, IMTP – isometric mid-thigh pull.

Table 3. Comparisons for changes in outcome variables between drop jump (DJ), countermovement jump (CMJ), COMB (DJ combined CMJ), and control groups.

Variables	DJ group		CMJ group		COMB group		Control group		ANCOVA P-value
	Mean ± standard deviation/ Median (Interquartile range)								
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
10 m sprint (s)	1.8±0.1	1.7±0.1*[ab]	1.8±0.1	1.7±0.1*[cd]	1.8±0.2	1.8±0.1	1.8±0.1	1.8±0.1	0.008#
30 m sprint (s)	4.5±0.2	4.4±0.2	4.4±0.3	4.2±0.2*	4.5±0.4	4.5±0.3	4.5 (3.3–4.6) †	4.4±0.3	0.160
CODS (s)	11.3±0.4	11.0±0.4*	11.1±0.8	10.9±0.5*	11.3±0.4	11.1±0.6	11.5±1.2	11.5±1.2	0.125
CMJ height (cm)	32.8±4.3	36.3±3.6*	34.8±2.6	38.4±3.6*	30.1±4.7	32.7±5.8*	31.5±5.2	32.5±5.0	0.125
DJ height (cm)	28.4±5.5	26.9±4.6	29.3±5.2	30.6±6.6	24.6±5.0	26.3±5.9	29.4±3.7	26.3±4.3	0.162
DJ contact time (ms)	0.24±0.05	0.22±0.02	0.22 (0.19–0.26) †	0.23±0.02	0.24±0.04	0.21±0.02	0.24±0.04	0.24±0.03	0.076
DJ RSI (au) ‡	1.8±0.4	1.2±0.3	1.2±0.4	1.3 (1.1–1.3) †	1.0±0.3	1.2±0.3	1.2±0.3	1.1±0.2	0.243
SLJ distance (m)	2.3±0.2	2.4±0.2*	2.4±0.2	2.5 (2.5–2.8) † *[d]	2.2±0.2	2.4±0.3*	2.3±0.2	2.3±0.1	0.037#
Triple-hop distance (m)	6.4±0.5	6.6±0.6	6.7±0.7	7.1±0.5	6.1±0.8	6.4±0.9	6.1±0.5	6.4±0.5	0.522
IMTP peak force (N)	1886±306	1969±236	2063±278	2146±445	1904±266	1991±315	1868±292	1970±241	0.979
IMTP average force (N)	1826±284	1900±193	1970±238	2023±417	1849±283	1945±307	1835±291	1939±130	0.989

Note: IMTP – isometric mid-thigh pulls, RSI – reactive strength index, ‡ – au: arbitrary units denoting the ratio between flight time and time contact), SLJ – standing long jump, a, b – significant difference compared to control and COMB groups, respectively. c, d – significant difference compared to COMB and control groups, respectively. * – within-group pre to post significant difference, # – significant group × time interaction, † – non-normally distributed data, presented as median and interquartile range.

Between-group changes

The ANCOVA revealed significant between-group differences in 10 m sprint time (p = 0.008, ηp2 = 0.311) and SLJ distance (p = 0.037, ηp2 = 0.220) at post-test. The post-hoc analysis with Bonferroni corrected t-test revealed improved 10 m sprint time in the DJ group and CMJ group compared to the control (p = 0.018 and p = 0.009, respectively) and COMB groups (p = 0.018 and p = 0.010, respectively). Further, SLJ improved in the CMJ group compared to control group (p = 0.041).

Discussion

This study aimed to conduct a comparative analysis of the effects resulting from six weeks of JT employing DJ (representing fast-SSC), CMJ (representing slow-SSC), or a combined

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protocol (COMB) on selected measures of physical fitness in healthy adult males. Based on the principle of training specificity (e.g., specific adaptation to imposed demands) (Ammann et al., 2016; Davies et al., 2015; Dos'Santos et al., 2020; Duda, 1988; McMahon et al., 2018; Pedley et al., 2017) we hypothesized that there would be i) greater improvements in sprinting and DJ performance after DJ training, ii) greater improvements in CMJ, SLJ, and triple hop test performance after CMJ training, and iii) greater CODS improvements after COMB training. Although all three JT interventions induced overall improvements in participants' physical fitness , particularly the isolated application of DJ and CMJ training exercises when compared to a control condition , the study's findings contradicted our hypotheses and the training specificity principle. Specifically, DJ training did not lead to more significant improvements in sprinting compared to CMJ training or greater enhancements in DJ performance compared to COMB or CMJ training. Similarly, CMJ training did not result in greater improvements in CMJ, SLJ, or the triple hop test compared to DJ or COMB training. Additionally, COMB training did not yield greater CODS improvements than all other interventions.

The findings of our study suggest that significant improvements can be achieved in 10 m linear sprint time (i.e., acceleration speed) through the execution of both DJ or CMJ after six weeks of training. Similarly, SLJ was improved in the CMJ group compared to the control group. Our results confirm the findings of previous studies that reported improvements in linear sprint performance (Sáez de Villarreal et al., 2012) and SLJ (Singh, Kushwah, Singh, Thapa, et al., 2022) after JT training. The observed improvement in the 10 m linear sprint time and SLJ distance may be related to the neuromuscular adaptations commonly observed after JT, including a greater number and/or rate of motor units recruited in agonist muscles, improved intra- and inter-muscular coordination via enhanced muscle activation strategies, changes in muscle architecture or improved stiffness of various elastic components of the muscle-tendon complex (Moran et al., 2023) (e.g., plantar flexors) leading to better SSC muscle function (e.g., re-utilization of elastic energy). These adaptations can improve force expression resulting in increased sprinting speed and jump distance (Markovic & Mikulic, 2010). In addition to these adaptations, DJ training could also have improved ground contact time during sprinting (Rimmer & Sleivert, 2000), while CMJ training may have improved the stride length during sprinting (Tottori & Fujita, 2019).

Of note, contrary to our hypothesis DJ training did not induce greater improvements in sprinting when compared to CMJ training. This hypothesis was primarily based on the assumptions (i.e., specificity training principle) that fast-SSC exercise (i.e., lower ground contact time) would improve the fast-SSC muscle function with greater magnitude compared to a slow-SSC exercise (i.e., higher ground contact time). However, we did not observe significant improvements in the ground contact time or the RSI after DJ training, which may partly explain why the sprinting performance did not improve when compared to CMJ training. Nonetheless, a previous JT study (8 weeks, 3 sessions/week) carried out in male physical education students aged 20.2 years reported improvements in sprinting performance with no concomitant decreases in ground contact time or RSI obtained from a DJ test (Coşkun et al., 2022). These findings suggest that improved sprinting performance through JT cannot be only attributed to ground contact time or RSI. These contrasting results demonstrate the multifactorial nature of sprinting performance (e.g., running speed; jump height-distance; CODS) (Coyle, 1995; Saunders et al., 2004; Sheppard & Young, 2006) and it is therefore plausible that both DJ and CMJ training can improve linear sprinting speed through differing adaptive neuromuscular pathways that were not identified in our study. For example, DJ training may improve the acceleration speed through reduced ground contact time during sprinting, without changes in stride length (Rimmer & Sleivert, 2000), while CMJ training may increase sprinting speed in line with increased stride length during sprinting, without changes in sprinting ground contact time (Tottori & Fujita, 2019). Indeed, it may also be possible that the CMJ training improved the propulsive impulse during the starting phase (i.e., the first few steps) resulting in an improved acceleration speed (Martín-Fuentes & van den Tillaar, 2022). Moreover, it may also be possible that both DJ and CMJ have increased the force production capabilities of the lower-limb muscles (without any influence in the GCT). However, future studies may consider the inclusion of ground contact time measurements not only during training sessions but also during sprinting test sessions.

In a similar vein to the above, we also hypothesized that slow-SSC-based CMJ training could stimulate greater improvements in similarly slow-SSC-based activities with resultant improvements in CMJ, SLJ and triple hop tests as compared to DJ training. However, contrary to our hypothesis, improvements of a similar magnitude were also observed in CMJ and SLJ through both DJ and CMJ training. As with sprinting speed performance, jumping performance is influenced by multiple intertwining factors (Aragón-Vargas & Gross, 1997). Accordingly, similar to the sprint speed tests described above, CMJ and DJ training might have improved jump performance to a similar magnitude through different adaptive mechanisms (e.g., motor unit recruitment vs. force production) (Markovic & Mikulic, 2010; Mero et al., 1992). Indeed, previous studies have also reported similar improvement in CMJ height after six weeks of bounce DJ (aiming to increase jump height while minimizing ground contact time) and countermovement DJ (aiming to increase jump height only) (Thomas et al., 2009; Young et al., 1999). In addition to this, the participants in our study were physically active adult males who did not have prior experience of executing DJ exercises. Accordingly, it may be plausible that the DJ training stimulus (producing force within a short timeframe) was sufficient to induce adaptations that resulted in improved CMJ performance.

We also hypothesized that greater improvements would be observed in CODS that utilizes both slow and fast SSC through a COMB training approach in comparison to DJ or CMJ training. However, we did not observe any significant difference in improvements between COMB training and DJ training or CMJ training and the control group. Our training intervention consisted exclusively of vertical jumps. A previous meta-analysis reported that a combination of depth jumps, vertical jumps and standing long jumps (i.e., vertical combined horizontal) induced greater improvements in CODS compared to depth jump or CMJs alone (Asadi et al., 2016). In addition, another study (Dello Iacono et al., 2017) also reported greater CODS improvements with horizontal drop jump training compared to vertical jump training in elite handball athletes. Indeed, Moran & colleagues (Moran et al.,

2021) also reported that horizontally-oriented JT was more effective than vertically-oriented JT in improving the horizontally-orientated movement, a key element in CODS. Indeed, CODS is heavily dependent on horizontally-orientated force production with faster athletes showing greater peak and mean horizontal propulsive forces, shorter ground contact times, more horizontally orientated peak resultant braking and propulsive forces, and greater horizontal to vertical mean and peak braking and propulsive force ratios over key instances of CODS movements (Dos'Santos et al., 2020). In this sense, a classification of exercises as fast-SSC or slow-SSC based only on ground contact time to prescribe JT exercises may not represent an optimal approach. A specification of other factors may be required, such as the pattern of force application (vertical vs horizontal), the symmetrical or asymmetrical nature of the exercise (e.g., unilateral vs bilateral) and the training status of the athlete (Moran et al., 2023).

Limitations

Some limitations should be acknowledged. Firstly, the participants in our study were physically active students but they had no prior experience of DJ training. The low training level of the participants may have distorted the specificity effect as untrained individuals appear more adaptable to neuromuscular training stimuli (Rhea et al., 2003). Thus, the training principle of specificity could be moderated by the training level of the participants. This is line with guidelines for exercise prescription across several groups and institutions (e.g., ACSM (2009) position stand on progression models for resistance exercise, etc.). Secondly, the duration of the study was limited to six weeks. However, this current study may be a basis for future long-term studies comparing fast- versus slow-SSC-based intervention across different populations (e.g., athletes) and confirm if similar findings are observed. Thirdly, although we computed the sample size requirements using appropriate methods prior to the start of the study, a larger sample may be appropriate for generalization of the findings. Fourthly, including biomechanical assessments as outcome variables during tests such as sprint, CODS, CMJs or DJs may provide deeper insights into the differences between kinetics as well as kinematic changes occurred during these tasks. Lastly, the inclusion of sRPE measurements could have provided an insight into the psycho-physiological aspects of the training load exerted by the experimental groups. Although our registered protocol included this measurement, we could not analyze the data due to low number of participants submitting the data (69 sRPE scores were submitted out of 348).

Conclusions

Although within-group improvements were observed in outcome variables after all three JT interventions, particularly notable for 10 m sprint after DJ training and CMJ training, and in SLJ after CMJ training, the present findings diverge from the conventional training principle of specificity, specifically the concept of ground contact time. Alternatively, it is conceivable that the classification of JT exercises based solely on fast-SSC (<250 ms ground contact time) and slow-SSC exercises (>250 ms ground contact time) might be an oversimplification of a multifaceted phenomenon. Therefore, to achieve more optimal and targeted JT exercise prescription, it might be wise to incorporate additional variables beyond ground contact time. These could encompass the direction-vector of force application (e.g., vertical, horizontal, combined), asymmetry movement pattern (e.g., unilateral jump, bilateral jump) and the training status of the individual, among other factor.

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Availability of data and material

All data generated or analyzed during this study will be/are included in the published article as Table(s) and Supplementary Table(s). Any other data requirement can be directed to the corresponding author upon reasonable request.

References

Ammann, R., Taube, W., & Wyss, T. (2016). Accuracy of partwear inertial sensor and optojump optical measurement system for measuring ground contact time during running. *Journal of Strength and Conditioning Research*, *30*(7), 2057-2063. https://doi.org/10.1519/jsc.0000000000001299

Aragón-Vargas, L. F., & Gross, M. M. (1997). Kinesiological factors in vertical jump performance: Differences among individuals. *Journal of Applied Biomechanics*, *13*(1), 24-44. https://doi.org/10.1123/jab.13.1.24

Asadi, A., Arazi, H., Young, W. B., & Sáez de Villarreal, E. (2016). The effects of plyometric training on change-of-direction ability: A meta-analysis. *International Journal of Sports Physiology and Performance*, *11*(5), 563-573. https://doi.org/10.1123/ijspp.2015-0694

ASCM. (2009). American college of sports medicine position stand. Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise*, *41*(3), 687-708. https://doi.org/10.1249/MSS.0b013e3181915670

Asmussen, E., & Bonde-Petersen, F. (1974). Storage of elastic energy in skeletal muscles in man. *Acta Physiologica Scandinavica*, *91*(3), 385-392. https://doi.org/10.1111/j.1748-1716.1974.tb05693.x

Bijur, P. E., Silver, W., & Gallagher, E. J. (2001). Reliability of the visual analog scale for measurement of acute pain. *Academic Emergency Medicine*, *8*(12), 1153-1157. https://doi.org/10.1111/j.1553-2712.2001.tb01132.x

Bobbert, M. F., Gerritsen, K. G., Litjens, M. C., & Van Soest, A. J. (1996). Why is countermovement jump height greater than squat jump height? *Medicine and Science in Sports and Exercise*, *28*(11), 1402-1412. https://doi.org/10.1097/00005768-199611000-00009

Bogdanis, G. C., Tsoukos, A., Kaloheri, O., Terzis, G., Veligekas, P., & Brown, L. E. (2019). Comparison between unilateral and bilateral plyometric training on single- and double-leg jumping performance and strength. *Journal of Strength and Conditioning Research*, *33*(3), 633-640. https://doi.org/10.1519/jsc.0000000000001962

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (Second ed.). Lawrence Erlbaum Associates.

Coşkun, B., Aras, D., Akalan, C., Kocak, S., & Hamlin, M. J. (2022). Plyometric training in normobaric hypoxia improves jump performance. *International Journal of Sports Medicine*, *43*(6), 519-525. https://doi.

 DOI 10.26773/mjssm.240308

org/10.1055/a-1656-9677

Coyle, E. F. (1995). Integration of the physiological factors determining endurance performance ability. *Exercise and Sport Sciences Reviews*, *23*, 25-63.

Davies, G., Riemann, B. L., & Manske, R. (2015). Current concepts of plyometric exercise. *International Journal of Sports Physical Therapy*, *10*(6), 760-786.

Dello Iacono, A., Martone, D., Milic, M., & Padulo, J. (2017). Vertical- vs. Horizontal-oriented drop jump training: Chronic effects on explosive performances of elite handball players. *Journal of Strength and Conditioning Research*, *31*(4), 921-931. https://doi.org/10.1519/jsc.0000000000001555

Dos'Santos, T., McBurnie, A., Thomas, C., Comfort, P., & Jones, P. A. (2020). Biomechanical determinants of the modified and traditional 505 change of direction speed test. *Journal of Strength and Conditioning Research*, *34*(5), 1285-1296. https://doi.org/10.1519/jsc.0000000000003439

Duda, M. (1988). Plyometrics: A legitimate form of power training? *The Physician and Sportsmedicine*, *16*(3), 212-218. https://doi.org/10.1080/00913847.1988.11709466

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3-13. https://doi.org/10.1249/MSS.0b013e31818cb278

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Laurent, C., Baudry, S., & Duchateau, J. (2020). Comparison of plyometric training with two different jumping techniques on achilles tendon properties and jump performances. *Journal of Strength and Conditioning Research*, *34*(6), 1503-1510. https://doi.org/10.1519/jsc.0000000000003604

Loturco, I., Pereira, L. A., Kobal, R., Zanetti, V., Kitamura, K., Abad, C. C., & Nakamura, F. Y. (2015). Transference effect of vertical and horizontal plyometrics on sprint performance of high-level u-20 soccer players. *Journal of Sports Sciences*, *33*(20), 2182-2191. https://doi.org/10.1080/02640414.2015.1081394

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

Martín-Fuentes, I., & van den Tillaar, R. (2022). Relationship between step-by-step foot kinematics and sprint performance. *International Journal of Environmental Research and Public Health*, *19*(11). https://doi.org/10.3390/ijerph19116786

McMahon, J. J., Suchomel, T. J., Lake, J. P., & Comfort, P. (2018). Understanding the key phases of the countermovement jump force-time curve. *Strength and Conditioning Journal*, *40*(4), 96-106. https://doi.org/10.1519/ssc.0000000000000375

Mero, A., Komi, P. V., & Gregor, R. J. (1992). Biomechanics of sprint running. A review. *Sports Medicine*, *13*(6), 376-392. https://doi.org/10.2165/00007256-199213060-00002

Moran, J., Liew, B., Ramirez-Campillo, R., Granacher, U., Negra, Y., & Chaabene, H. (2023). The effects of plyometric jump training on lower-limb stiffness in healthy individuals: A meta-analytical comparison. *Journal of Sport and Health Science*, *12*(2), 236-245. https://doi.org/10.1016/j.jshs.2021.05.005

Moran, J., Ramirez-Campillo, R., Liew, B., Chaabene, H., Behm, D. G., García-Hermoso, A., Izquierdo, M., & Granacher, U. (2021). Effects of vertically and horizontally orientated plyometric training on physical performance: A meta-analytical comparison. *Sports Medicine*, *51*(1), 65-79. https://doi.org/10.1007/s40279-020-01340-6

Pedley, J. S., Lloyd, R. S., Read, P., Moore, I. S., & Oliver, J. L. (2017). Drop jump: A technical model for scientific application. *Strength and Conditioning Journal*, *39*(5), 36-44. https://doi.org/10.1519/ssc.0000000000000331

Ramirez-Campillo, R., Álvarez, C., García-Hermoso, A., Ramírez-Vélez, R., Gentil, P., Asadi, A., Chaabene, H., Moran, J., Meylan, C., García-de-Alcaraz, A., Sanchez-Sanchez, J., Nakamura, F. Y., Granacher, U., Kraemer, W., & Izquierdo, M. (2018). Methodological characteristics and future directions for plyometric jump training research: A scoping review. *Sports Medicine*, *48*(5), 1059-1081. https://doi.org/10.1007/s40279-018-0870-z

Ramirez-Campillo, R., Álvarez, C., García-Pinillos, F., García-Ramos, A., Loturco, I., Chaabene, H., & Granacher, U. (2020). Effects of combined surfaces vs. Single-surface plyometric training on soccer players' physical fitness. *Journal of Strength and Conditioning Research*, *34*(9), 2644-2653. https://doi.org/10.1519/jsc.0000000000002929

Ramírez-Campillo, R., Burgos, C. H., Henríquez-Olguín, C., Andrade, D. C., Martínez, C., Álvarez, C., Castro-Sepúlveda, M., Marques, M. C., & Izquierdo, M. (2015). Effect of unilateral, bilateral, and combined plyometric training on explosive and endurance performance of young soccer players. *Journal of Strength and Conditioning Research*, *29*(5), 1317-1328. https://doi.org/10.1519/jsc.0000000000000762

Ramírez-Campillo, R., Gallardo, F., Henriquez-Olguín, C., Meylan, C. M., Martínez, C., Álvarez, C., Caniuqueo, A., Cadore, E. L., & Izquierdo, M. (2015). Effect of vertical, horizontal, and combined plyometric training on explosive, balance, and endurance performance of young soccer players. *Journal of Strength and Conditioning Research*, *29*(7), 1784-1795. https://doi.org/10.1519/jsc.0000000000000827

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

Ramirez-Campillo, R., Moran, J., Drury, B., Williams, M., Keogh, J. W., Chaabene, H., & Granacher, U. (2021). Effects of equal volume but different plyometric jump training intensities on components of physical fitness in physically active young males. *Journal of Strength and Conditioning Research*, *35*(7), 1916-1923. https://doi.org/10.1519/jsc.0000000000003057

Ramirez-Campillo, R., Moran, J., Oliver, J. L., Pedley, J. S., Lloyd, R. S., & Granacher, U. (2022). Programming plyometric-jump training in soccer: A review. *Sports (Basel)*, *10*(6). https://doi.org/10.3390/sports10060094

Rhea, M. R., Alvar, B. A., Burkett, L. N., & Ball, S. D. (2003). A meta-analysis to determine the dose response for strength development. *Medicine and Science in Sports* *and Exercise*, *35*(3), 456-464. https://doi.org/10.1249/01.Mss.0000053727.63505.D4

Rimmer, E., & Sleivert, G. (2000). Effects of a plyometrics intervention program on sprint performance. *Journal of Strength and Conditioning Research*, *14*(3), 295-301.

Ruffieux, J., Wälchli, M., Kim, K. M., & Taube, W. (2020). Countermovement jump training is more effective than drop jump training in enhancing jump height in non-professional female volleyball players. *Frontiers in Physiology*, *11*, 231. https://doi.org/10.3389/fphys.2020.00231

Sáez de Villarreal, E., Requena, B., & Cronin, J. B. (2012). The effects of plyometric training on sprint performance: A meta-analysis. *Journal of Strength and Conditioning Research*, *26*(2), 575-584. https://doi.org/10.1519/JSC.0b013e318220fd03

Saunders, P. U., Pyne, D. B., Telford, R. D., & Hawley, J. A. (2004). Factors affecting running economy in trained distance runners. *Sports Medicine*, *34*(7), 465-485. https://doi.org/10.2165/00007256-200434070-00005

Seiberl, W., Hahn, D., Power, G. A., Fletcher, J. R., & Siebert, T. (2021). Editorial: The stretch-shortening cycle of active muscle and muscle-tendon complex: What, why and how it increases muscle performance? *Frontiers in Physiology*, *12*, 693141. https://doi.org/10.3389/fphys.2021.693141

Sheppard, J. M., & Young, W. B. (2006). Agility literature review: Classifications, training and testing. *Journal of Sports Sciences*, *24*(9), 919-932. https://doi.org/10.1080/02640410500457109

Singh, G., Kushwah, G., Singh, T., Ramírez-Campillo, R., & Thapa, R. K. (2022). Effects of six weeks outdoor versus treadmill running on physical fitness and body composition in recreationally active young males: A pilot study. *PeerJ*, *10*, e13791. https://doi.org/10.7717/peerj.13791

Singh, G., Kushwah, G. S., Singh, T., Thapa, R. K., Granacher, U., & Ramirez-Campillo, R. (2022). Effects of sand-based plyometric-jump training in combination with endurance running on outdoor or treadmill surface on physical fitness in young adult males. *Journal of Sports Science and Medicine*, *21*(2), 277-286. https://doi.org/10.52082/jssm.2022.277

Talukdar, K., Harrison, C., McGuigan, M., & Borotkanics, R. (2022). The effects of vertical vs. Horizontal plyometric training on sprinting kinetics in post peak height female student athletes. *International Journal of Strength and Conditioning*, *2*(1). https://doi.org/10.47206/ijsc.v2i1.89

Thapa, R. K., Clemente, F. M., Moran, J., Garcia-Pinillos, F., Scanlan, A. T., & Ramirez-Campillo, R. (2023). Warm-up optimization in amateur male soccer players: A comparison of small-sided games and traditional warm-up routines on physical fitness qualities. *Biology of Sport*, *40*(1), 321-329. https://doi.org/10.5114/biolsport.2023.114286

Thapa, R. K., Sarmah, B., Chaware, U., Afonso, J., Moran, J., Chaabene, H., & Ramirez-Campillo, R. (2024). Fast and slow jump training methods induced similar improvements in measures of physical fitness in young females. *Women in Sport and Physical Activity Journal*, *32*(1), wspaj.2023-0071.

Thapa, R. K., Sarmah, B., Singh, T., Kushwah, G. S., Akyildiz, Z., & Ramirez-Campillo, R. (2023). Test-retest reliability and comparison of single- and dual-beam photocell timing system with video-based applications to measure linear and change of direction sprint times. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, *Advance online publication*, 1-9. https://doi.org/10.1177/17543371231203440

Thomas, K., French, D., & Hayes, P. R. (2009). The effect of two plyometric training techniques on muscular power and agility in youth soccer players. *Journal of Strength and Conditioning Research*, *23*(1), 332-335. https://doi.org/10.1519/JSC.0b013e318183a01a

Tottori, N., & Fujita, S. (2019). Effects of plyometric training on sprint running performance in boys aged 9-12 years. *Sports (Basel)*, *7*(10). https://doi.org/10.3390/sports7100219

Young, W. B., Wilson, G. J., & Byrne, C. (1999). A comparison of drop jump training methods: Effects on leg extensor strength qualities and jumping performance. *International Journal of Sports Medicine*, *20*(5), 295-303. https://doi.org/10.1055/s-2007-971134