Fast and slow jump training methods induced similar improvements in measures of physical fitness in young females

Running Head: Fast vs. slow jump training for females

Rohit K. Thapa[1], Bhargav Sarmah[2], Utsav Chaware[2], José Afonso[3], Jason Moran[4], Helmi Chaabene[5,6], Rodrigo Ramirez-Campillo[7]

[1] Symbiosis School of Sports Sciences, Symbiosis International (Deemed University), 412115 Pune, India.

[2] School of Physical Education and Sports, Rashtriya Raksha University, Gandhinagar 382305, India.

[3] Centre for Research, Education, Innovation, and Intervention in Sport (CIFI 2 D), Faculty of Sport of the University of Porto, Rua Dr. Plácido Costa, 91, 4200-450 Porto, Portugal.

[4] School of Sport, Rehabilitation and Exercise Sciences, University of Essex, Colchester, Essex CO43SQ, United Kingdom.

[5] Division of Training and Movement Sciences, Research Focus Cognition Sciences, University of Potsdam, Am Neuen Palais 10, Building 12, 14469 Potsdam, Germany.

[6] High Institute of Sports and Physical Education of Kef, University of Jendouba, Kef 7100. Tunisia

[7] Exercise and Rehabilitation Sciences Institute, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago 7591538 Chile.

Corresponding author

Dr. Rohit K. Thapa, Ph.D.

Symbiosis School of Sports Sciences,

Symbiosis International (Deemed University),

Pune, 412115, India.

Email: rohit.thapa@ssss.edu.in

Mobile: +919678324029

ORCID: https://orcid.org/0000-0002-1258-9065

Key Points

- Both fast and slow stretch-shortening cycle (SSC) exercise intervention based on the ground contact time induces similar improvement in non-athlete females.
- Exercises based on the SSC muscle action cannot be used to develop specific physical fitness abilities with similar SSC muscle action.
- For example, the drop jump (i.e., fast SSC exercise) intervention does not necessarily show greater improvement in linear sprinting (i.e., fast SSC activity) compared to countermovement (i.e., slow SSC exercise) intervention.

Fast and slow jump training methods induced similar improvements in measures of physical fitness in young females

Abstract

This study aimed to contrast the impacts of an exercise intervention using either bounce drop jump (DJ; fast stretch-shortening cycle [SSC] exercise) or countermovement jump (CMJ; slow-SSC exercise) on measures of physical fitness in young females. A total of twenty-three young females (age: 19.7±1.0 years, height: 159.8±4.2 cm, body mass: 54.3±14.3 kg) were randomly assigned to either DJ (n=12) or CMJ (n=11) training, which spanned six weeks. Pre- and post-training assessments were conducted for 10 m and 30 m linear sprints, change-of-direction speed (CODS), CMJ, DJ (jump height, contact time, reactive strength index [RSI]), standing long jump (SLJ), triple-hop distance, and isometric strength. Apart from the variance in jump technique, both interventions were standardized in terms of total repetitions, intensity, and surface type. No significant group × time effect was observed in any dependent variables (all $p>0.05$). A significant time effect was observed in 10 m ($p<0.001$, ES = 0.70) and 30 m ($p<0.001$, ES = 0.79) linear sprint, CMJ height ($p=0.012$, ES = 0.34), DJ contact time ($p=0.012$, ES = 0.34), and triple-hop distance ($p=0.006$, ES = 0.38). Both DJ and CMJ training interventions led to comparable improvements in linear sprints, CMJ height, DJ contact time, and triple-hop distance. These findings suggest that the duration of ground contact during intervention exercises (i.e., fast vs. slow SSC) did not significantly influence initial (six-week) physical fitness adaptations in young females. However, extending these results to highly-trained groups (e.g., athletes) warrants further investigation.

Keywords: Plyometric exercise, human physical conditioning, resistance training, muscle strength, exercise, athletic performance.

Introduction

Plyometric jump training (PJT) involves effectively harnessing the stretch-shortening cycle (SSC) through exercise to induce a diverse range of human adaptations, including physiological, biomechanical, and anatomical changes (Markovic & Mikulic, 2010; Seiberl et al., 2021). For example, PJT has the potential to enhance various aspects such as muscle cross-sectional area, force, velocity, power capabilities, and electromyographic activity, among other adaptations (Arntz et al., 2022; Markovic & Mikulic, 2010). These adaptations likely contribute to the observed improvements in skill- (e.g., speed, jump, change of direction speed [CODS], balance) and health-related physical fitness components (e.g., strength, endurance, flexibility, body composition) that are commonly associated with PJT (Barrio, Alvarez, et al., 2023; Barrio, Thapa, et al., 2023; Ojeda-Aravena et al., 2023; Ramirez-Campillo et al., 2020; Ramirez-Campillo et al., 2022; Ramirez-Campillo et al., 2023; Singh et al., 2022).

The prescription of PJT exercises can be guided by factors such as direction-vector (e.g., horizontal, vertical), limb selection (e.g., unilateral, bilateral), and external load used (e.g., resisted, assisted) (Barrio, Thapa, et al., 2023). Additionally, PJT exercises can be classified into two categories: *fast* or *slow*, based on the movement speed, often measured by the duration that the foot remains in contact with the ground during the jump (referred to as ground contact time [GCT]) (Duda, 1988; Thapa et al., 2020). Typically, movements involving a GCT of ≤250 ms are categorized as *fast*, whereas those exceeding 250 ms are considered *slow* (Seiberl et al., 2021). Two exercises that exemplify opposite ends of this categorization spectrum are the bounce drop jump (DJ) and the countermovement jump (CMJ) (McMahon et al., 2018; Pedley et al., 2017). In the context of DJ, the GCT should be minimized to usually less than 250 ms (Pedley et al., 2017), while the GCT in a CMJ generally exceeds 500 ms (McMahon et al., 2018).

While DJ and CMJ exercises are commonly prescribed in PJT interventions, supposedly as exercises that target different SSC characteristics along the force-velocity curve spectrum, the individual effects of these exercises have seldom been directly compared within PJT studies (Barrio, Thapa, et al., 2023; Duchateau & Amiridis, 2023). In fact, to the best of the authors' knowledge, only two previous studies compared the isolated training effects of DJ and CMJ with one study conducted on non-professional female volleyball player (Ruffieux et al., 2020) and another conducted on male youth soccer players (Thomas et al., 2009). However, these studies primarily aimed to compare these two exercises based on variables other than GCT. For instance, in the study by Ruffieux et al. (2020), the authors did not explicitly outline whether participants received specific instructions to minimize GCT during DJs. Indeed, after the intervention, participants' performance in the DJ reached a GCT of ~380 ms. While Tomas et al. (Thomas et al., 2009) instructed participants to minimize GCT during intervention sessions, the authors did not measure (validate) GCT in the DJ exercises during PJT sessions. Furthermore, (Thomas et al., 2009) did not incorporate pre- and post-intervention assessments for GCT during DJ testing.

The potential significance of GCT during PJT exercises is consistent with the GCT observed during various physical fitness tests, thereby relating to the likelihood of adaptation transference (i.e., the principle of training specificity) (Duchateau & Amiridis, 2023; Loturco et al., 2015; Loturco et al., 2014; Ramirez-Campillo et al., 2019). For example, in linear sprinting, GCT is approximately ~200 ms during step 1 and ~120 ms from step 10 onward (Blauberger et al., 2021). Standing long jump and triple-hop jump involve GCT exceeding 250 ms (Davey et al., 2021), while CODS tests typically encompass GCT below 250 ms (e.g., linear sprint phase) as well as GCT of roughly 500 ms (e.g., directional changes) (Dos'Santos et al., 2020). Therefore, in line with the principle of training specificity (Laurent et al., 2020), it may be plausible to hypothesize distinct adaptations following DJ compared to CMJ training, resulting in greater improvements in physical fitness tests characterized by GCT of similar magnitude as the jump exercise conducted during the PJT intervention. However, whether the classification of PJT exercises based on the SSC duration (*fast* vs. *slow*) can be used for specific training adaptations is yet to be determined.

Moreover, Louder et al. (2023) have highlighted sex-related differences in DJ. Specifically, compared to males, females exhibited a lower reactive strength index (RSI), reduced rebound jump, and a more pronounced DJ peak force reduction (i.e., the difference between peak ground reaction force and first successive local minimum ground reaction force). Boullosa et al. (2020) documented enhanced 1000 m time trial performance in males after a DJ-based post-activation performance enhancement protocol, although this effect was not observed in females. In contrast, some studies have reported similar responses to PJT in both sexes (Ramírez-Campillo, Abad-Colil, et al., 2016; Ramírez-Campillo, Vergara-Pedreros, et al., 2016). Notably, the scarcity of PJT research involving females is a notable gap in this research domain (Ramirez-Campillo et al., 2020) with more studies required in the female population considering the anatomical [e.g., greater knee valgus during drop jump and landing (Prieske et al., 2015)] as well as physiological differences [e.g., the female athlete triad (Nazem & Ackerman, 2012)] from males, often increasing the risk of injuries (Legerlotz & Nobis, 2022). Moreover, whether the categorization of PJT exercises based on GCT could elicit improvements in non-SSC exercises, such as isometric leg strength, remains unclear, given that prior PJT studies have presented contrasting findings (Burgess et al., 2007; Lum et al., 2022). In addition, whether there are any differences in muscle pain after the PJT session based on GCT is unclear, with a recent scoping review reporting lack of studies actually reporting the pain perception in PJT studies (Ramirez-Campillo et al., 2020). Therefore, the main aim of this study is to contrast the effects of exercise based on fast-SSC (DJ) and slow-SSC (CMJ) on various measures of physical fitness in young females. Guided by the principle of training specificity, the hypotheses were as follows: (i) DJ training would lead to greater enhancements in linear sprint time and DJ performance metrics (jump height, GCT, RSI); (ii) CMJ training would result in superior improvements in countermovement jump (CMJ), standing long jump (SLJ), and triple-hop distance; and (iii) similar improvements in isometric strength and CODS would be observed after both DJ and CMJ training.

Methods

Participants

Based on a priori sample size estimation, 12 participants (6 per group) were indicated to effectively explore the interaction effect, considering a power of 0.80, an alpha error <0.05, a correlation of 0.5 between repeated measures, and an effect size f = 0.47 (i.e., large magnitude) (Ruffieux et al., 2020). Twenty-three young females who were a part of physical education curriculum at a university were initially contacted. The participants were recreationally active and can be classified as 'Tier 1' level according to participant classification framework by McKay et al. (2021). All participants initially involved in the study underwent an eligibility assessment through questionnaires, according to the following inclusion criteria: i) absence of significant lower limb injury in the last six months; ii) capability to perform both DJ and CMJ with correct technique (as detailed in the "experimental design" section) with no major discomfort or pain; iii) willingness to engage in twelve training sessions of either DJ or CMJ, along with pre-and post-intervention physical fitness measurements. Participants were not excluded based on their adherence to PJT. Nevertheless, an attendance rate classification was applied to explore the potential effects of changes between pre-and post-tests. All twenty-three participants were eligible and were randomly allocated (using an online randomization tool, www.randomizer.org) to either the DJ or CMJ training group, using a 1:1 allocation ratio. The allocation sequence remained concealed until the beginning of the study. The demographic features of participants within each group were similar (p = 0.261 – 0.529)

(Table 1). Participants were provided with an explanation of the potential risks and benefits associated with the study, and upon comprehension, informed consent forms were duly signed. The Internal Review Board of *****blinded for peer review***** provided ethical approval to conduct the study **(approval no. ******).** The methods outlined in this study are similar to a study protocol prospectively registered in the OSF platform for male participants with doi *****blinded for review*****.

*****Insert Table 1 near here*****

Experimental design

A two (within-subject; pre-post) by two (between-subject; CMJ and DJ groups) randomized study design was conducted to compare the effects of the CMJ and DJ interventions on various measures of physical fitness in females. Baseline and post-intervention assessments were performed between 1700 and 2000 h, with at least 48 h of rest after the last training session. The sequence of the testing order was the same for all the participants and tests. Outdoor assessments (i.e., linear sprints and CODS) during pre- and post-intervention were performed under similar environmental conditions of temperature, humidity, and wind velocity (i.e., 31.8 – 33.1 °C, 40.0 – 57.0 % [no rain], and 3.8 – 6.0 km.h^{-1}, respectively), reducing their potential effect on the result of the dependent variables.

Before group allocation, five familiarisation sessions of 20 to 30 min duration were conducted for the technical execution of the CMJ and DJ exercises. The first three sessions were focused on correcting the technical execution of jumping and landing during both exercises, with feedback on DJ GCT provided during these sessions. During these sessions, the focus was placed on a few critical verbal cues such as (i) spine erect and shoulders back, (ii) chest over knees, (iii) jumping straight up without excessive side-to-side or forward-backward movement, (iv) soft landing including toe-to-heel rocking and bent knee, and (v) instant recoil for the concentric part of the jump (for the DJ). The last two sessions focused on familiarising a typical DJ and CMJ session (50 jumps were performed in each session, from low to near-maximal or maximal intensity-effort) to be used during the intervention. All twenty-three participants were finally recruited based on the ability to perform both DJ and CMJ with the correct techniques (i.e., the ability to adhere to the five cues mentioned above). Anthropometric and demographic data were collected, and the testing procedures were explained during these familiarisation sessions. In addition, the proper use and familiarisation of a visual analog scale (Bijur et al., 2001) was also explained and practiced during the familiarisation 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 near here*****

Training intervention

Both the experimental groups followed the specific exercise protocol for six weeks, sufficient to induce adaptations in non-athletic populations (Markovic & Mikulic, 2010). Further, two sessions per week were selected based on previous indications that such PJT frequency is sufficient to induce positive physical fitness adaptations (Ramirez-Campillo, Álvarez, et al., 2018). Each group completed twelve PJT sessions in addition to their (similar) habitual physical activity sessions (i.e., all participants were enrolled in the same physical education classes). During the training sessions, the participants were given specific instructions while performing the DJ or CMJ. For example, the participants were instructed to jump as high and fast as possible while minimizing the ground contact time during DJ and to jump as high as possible during CMJ. To gradually increase the load on the musculoskeletal system (e.g., Achilles tendon), a softer surface (i.e., natural grass football pitch) was used in weeks 1 and 2, followed by a more rigid surface (i.e., concrete) in weeks 3-6 (Ramírez-Campillo et al., 2013). Detailed information regarding the weekly training load and progression that was used is provided in Table 2. In addition, a minimum of three participants from the DJ group were asked (at random) to perform DJ repetitions during training sessions using contact time jump platforms (Chronojump Boscosystem, Barcelona, Spain) to verify the expected GCT typical for this jump exercise (i.e., <250 ms) in weeks 2, 4, and 6.

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

Physical fitness variables

The physical fitness assessments were conducted on two separate days, with the outdoor assessments conducted on the first day (i.e., linear sprints and CODS) and laboratory-based assessments conducted on the second day (i.e., jumps and isometric maximal test). All the assessments were conducted by the same research assistants who were blinded to the participant’s group allocation. The participants underwent a general warm-up of approximately 10 minutes, including running at a self-selected pace and changing directions. Thereafter, participants performed dynamic stretching of the adductor (i.e., internal rotation), abductor (i.e., external rotation), hamstring (i.e., single stiff-leg forward bending stretch), glutes (i.e., hip flexion and extension), and ankles (i.e., ankle rotation) followed by five 10-m linear sprints at 60%, three linear sprints at 80%, and two sprints at 90% of self-estimated maximal effort (participants jogged back after each sprint to the starting point). After that, specific warm-ups precede each test.

Speed and change of direction speed

A 30 m linear sprint test was conducted to measure speed (maximal) with a 10 m split time (acceleration). In addition, the modified agility-T test was used to assess the CODS and was conducted with methods outlined in a previous study (Thapa, Clemente, et al., 2023). Both tests utilised reliable dual-beam photocell timing gates (Chronojump Boscosystem, Barcelona, Spain) (Thapa, Sarmah, et al., 2023) on a natural grass surface. Three trials were conducted for each test, with an inter-trial rest of 3 minutes. The best trial (lowest time) was selected for the analysis.

Jump-related performance

The CMJ, DJ, SLJ, and triple-hop test (double leg) jumps were conducted to assess the lower-body jump performance. The CMJ and DJ were assessed using a portable contact mat (Chronojump Boscosystem, Barcelona, Spain) with arms akimbo. The instructions during CMJ were to jump as high as possible, and instructions during DJ were to jump as high as possible whilst minimizing the GCT. Further, the DJ was conducted from a height of 20 cm (Torres-Banduc et al., 2021). The SLJ and triple-hop distance were measured using a measuring tape attached to the laboratory floor, with protocols for both tests available elsewhere (Singh et al., 2022; Wood, 2008). Three trials were conducted for each assessment, with a recovery period of ~3 minutes between trials. The best trial (highest value) was selected for analysis.

Isometric maximal strength

The isometric maximal strength (i.e., isometric mid-thigh pulls) was measured with a portable strain gauge with 160Hz frequency (Chronojump Boscosystem, Barcelona, Spain) attached to a leg dynamometer. The pulling bar was placed at the height of the individual's mid-thigh with an angle of 145° at the hip (Dos'Santos et al., 2017). Two sub-maximal trials were allowed to be performed following which the participants were asked to pull as hard as possible for ~5 seconds, aiming to straighten the legs without bending the back. Peak and average force (N) were recorded. Three trials were conducted with a three-minute rest period between trials, with the best trial (highest value) selected for analysis.

The interclass correlation coefficient (ICC) with 95% confidence interval (CI) for each physical fitness test is provided in Table 3.

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

Pain analogue scale

Pain perception after intervention sessions were assessed using a visual analog scale with a score of 0 to 10 points (Bijur et al., 2001). A google form was sent to each participant asking to report the perception of muscle pain in the lower limb from a scale of 0 (no pain) to 10 (worst possible pain). The forms were sent immediately, 24 h, and 48 h after the first (i.e., at week 1) and last (i.e., at week 6) training session.

Statistical analyses

All statistical analyses (unless stated differently) were performed using the SPSS software (version 20.0.0, IBM, New York, USA). The normality assumption was tested using the Shapiro-Wilk test. The normality assumptions were violated for SLJ and DJ height in the CMJ group and for 10 m linear sprint time and DJ contact time in the DJ group. A two-step method was used to transform the non-normal data (to normal) to perform the parametric tests with a detailed procedure available in the study by Templeton (2011). Normally distributed data were presented as mean and standard deviation, while non-normally distributed data were presented as median and interquartile range. Independent sample t-tests and Kruskal-Wallis tests were used to analyze the demographic and pain analog data. Two (pre-post) by two (CMJ, DJ) mixed design analysis of variance (ANOVA) was used to analyze the main effect of time and the interaction effects. Partial eta squared (η_p^2) derived from the ANOVA output were used as effect size (ES) scores. Further, paired t-tests were conducted to assess within-group changes. Hedge's *g* ES was calculated using the mean and standard deviation values of pre- and post-assessments using a customized Microsoft Excel Sheet. Percentage change scores were also calculated for each variable in each group using the equation in the Microsoft Excel sheet: $[(\text{mean}_{\text{post}} - \text{mean}_{\text{pre}})/\text{mean}_{\text{pre}}] \times 100$. The magnitude of effects for η_p^2 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 intraclass correlation coefficient (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

No significant difference was reported at baseline for any dependent variable (independent t-test $p = 0.098 – 0.968$).

Pain analogue scale

No between-group difference in the perception of pain was reported by the participants immediately ($p = 0.108 – 0.171$), 24 h ($p = 0.476 – 0.852$), and 48 h ($p = 0.476 – 0.662$) after the first and last training session.

Within-group analyses

A large main effect of time was observed in 10 m ($p<0.001$, ES = 0.70) and 30 m ($p<0.001$, ES = 0.79) linear sprint time, CMJ height ($p=0.012$, ES = 0.34), DJ contact time ($p=0.012$, ES = 0.34), and triple-hop distance ($p=0.006$, ES = 0.38).

Furthermore, significant moderate to small improvements were observed in the 10 m and 30 m linear sprint time ($p<0.001$-0.001, ES = 0.69 – 1.00) and triple-hop distance ($p=0.040$, ES = 0.38) in the CMJ group. For the DJ group, significant trivial to moderate enhancements were noted in the 10 m and 30 m linear sprint time ($p<0.001$-0.001, ES = 0.28 – 0.56), CMJ height ($p=0.015$, ES = 0.66), and triple-hop distance ($p=0.040$, ES = 0.16). The pre- to post-intervention percentage change scores are presented in Figure 2.

*****Figure 2 near here*****

Group × time effect

No significant group × time interaction was observed in any dependent variables (all $p > 0.05$). Detailed statistical outcomes are displayed in Table 4.

Discussion

This study aimed to compare the effects of DJ-based training (*fast* SSC) vs. CMJ-based training (*slow* SSC) on various measures of physical fitness in young females. The main findings indicated that both training interventions were equally effective in significantly improving 10 m and 30 m linear sprint, CMJ height, DJ contact time, and triple-hop distance. Contrary to the initial hypothesis, there were no significant difference between the groups in any dependent variables.

Improvements in physical fitness may be due to adaptations such as increased motor unit recruitment, enhanced motor unit firing strategy, improved intra-muscular coordination, reduced inhibition (i.e., Golgi tendon's inhibitory response), increased proprioception, enhanced stretch reflex, and enhanced concentric and eccentric muscle action which improves the SSC muscle function (Markovic & Mikulic, 2010). Moreover, PJT may also improve the muscle architecture of the lower limb (e.g., increased muscle thickness, pennation angle) (Arntz et al., 2022; Ramírez-delaCruz et al., 2022) and increased tendon stiffness (Moran et al., 2023; Ramírez-delaCruz et al., 2022), which are associated with improvement of athletic performance. The extent to which the mentioned potential adaptations occurred in distinct manners following DJ and CMJ training remains uncertain, as we did not assess physiological-biomechanical variables. Nonetheless, it is plausible that comparable biological adaptations could occur in young females after undergoing six weeks of DJ and CMJ training, considering the similar improvements in physical fitness achieved by these participants. However, it is important to note that participants were relatively new to PJT, placing them in the initial "any training is good training" phase of the training-induced adaptation continuum (ASCM, 2009; Kraemer & Ratamess, 2004). Therefore, it is feasible to argue that the aforementioned adaptations might have occurred primarily through effective utilization of the SSC during the PJT exercises, whether *fast* or *slow*. While the findings suggest that GCT may not serve as an optimal marker for tailoring jump training regimens to young females, the level of participants included in the study (i.e., non-athlete) precludes a robust conclusion. It is worth noting that participants did undergo five familiarisation sessions with both CMJ and DJ exercises. Nonetheless, these sessions may not represent a significant training stimulus. To ascertain whether GCT during PJT holds significance as an indicator for specific training prescription in young females, potentially yielding outcomes beyond physical fitness, especially over extended intervention periods (i.e., greater than six weeks), future studies could encompass additional physiological and biomechanical assessments.

Furthermore, both interventions did not yield any significant improvements in measures such as CODS, DJ height, DJ-RSI, SLJ distance, and IMTP peak force. This contrasts with a prior meta-analysis wherein PJT was shown to enhance CODS in both males and females (Asadi et al., 2016) and an experimental study that reported improved SLJ performance in physically active males (Singh et al., 2022). One potential explanation for this discrepancy could be attributed to the type of PJT used in the current study, which was primarily vertically oriented. A meta-analysis has previously reported that a combination of both vertical and horizontal PJT exercises (e.g., depth jumps, vertical jumps, and SLJs) tends to induce greater improvements in CODS compared to single-mode vertical jumps (e.g., depth jump or CMJs) (Asadi et al., 2016). In addition, another study highlighted superior gains in CODS through horizontal DJ training compared to vertical jump training (Dello Iacono et al., 2017). Indeed, Moran et al. (Moran et al., 2021) also underscored that horizontally-oriented PJT was more effective than vertically-oriented PJT in improving horizontally-orientated movement, a key element in CODS. In this sense, the CODS is known to be heavily dependent on horizontally oriented force production, with greater peak and mean horizontal propulsive force, shorter ground contact times, horizontally oriented peak resultant braking, and propulsive forces shown by faster athletes over critical instances of CODS movements (Dos'Santos et al., 2020). The orientation of the PJT exercise's direction vector could potentially account for the absence of improvement in the SLJ. While there was a slight enhancement in the DJ height and RSI, statistical significance was not achieved. Despite participants not experiencing an increase in DJ height, a significant reduction in DJ contact time was observed. This suggests that participants may have adapted their strategy to decrease GCT while maintaining the jump height after six weeks of PJT training. However, there was no notable improvement in RSI. A recent meta-analysis reported significant RSI improvements with PJT among healthy participants (Ramirez-Campillo et al., 2023). However, this study's sub-group analysis suggested that more than seven weeks of PJT and a frequency of three or more weekly sessions were necessary for substantial gains in RSI (Ramirez-Campillo et al., 2023). Therefore, a greater duration of PJT training is likely required to induce sufficient adaptations to improve the RSI in young females.

Furthermore, the IMTP did not exhibit improvements after PJT. These results align with a previous study that measured IMTP after six weeks of PJT intervention, reporting no improvement (Lum et al., 2022). Indeed, a ten-week PJT study found no significant increase in IMTP peak force (Cormie et al., 2010). The lack of training specificity in motor coordination may contribute to the lack of improvement in the IMTP peak force. Lastly, there were no between-group differences in pain perception after the first and last intervention sessions. It is likely that the participants were adapted to performing the specific exercises after the six-week intervention, while the five familiarisation sessions may have affected the pain score for the first training session. Indeed, to verify if the perception of pain is different between DJ and CMJ training sessions, a randomized cross-over study should be conducted to minimize the between-group variances.

Limitations

There are limitations in the present study that should be acknowledged. Firstly, we lost ~20% of participants during the interventions. Although the remaining participants had 100% adherence to the intervention, the attrition rate may have affected the final results. Secondly, the participants in the study were students with no prior experience in 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 principle of training specificity could be moderated by the training level of the participants. This aligns with guidelines for exercise prescription across several groups and institutions (e.g., ACSM (2009) position stand on progression models for resistance exercise). Thirdly, although we computed the sample size requirements using appropriate methods prior to the start of the intervention, a larger sample size may be appropriate for the 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 and kinematic changes that occurred during these tasks. Fifthly, a single drop height was used in the current study. An individualized drop height (e.g., using the optimal RSI) may affect the training responses (Ramirez-Campillo, Alvarez, et al., 2018). Sixthly, including session's rating of perceived exertion measurements could have further provided insight into the psycho-physiological aspects of the training load exerted by DJ or CMJ intervention. Lastly, the menstrual cycle of the participants were not considered during the intervention which could also have affected the results (e.g., the female athlete triad) (Nazem & Ackerman, 2012).

Conclusion

Physical fitness exhibited comparable enhancements following DJ and CMJ training interventions, suggesting that classifying PJT exercises based on GCT characteristics (i.e., *fast* vs. *slow* SSC) may not necessarily serve as an isolated indicator for tailoring PJT regimens to young non-athlete females. The multifaceted nature of physical fitness adaptations among young females suggests that attributing these improvements solely to the anticipated effects of SSC muscle actions employed during PJT might be overly simplistic.

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Tables

Table 1. Participants' demographics in countermovement jump (CMJ) and drop jump (DJ) training groups.

	CMJ (n=8)	**DJ (n=10)**	***P* – value***
Age (y)	19.4±1.1	19.9±1.0	0.436
Height (m)	1.61±0.05	1.59±0.04	0.529
Body mass (kg)	59.4±18.0	50.3±9.9	0.261

*Independent t-test

Table 2. Training load distribution across the six-week duration.

Week	**Drop jump group**	**Countermovement jump group**
	Repetitions × block × series	
1 – 2	10 × 3 × 3	10 × 3 × 3
3 – 4	12 × 3 × 3	12 × 3 × 3
5 – 6	14 × 3 × 3	14 × 3 × 3

* Rest between repetitions, blocks, and series: 3 – 5 s, 60 s, and 180 s, respectively; Both groups completed 1,296 jumps during the intervention.

Table 3. Interclass correlation coefficient (ICC) with 95% confidence interval (CI).

Variables	**ICC (95%CI)**
10 m sprint (s)	0.89 (0.80 – 0.94)
30 m sprint (s)	0.93 (0.89 – 0.96)
Change of direction speed (s)	0.89 (0.82 – 0.94)
Countermovement jump (cm)	0.91 (0.85 – 0.95)
Drop jump height (cm)	0.93 (0.89 – 0.96)
Drop jump contact time (s)	0.79 (0.67 – 0.88)
Drop jump reactive strength index (AU)	0.86 (0.78 – 0.92)
Standing long jump distance (m)	0.92 (0.86 – 0.95)
Triple-hop distance (m)	0.95 (0.90 – 0.97)
Isometric mid-thigh pull peak force (N)	0.92 (0.86 – 0.96)
Isometric mid-thigh pull average force (N)	0.88 (0.80 – 0.93)

Table 4. Between-group comparisons of changes in physical fitness variables before and after the training interventions

Variables	**CMJ group (n=8)**			**DJ group (n=10)**			**Time Effect**	**Group × Time**
	Pre	**Post**	**ES (*g*)**	**Pre**	**Post**	**ES (*g*)**	***P*-value (η_p^2)**	***P*-value (η_p^2)**
	Mean ± standard deviation			**Mean ± standard deviation**				
10 m sprint (s)	2.22±0.14	2.08±0.11*	1.00 ^{M}	2.21 (0.45) †	2.03 (0.26) †	0.56 ^{S}	**<.001** (.70) ^{L}	.930 (.001) ^{S}
30 m sprint (s)	5.66±0.41	5.39±0.32*	0.69 ^{M}	5.76±0.82	5.53±0.76*	0.28 ^{S}	**<.001** (.79) ^{L}	.590 (.019) ^{S}
CODS (s)	13.04±1.07	12.84±0.8	0.20 ^{S}	13.18±1.59	13.28±1.26	0.07 ^{T}	.768 (.01) ^{S}	.362 (.052) ^{S}
CMJ height (cm)	19.5±2.1	20.8±2.9	0.50 ^{S}	18.5±3.8	20.8±3.0*	0.66 ^{M}	**.012** (.34) ^{L}	.441 (.038) ^{S}
DJ height (cm)	16.7 (5.1) †	18.2±2.1	0.02 ^{T}	18.3±5.7	18.6±4.1	0.07 ^{T}	.698 (.01) ^{S}	.969 (.000) ^{S}
DJ contact time (s)	0.24±0.03	0.22±0.03	0.65 ^{M}	0.28 (0.09) †	0.23±0.03	0.85 ^{M}	**.012** (.34) ^{L}	.407 (.043) ^{S}
DJ RSI (au) ‡	0.76±0.10	0.80±0.13	0.27 ^{S}	0.72±0.30	0.76±0.26	0.16 ^{T}	.386 (.05) ^{S}	.875 (.002) ^{S}
SLJ distance (m)	1.65 (0.09) †	1.76±0.14	0.66 ^{M}	1.58±0.32	1.61±0.41	0.08 ^{T}	.375 (.05) ^{S}	.885 (.001) ^{S}
Triple-hop distance (m)	4.35±0.47	4.53±0.47*	0.38 ^{S}	4.42±0.98	4.58±1.00*	0.16 ^{T}	**.006** (.38) ^{L}	.865 (.002) ^{S}
IMTP peak force (N)	1412±288	1408±292	0.01 ^{T}	1234±126	1289±204	0.31 ^{S}	.455 (.04) ^{S}	.388 (.047) ^{S}
IMTP average force (N)	1373±293	1368±282	0.02 ^{T}	1206±119	1254±199	0.28 ^{S}	.501 (.03) ^{S}	.410 (.043) ^{S}

Note: CMJ – countermovement jump, CODS – change of direction speed, DJ – drop jump, ES (*g*) – Hedge's *g* effect size, η_p^2 – partial eta squared, IMTP – isometric mid-thigh pull, RSI – reactive strength index, SLJ – standing long jump, ^{T} – trivial, ^{S} – small, ^{M} – moderate, ^{L} – large, * – within-group pre to post significant difference, ‡ – au: arbitrary units denoting the ratio between flight time and time contact, † – non-normally distributed data, presented as median and interquartile range.

Figures with Captions

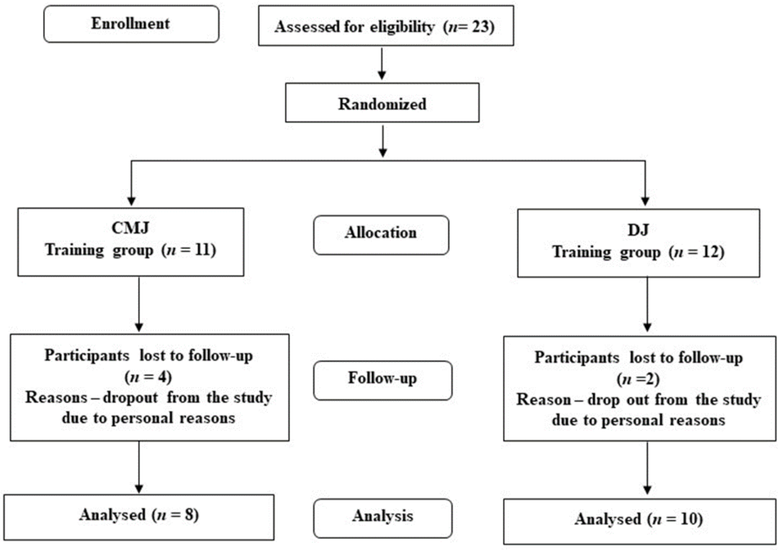

Figure 1. Schematic representation of the study stages.

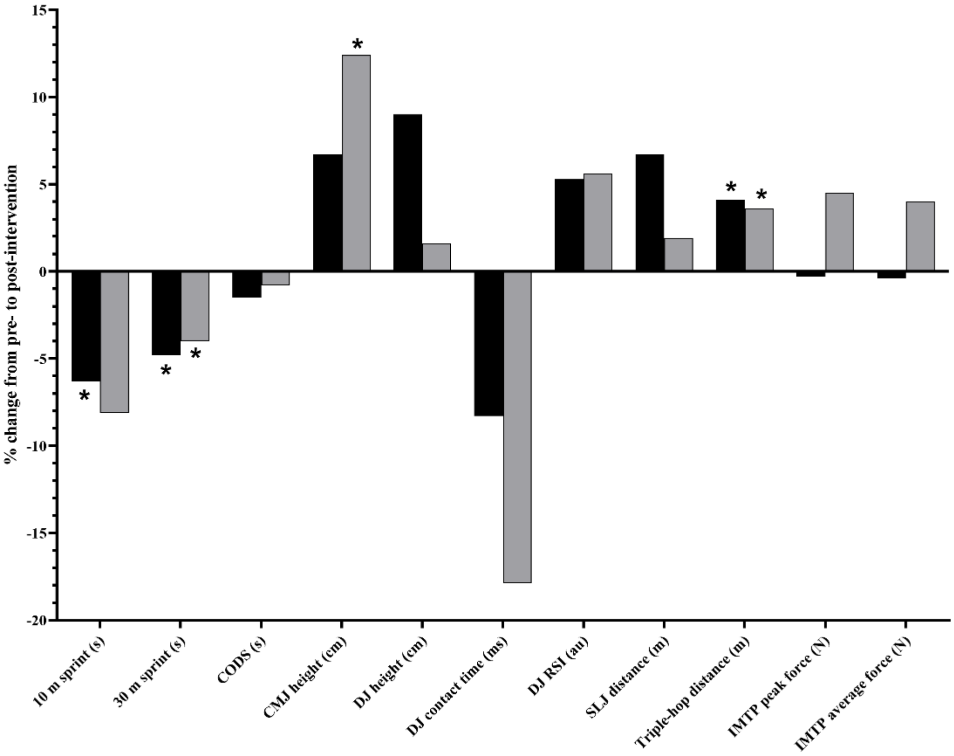

Figure 2. Graphical representation of pre- to post-intervention percentage change in physical fitness variables for each group. Note – black bars denote countermovement jump (CMJ), and grey bars denote drop jump (DJ) training groups. * - denotes significant difference from pre- to post-intervention, au – arbitrary units, CODS – change of direction speed, RSI – reactive strength index, SLJ – standing long jump, IMTP – isometric mid-thigh pull.