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Acute effect of bounce drop jump and countermovement drop jump with and without additional load on jump performance parameters and reactive strength index on young gymnasts

original paper
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ABSTRACT
Purpose. Reactive strength index defines an athlete's stretch-shortening cycle function and rebound capabilities. The purpose of the study was to examine the effect of two types of drop jumps (bounce drop jump: BDJ and countermovement drop jump: CDJ) on the jump parameters and reactive strength index under two different conditions (with and without additional load) from different drop box heights.
Methods. Twelve female artistic gymnasts aged 10–12 years old volunteered to participate in this study. Drop jumps (DJ) were performed from 20-, 25-, 30, and 35-cm heights under two conditions: without additional load (FREE) and with additional load (VEST).
Results. No interaction effect was found between the drop jump height, drop jump type and condition parameters, between the drop jump type and load parameters, or between the drop jump height and condition parameters. However, an interaction effect was observed between the drop jump type and load parameters for the reactive strength index. The drop box height (DBH) did not affect any of the dependent variables and the drop jump type with the VEST condition was more effective in improving the examined variables.
Conclusions. The CDJ produces a lower reduction in the jump height under both the FREE and VEST conditions from different DBHs with an optimum DBH of 30 cm, while stiffness can be improved with both types of jumps from a DBH 25 cm. The characteristics of jumps, such as BDJ and CDJ and DBH, are determinants of the resulting jump height.
Key words: jump height, stiffness, reactive strength index

Introduction

Artistic gymnastics is a sport characterised by rapid muscle contractions during the performance of acrobatic routines on various apparatuses, such as on the vault, balance beam and floor exercises, where explosive leg power plays an important role in connecting elements and acrobatic elements. Especially during the performance of complicated acrobatic series, e.g., double salto backward plus salto forward, where gymnasts must re-contract their muscles after landing, the reactive strength index (RSI) is a reliable indicator of successful performance of acrobatic elements. A common method to improve jump height is plyometric training (PT) [1], which is thought to be essential for the development and improvement of the Stretch-Shortening Cycle (SSC) [2]. Previous finding show that RSI is sport-dependent [3] and that the type of jump is affected differently by the applied PT. More specifically, PT has a greater effect on jump height (JH) in 'slow' stretching cycles (SSCs) such as Counter Movement Jump (CMJ) [4] or Countermovement Drop Jump (CDJ) than in either squat jump (SJ) or in 'fast' SSC jumps such as Bounce Drop Jumps (BDJ) [5], concluding that the DJ technique was the most important variable to be controlled to ensure adequate training effects [6].

The explosiveness in performing plyometric exercises (PE) referring to the RSI [7], which assesses an athlete's jumping ability to change from an eccentric contraction to a concentric contraction [8], and reactive strength [9] which is the quotient of the JH and contact time (Tc) [1, 10], supporting that RSI can increase following PT [2]. Therefore, effective performance re-

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quires an adequate level of lower limb power [11], by applying PT, such as drop jumps (DJs) [12], to assess RSI [13]. Performing a DJ, an athlete drops from a given height, usually between 20–60 cm [5] and immediately upon landing, performs a vertical jump of maximum effort while simultaneously trying to minimise the contact time (Tc) [6]. As Kinser et al. stated [14], DJs contain an eccentric and a concentric phase, which constitute a stretch-shortening cycle and depend both on the contractile elements and elastic properties of the muscle and connective tissue. However, it is claimed that muscle damage occurs when performing DJs due to eccentric contraction and high ground reaction forces [15]. Reactive strength defines an individual's ability to change from an eccentric contraction to a concentric contraction [8] and the reactive strength index (RSI) defines an athlete's stretch-shortening cycle function and evaluates the athlete's rebound capabilities [9], and can be calculated by dividing the height of the jump by the ground contact time [1]. The CMJ [5] and the DJ are two types of jumps which involve a preparatory movement downwards before a vigorous extension of the hips, knees and ankles propels the body upwards. The main difference between these two types is that in executing the DJ, the participant drops from a predetermined height and performs a maximal-effort vertical jump while also trying to minimise Tc on landing [6] in order to assess reactive strength [13]. However, the DJ manifests a larger magnitude and rate of eccentric loading than the CMJ, which stimulates a more effective utilisation of the stretch-shortening cycle, and in turn, greater force production in the concentric phase [16]. Although previous findings by Winchester and colleagues [17] report that an additional load is the best training stimulus to maximise power output, data by Larson [18] support that no differences exist in the jumping height between groups with and without additional load. However, additional loading during DJs will cause disruption to the SSC [19] due to the excessive stress on the muscles and joints [15] and the increase in the contact time.

The present study attempts to provide useful information concerning the more appropriate drop height with and without additional load for PT. Few studies have investigated whether one of these two types of jumps (BDJ and CDJ) are more effective in improving JH. To the best of our knowledge, no previous studies have examined the effect of BDJ and CDJ on DJ performance.

So, the purpose of the present study was to examine the effect of these two types of DJs on jump height (JH), Time of contact (Tc), stiffness, velocity, and reactive strength index (RSI), under two different conditions with additional load (VEST) and without additional load (FREE) from different drop box heights (DBH) (20, 25,30, 35 cm). It was hypothesised that DJs with an additional load (VEST) would produce greater gains in jump height (JH), Tc, stiffness, velocity, and RSI than DJs without an additional load (FREE) and that the CDJ will outperform the BDJ on the aforementioned variables. Furthermore, a hierarchical multiple regression analysis was conducted in order to predict the DV (JH).

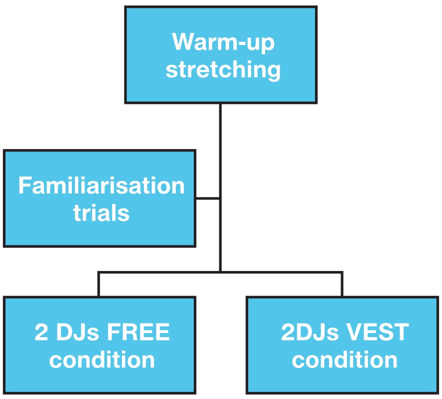
Material and methods

Subjects

Twelve competitive female artistic gymnastics, aged 10–12 years old (Tanner stage 1–2) [20] (age 11.25 ± 0.75 years; body mass 30.41 ± 1.83 kg; body height 132.75 ± 2.80 cm), volunteered to participate in the present study. All members had at least 4 years of specific gymnastics training history and were familiar with the exercises used (BDJ, CDJ) as they were part of their daily training practice. All subjects' parents gave written informed consent before participating in any of the testing. The participants were informed extensively about the experiment procedures and the possible risks or benefits of the project, and had no musculoskeletal injuries in the previous 6 months.

Testing procedure

Participants were assessed using a contact mat connected to a Chrono Jump Bosco/System unit and costumed stairway steps of 20-, 25-, 30-, and 35-cm height were used to allow the subjects to perform the DJs. The use of a contact mat has been proven as an effective assessment tool for gymnasts, allowing direct and immediate feedback in the gymnasium without altering the daily training [21]. The subjects were instructed to drop as vertically as possible on their toes, followed by their heels while minimising the forward displacement. Then a full extension followed and no leg flexion was allowed during the flight phase to minimise the flight time biases. The gymnasts performed a general warm-up, which consisted of a 2-min run on a motorised treadmill (Technogym Runrace 1200, Gambettola, Italy) at a speed of 2.22 $m \cdot s^{-1}$, followed by a light static stretching of the lower limbs [21–24]. After a passive recovery of 1 min, a familiarisation drop jump (DJ) was performed on each condition (with/without additional load). Two minutes later, each gymnast performed 2 DJs at each height with 1-min rest between trials in the FREE condition (total 8 DJs), and the next day, the same procedure was applied in the VEST condition [25]. The DJ that scored the highest JH was further statistical analysed. The examination was performed under two different conditions, without additional load (FREE) and with additional load (VEST) which corresponded to 7% of the body weight of the participant [26]. A total of 16 jumps per subject were performed (Figure 1). In order to minimise 'order effect', the drop box height (DBH) was randomly assigned to each participant. The main instruction was to 'drop as vertically as possible performing the maximum flight time (FT) and take-off immediately after the landing as quickly as possible with the shortest Tc'. The trial was repeated by the subject if the Tc was longer than 400 ms.



DJ – drop jump
FREE – without additional load, VEST – with additional load

Figure 1. Schematic representation of the experimental protocol

Statistical analysis

IBM SPSS 21 was used for the statistical analyses. The arithmetic mean, SD, and range were calculated for each variable and trial. The Shapiro-Wilk test was used to check the normality of the raw data. The impact of the drop-box height (DJH) (20, 25, 30 and 35 cm) type of jump (BDJ and CDJ) and the usage of additional load on the dependent variables (DV) (JH, Tc, stiffness, velocity, and RSI) was explored with a 3-way [DJH × type of jump × load] repeated measures analysis of variance. Sphericity was checked using Mauchly's test, and the Greenhouse-Geisser correction on degrees of freedom was applied when necessary. The presence of an interaction effect between the three factors was checked. In the absence of an interaction, the primary effects of the three factors (DJH, type of jump, load) on the DVs were investigated. All statistical significances were tested at the $\alpha = 0.05$ probability of type I error. Furthermore, a hierarchical multiple regression analysis was conducted to predict the JH for each type of jump and for each condition. The goal was to detect the sub variables (Ts, stiffness, velocity and RSI) that would significantly predict the JH of the participants.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Institutional Ethics Board, and all procedures, were in accordance with the ethics of the University of Athens (approval No.: 1369/20-4-2020).

Informed consent

Informed consent has been obtained from all individuals included in this study and their parents.

Results

The results showed no interaction effect between the three factors (DJH × drop jump type × load) for all the dependent variables: (i) Jump height: $F_{(3.33)} = 0.305$, $p = 0.821$; (ii) Tc: $F_{(3.33)} = 2.701$, $p = 0.061$; (iii) Tf: $F_{(3.33)} = 0.940$, $p = 0.433$; (iv) Stiffness: $F_{(3.33)} = 0.417$, $p = 0.742$; (v) Velocity: $F_{(3.33)} = 0.529$, $p = 0.606$; and RSI: $F_{(3.33)} = 0.678$, $p = 0.556$. No interaction effect between the factors drop jump type and load was found for the following dependent variables: (i) Jump height: $F_{(1.33)} = 1.509$, $p = 0.245$; (ii) Tc: $F_{(1.33)} = 1.714$, $p = 0.217$; (iii) Tf: $F_{(1.33)} = 0.879$, $p = 0.369$; (iv) Stiffness: $F_{(1.33)} = 2.866$, $p = 0.119$; (v) Velocity: $F_{(1.33)} = 0.449$, $p = 0.517$. However, there was an interaction effect between type of jump and load for the RSI: $F_{(3.33)} = 6.704$, $p = 0.025$. Furthermore, no interaction effect between the factors DJH and load was found for all the dependent variables: (i) Jump height: $F_{(3.33)} = 1.775$, $p = 0.171$; (ii) Tc: $F_{(3.33)} = 1.571$, $p = 0.215$; (iii) Tf: $F_{(3.33)} = 1.181$, $p = 0.332$; (iv) Stiffness: $F_{(3.33)} = 1.850$, $p = 0.157$; (v) Velocity: $F_{(3.33)} = 0.741$, $p = 0.535$. Statistical analysis showed no significant primary effect for the factor DJH for all the dependent variables: (i) Jump height: $F_{(3.33)} = 1.358$, $p = 0.273$; (ii) Tc: $F_{(3.33)} = 1.351$, $p = 0.275$; (iii) Tf: $F_{(3.33)} = 1.090$, $p = 0.367$; (iv) Stiffness: $F_{(3.33)} = 1.975$, $p = 0.137$; (v) Velocity: $F_{(3.33)} = 0.218$ $p = 0.883$.

However, a significant primary effect for the factor drop jump type was found for: (i) Jump height: $F_{(1.11)} = 15.467$, $p = 0.002$ (Table 1); (ii) Tc: $F_{(1.11)} = 6.682$, $p = 0.025$ (Table 2); (iii) Stiffness: $F_{(1.11)} = 22.625$, $p = 0.001$ (Table 3); (iv) Velocity: $F_{(1.11)} = 13.468$, $p = 0.004$ (Table 4);

and (v) RSI: $F_{(1.11)} = 20.497$, $p = 0.001$ (Table 5). Also, a significant primary effect for the factor load was found for: (i) Jump height: $F_{(1.11)} = 15.412$, $p = 0.002$ (Table 1); (ii) Stiffness: $F_{(1.11)} = 5.637$, $p = 0.037$ (Table 3); (iii) Velocity: $F_{(1.11)} = 15.648$, $p = 0.002$ (Table 4); RSI: $F_{(1.11)} = 9.832$, $p = 0.01$ (Table 5). However, ignoring the DBH, the per cent differentiation of each type of jump is at the same levels between the two conditions (7.16% and 7.66%, respectively) (Figure 2).

This study employed a correlational design. The criterion variable (DV) was jump height (JH) and there were four predictor variables; velocity, RSI, Tc, and stiffness. The purpose was to examine whether the JH can be predicted from their predictor variables. A hierarchical multiple regression analysis was conducted for each type of jump (BDJ-CDJ) and for each condition (BDJ-CDJ) separately, in order to predict the DV

Table 1. Descriptive data for JH on BDJ and CDJ on FREE and VEST conditions from various DBH (mean ± *SD*)

Drop jump type		JH (cm)			
	BDJ	22.15 ± 4.68			
	CDJ	24.47 ± 4.98 ↑			
		BDJ FREE	BDJ VEST	CDJ FREE	CDJ VEST
		23.47 ± 4.20[$]	21.79 ± 4.36	25.44 ± 4.85[$]	23.49 ± 4.97
		DBH			
		20	25	30	35
	BDJ	21.93 ± 4.97	22.26 ± 4.68	23.45 ± 5.01	20.94 ± 3.93
	CDJ	25.03 ± 4.99 ↑	24.44 ± 5.11 ↑	24.19 ± 4.62	24.21 ± 5.46 ↑
FREE	BDJ	23.43 ± 4.77	24.00 ± 4.56	23.90 ± 4.55	22.55 ± 3.11
	CDJ	25.72 ± 4.68 ↑	26.04 ± 4.87 ↑	24.70 ± 4.77	25.30 ± 5.56
VEST	BDJ	20.43 ± 4.89	20.52 ± 4.28	22.20 ± 5.13	19.33 ± 4.12
	CDJ	24.33 ± 5.38 ↑	22.84 ± 5.03 ↑	23.67 ± 4.60	23.11 ± 5.36 ↑

JH – jump height, BDJ – bounce drop jump, CDJ – countermovement drop jump, DBH – drop box height
FREE – without additional load, VEST – with additional load
[$] significant higher values compared to VEST, ↑ significant higher values compared to BDJ
$p < 0.001$

Table 2. Descriptive data for Tc on BDJ and CDJ on FREE and VEST conditions from various DBH (mean ± *SD*)

Type of jump		Tc (ms)			
	BDJ	0.309 ± 0.16			
	CDJ	0.397 ± 0.11 ↑			
		BDJ FREE	BDJ VEST	CDJ FREE	CDJ VEST
		0.306 ± 0.14	0.311 ± 0.18	0.391 ± 0.14	0.403 ± 0.07
		DBH			
		20	25	30	35
	BDJ	0.284 ± 0.16	0.328 ± 0.25	0.310 ± 0.21	0.247 ± 0.06
	CDJ	0.380 ± 0.08 ↑	0.425 ± 0.16	0.422 ± 0.08 ↑	0.399 ± 0.08 ↑
FREE	BDJ	0.220 ± 0.05	0.278 ± 0.15	0.272 ± 0.18	0.240 ± 0.07
	CDJ	0.353 ± 0.10	0.456 ± 0.22	0.369 ± 0.09	0.383 ± 0.08
VEST	BDJ	0.349 ± 0.22	0.293 ± 0.16	0.349 ± 0.24	0.254 ± 0.04
	CDJ	0.406 ± 0.50	0.393 ± 0.60	0.398 ± 0.09	0.415 ± 0.08 ↑

Tc – contact time, BDJ – bounce drop jump, CDJ – countermovement drop jump, DBH – drop box height
FREE – without additional load, VEST – with additional load
↑ significant higher values compared to BDJ
$p < 0.001$

Table 3. Descriptive data for stiffness on BDJ and CDJ on FREE and VEST conditions from various DBH (mean ± *SD*)

Drop jump type		Stiffness ($kN \cdot m^{-1}$)			
	BDJ	14,404 ± 6,948.70			
	CDJ	6,932.34 ± 2,977.19↑			
		BDJ FREE	BDJ VEST	CDJ FREE	CDJ VEST
		16,113.73 ± 7,725.12$	13,009.23 ± 6,840.09	7,163.75 ± 3,370.93$	6,155.81 ± 2,174.19
		DBH			
		20	25	30	35
	BDJ	15,436.23 ± 7,665.77	12,999.67 ± 7,453.52	14,325.21 ± 7,176.95	14,857.38 ± 5,483.86
	CDJ	6,993.25 ± 2,958.38	7,247.67 ± 2,998.93	7,711.25 ± 3,618.43	6,317.21 ± 2,282.57
FREE	BDJ	17,588.42 ± 6,189.12	13,458.00 ± 8,155.35	17,331.08 ± 9,780.83#	16,077.42 ± 6,543.80
	CDJ	8,212 ± 3,604.39#	6,032.17 ± 2,993.37	7,738.17 ± 4,279.51	6,672.00 ± 2,250.51
VEST	BDJ	13,285.25 ± 8,629.29	12,541.33 ± 7,013.72	12,573.00 ± 7,647.24	13,637.33 ± 4,100.00
	CDJ	5,773.83 ± 1,436.58	6,282.67 ± 1,944.57	6,604.33 ± 2,891.53	5,962.42 ± 2,356.80

BDJ – bounce drop jump, CDJ – countermovement drop jump, DBH – drop box height
FREE – without additional load, VEST – with additional load
$ significant higher values compared to VEST, ↑ significant higher values compared to BDJ

Table 4. Descriptive data for velocity on BDJ and CDJ on FREE and VEST conditions from various DBH (mean ± *SD*)

Type of jump		Velocity (m/s)			
	BDJ	2.075 ± 0.230			
	CDJ	2.184 ± 0.230↑			
		BDJ FREE	BDJ VEST	CDJ FREE	CDJ VEST
		2.137 ± 0.190#	2.012 ± 0.250	2.235 ± 0.220#	2.134 ± 0.230
		DBH			
		20	25	30	35
	BDJ	2.060 ± 0.24	2.081 ± 0.22	2.098 ± 0.21	2.059 ± 0.26
	CDJ	2.203 ± 0.23↑	2.183 ± 0.23↑	2.185 ± 0.23	2.165 ± 0.26
FREE	BDJ	2.133 ± 0.22#	2.162 ± 0.21#	2.156 ± 0.21#	2.098 ± 0.15
	CDJ	2.235 ± 0.21	2.262 ± 0.19#	2.226 ± 0.26	2.216 ± 0.26
VEST	BDJ	1.987 ± 0.25	2.001 ± 0.22	2.041 ± 0.19	2.020 ± 0.34
	CDJ	2.172 ± 0.25	2.104 ± 0.24	2.145 ± 0.21	2.114 ± 0.26

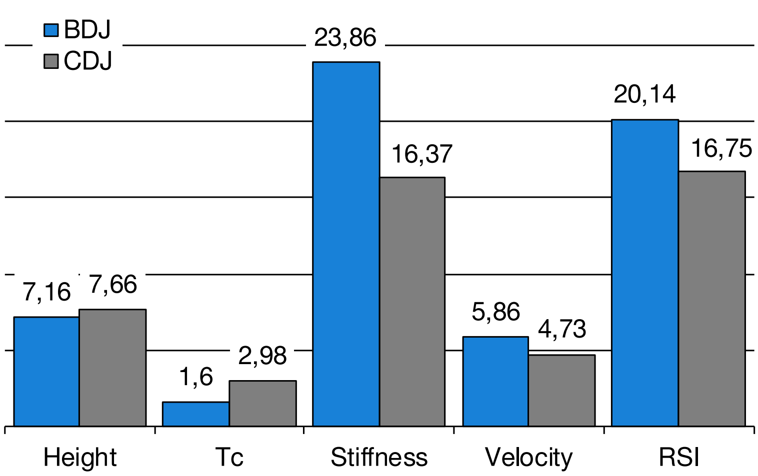
BDJ – bounce drop jump, CDJ – countermovement drop jump, DBH – drop box height
FREE – without additional load, VEST – with additional load
↑ significant higher values compared to BDJ, # significant higher values compared to VEST
$p < 0.001$

(jump height: JH). According to the analysis, there are mainly two factors (velocity and RSI) that contribute significantly to JH during the performance of a BDJ and CDJ. More specifically, in BDJ FREE, velocity ($t = 45.09$, $p < 0.001$, and RSI ($t = 2.53$, $p < 0.05$) positively predicted JH, where a higher velocity and higher RSI were associated with a higher JH. The final model was significant, $F_{(4.43)} = 2.386$, $p < 0.001$, and explained 99.5 per cent of the variance of the JH. The coefficients are shown in Table 6. In BDJ VEST, velocity ($t = 5.24$, $p < 0.001$) positively predicted JH, so that a higher velocity was associated with a higher JH. The final model was also significant, $F_{(4.43)} = 14.27$, $p < 0.001$, and explained 57.0 per cent of the variance of the JH. The coefficients are shown in Table 7. In CDJ FREE, velocity ($t = 6.12$, $p < 0.001$); RSI ($t = 6.89$, $p < 0.001$); Tc ($t = 4.39$, $p < 0.001$) positively predicted JH. The fi-

Table 5. Descriptive data for RSI on BDJ and CDJ on FREE and VEST conditions from various DBH (mean ± *SD*)

Type of jump		RSI			
	BDJ	0.951 ± 0.37 ↑			
	CDJ	0.647 ± 0.17			
		BDJ FREE	BDJ VEST	CDJ FREE	CDJ VEST
		1.038 ± 0.38$	0.864 ± 0.35	0.697 ± 0.19$	0.597 ± 0.15
		DBH			
		20	25	30	35
	BDJ	0.959 ± 0.44 ↑	0.946 ± 0.39 ↑	1.031 ± 0.37 ↑	0.868 ± 0.27 ↑
	CDJ	0.682 ± 0.17	0.618 ± 0.19	0.661 ± 0.18	0.624 ± 0.17
FREE	BDJ	1.114 ± 0.38 ↑$	1.031 ± 0.44	1.061 ± 0.43	0.944 ± 0.26 ↑$
	CDJ	0.760 ± 0.16 ↑$	0.648 ± 0.24	0.697 ± 0.18	0.679 ± 0.18 ↑$
VEST	BDJ	0.804 ± 0.47	0.861 ± 0.33	1.001 ± 0.30	0.791 ± 0.26
	CDJ	0.605 ± 0.14	0 .588 ± 0.13	0.626 ± 0.18	0.569 ± 0.14

RSI – reactive strength index, BDJ – bounce drop jump, CDJ – countermovement drop jump, DBH – drop box height
FREE – without additional load, VEST – with additional load
↑ significant higher values compared to CDJ, $ significant higher values compared to VEST
$p < 0.001$



Tc – contact time
RSI – reactive strength index
BDJ – bounce drop jump
CDJ – countermovement drop jump

Figure 2. Percent difference on each type of jump between FREE and VEST condition

nal model was significant, $F_{(4.43)} = 272.85$, $p < 0.001$, and explained 96.2 per cent of the variance of the JH. The coefficients are shown in Table 8. In CDJ VEST, velocity ($t = 19.07$, $p < 0.001$, and stiffness ($t = –2.62$, $p < 0.05$) predicted the JH. The final model was significant, $F_{(4.43)} = 3{,}482$, $p < 0.001$, and explained 99.7 per cent of the variance of the JH. The coefficients are shown Table 9.

Discussion

The main findings of the study do not support the initial hypothesis that DJs with additional load (VEST) compared to the jumps performed without additional load (FREE) will improve each of the examined DVs (JH, Tc, stiffness, velocity, RSI). The results show that DBH does not affect any of the DVs, therefore the participants were equally effective in performing these jumps. However, our hypothesis that the CDJ is more efficient than the BDJ on the examined DVs was verified. The CDJ significantly differentiates the JH, Tc, stiffness, velocity and RSI on DJ performance. Despite the fact that no interaction effect was found between the three factors (DJH × drop jump type × load), it is mentioned that these differences are reported only for DBH 20 and DBH 25, with the CDJ displaying signifi-

Table 6. Coefficients obtained from hierarchical multiple regression analysis of BDJ FREE condition

	B	SEB	β
Step 1			
Constant	–22.8	0.53	
Velocity	21.6	0.25	0.99***
Step 2			
Constant	–22.04	0.54	
Velocity	21.06	0.29	0.97***
RSI	0.48	0.15	0.04**
Step 3			
Constant	–21.99	0.53	
Velocity	20.88	0.30	0.96***
RSI	0.62	0.17	0.05***
Tc	0.61	0.35	0.02
Step 4			
Constant	–21.54	0.84	
Velocity	20.64	0.46	0.95***
RSI	0.81	0.32	0.07*
Tc	0.59	0.35	0.02

RSI – reactive strength index, Tc – time contact
R^2 = 0.99 for step 1 (p < 0.001)
ΔR^2 = 0.01 for step 2 (p < 0.01)
* p < 0.05, ** p < 0.01, *** p < 0.001
$R^2_{\chi 1}$ = 0.994, $R^2_{\chi 2}$ = 0.001

Table 7. Coefficients obtained from hierarchical multiple regression analysis of BDJ VEST condition

	B	SEB	β
Step 1			
Constant	–3.29	3.63	
Velocity	12.46	1.79	0.72***
Step 2			
Constant	–2.13	3.48	
Velocity	10.46	1.89	0.60***
RSI	3.31	1.36	0.26*
Step 3			
Constant	–2.13	3.62	
Velocity	10.46	1.95	0.60***
RSI	3.31	1.62	0.26***
Tc	0.02	2.83	0.01
Step 4			
Constant	–1.69	4.18	
Velocity	10.40	1.98	0.60***
RSI	–0.56	3.89	–0.23
Tc	0.59	0.35	0.02
Stiffness	0.00	0.00	–0.41

RSI – reactive strength index, Tc – time contact
R^2 = 0.52 for step 1 (p < 0.001)
ΔR^2 = 0.56 for step 2 (p < 0.05)
* p < 0.05, *** p < 0.001
$R^2_{\chi 1}$ = 0.514, $R^2_{\chi 2}$ = 0.056

Table 8. Coefficients obtained from hierarchical multiple regression analysis of CDJ FREE condition

	B	SEB	β
Step 1			
Constant	–20.74	2.63	
Velocity	12.46	2.07	0.96***
Step 2			
Constant	–20.74	1.93	
Velocity	19.86	0.93	0.92***
RSI	2.57	1.10	0.10*
Step 3			
Constant	–21.15	1.75	
Velocity	16.58	1.29	0.77***
RSI	8.59	2.06	0.34***
Tc	9.08	2.73	0.26**
Step 4			
Constant	–9.81	2.81	
Velocity	10.38	1.69	0.48***
RSI	17.05	2.47	0.67***
Tc	9.89	2.25	0.28***
Stiffness	–0.001	0.00	–0.36***

RSI – reactive strength index, Tc – time contact
R^2 = 0.92 for step 1 (p < 0.001)
ΔR^2 = 0.01 for step 2 (p < 0.050)
ΔR^2 = 0.01 for step 3 (p < 0.01)
ΔR^2 = 0.02 for step 4 (p < 0.001)
* p < 0.05, ** p < 0.01, *** p < 0.001
$R^2_{\chi 1}$ = 0.919, $R^2_{\chi 2}$ = 0.009, $R^2_{\chi 3}$ = 0.017, $R^2_{\chi 4}$ = 0.017

Table 9. Coefficients obtained from hierarchical multiple regression analysis of CDJ VEST condition

	B	SEB	β
Step 1			
Constant	–21.55	0.41	
Velocity	21.10	0.19	0.96***
Step 2			
Constant	–21.66	0.42	
Velocity	21.25	0.25	1.01***
RSI	-0.35	0.41	–0.01
Step 3			
Constant	–21.84	0.49	
Velocity	20.65	0.87	0.97***
RSI	0.83	1.68	0.02
Tc	1.86	2.59	0.03
Step 4			
Constant	–18.32	1.42	
Velocity	19.13	1.00	0.91***
RSI	3.21	1.83	0.09
Tc	0.47	2.49	0.07
Stiffness	0.00	0.00	–0.01*

RSI – reactive strength index, Tc – time contact
R^2 = 0.99 for step 1 (p < 0.001)
* p < 0.05, ** p < 0.01, *** p < 0.001
$R^2_{\chi 1}$ = 0.996

cant higher values than the BDJ ($p < 0.05$). The type of jump significantly differentiates the JH, Tc, stiffness, velocity and RSI. Significant differences were observed in JH only by DBH 20, DBH 25 and DBH 35, showing significantly higher values in CDJ than the corresponding BDJ values.

Although, no statistically significant differences were revealed, results showed that there was a trend towards higher JH values from DBH 20 and DBH 25 cm in each condition (FREE/VEST), whereas there was also a trend towards decreasing JH performance as the DBH increased in each type of jump when performed under each condition (FREE or VEST). In addition, results showed that the JH was reduced when the DJs were performed under the VEST condition. This finding can be explained by the fact that in this case, VEST elicited a longer time between the eccentric and concentric peak power, decreasing the efficacy of the SSC by a greater loss of stored elastic energy by minimising the contribution of elastic elements of the muscle-tendon unit [27] inducing excessive stress on the muscles and joints [15], as well as increasing contact time, and these two variables considerably deteriorated the SSC [19]. It is noted that as the DBH increased, there was also an increase in Tc and therefore the JH did not change [28]. A possible interpretation of the higher values in CDJ than BDJ is that gymnasts are more familiar with this type of jump since a similar method of take-off is observed in the majority of the gymnastics exercises performed during training. Our findings are in line with previous data which state that the use of an additional load (VEST) is not recommended to increase the effectiveness of PT [18] and thus may have a negative effect on JH as increase Tc and induce excessive stress on the muscles and joints, [12] causing considerable deterioration of the SSC [19]. This supports the findings by Young et al. [29], who found no group differences in CMJ height, and reinforces the findings by Matic et al. [30], who reported that DBH should have some adjustment based on each participant's neuromuscular capacity to produce maximal muscle strength. However, our findings oppose to those of Marshall and Moran [10], who found that CDJ significantly increased the CMJ height compared to BDJ in adult students. A higher DBH will result in a lower JH, which strengthens the findings of Komi [31], who emphasised that the level of the participants is a factor that affects performance, since untrained individuals show a decrease in performance as the DBH increases. The fact that the DBH was the same for all practitioners may have had a different effect on each participant as a previous study stated that an increment in JH was revealed when subjects performed DJs from their optimal DBH, whereas no increment was observed when performing from a fixed DBH [32].

The CDJ showed significantly JH higher values than the BDJ regardless of the condition (FREE & VEST) and the DBH, as well as significantly higher average values in the FREE condition in each type of jump (BDJ, CDJ) ignoring the DBH. In addition, the CDJ showed significantly higher values in the FREE compared to the VEST condition. The percentage difference of each type of jump between the two conditions (7.16% and 7.66%, respectively) fluctuated at the same levels, indicating that the condition (FREE/VEST) does not affect the JH (Figure 2). The fact that participants showed higher JH values from a lower DBH is also related to the spinal stretch reflexes and H-reflexes that are dependent on the DBH [33]. In turn, these reflexes influence the stiffness characteristics of the muscle-tendon complex [34], creating higher values of stiffness at low DBHs and therefore the resulting muscular activity at the short latency response (SLR) was hypothesised to result in higher muscle stiffness and therefore an improved capacity to store elastic energy [35]. The JH loss between the two conditions is smaller in the CDJ due to the greater amount of elastic energy stored as a consequence of the longer eccentric phase. The respective values for the CDJ at DBH 20, 25, 30 and 35 cm were 22.4%, 24.8%, 18.9% and 20.9%, respectively, whereas the corresponding values for the BDJ were 30.0%, 34.4%, 20.1% and 28.4%, respectively. Our results partly confirm the findings by Peng [36], who found that the stiffness decreases gradually with the increasing DBH, resulting in smaller SSC benefits. In addition, as Taube et al. stated, dropping from a higher DBH causes the DJ to overstretch the muscles during landing, decreasing the lower extremity stiffness, which easily induces the neuroprotective inhibition process and reduces the Hoffmann reflex activity [37]. Our results support that an appropriate level of joint stiffness can effectively trigger the SSC mechanism to improve the JH. Taking into consideration that RSI is a method to measure optimal DJ height, our study showed that RSI revealed the highest values for the BDJ FREE condition. It seems there is a relation between JH and DBH due to the capacity of the neuromuscular system not only to use the SSC efficiently but also to protect the muscle-tendon unit from potential injury when the DBH increases; a response that is made possible by spinal inhibitory neural mechanisms [38, 39]. In other words, the DBH influences the neuromuscular activity and through this, the jumping technique [33, 38]. It is recommended to carry out a future study taking into account the contact time when performing the DJ in order to determine the ideal DBH for each participant, and consequently, JH improvement.

Significantly lower Tc values in the BDJ than in the CDJ can be attributed to the elastic energy stored in the eccentric phase and in its reuse in the following concentric phase, regardless the condition and the DBH ($p < 0.001$). However, there were no significant differences between the 2 conditions for the BDJ and CDJ ($p > 0.05$). This finding is in contrast with the data of Struzik et al. [40], who found significant differences on Tc between the two types of jumps, even from different DBHs. Regarding the DBH in the CDJ, there was a gradual increase of the Tc from DBH 20, DBH 25 and DBH 30. However, the differences in the Tc of each type of jump did not differ significantly from the DBH, except for VEST 35. It seems that, in this case, participants need a longer Tc to meet the requirements of the CDJ from DBH VEST 35.

Furthermore, the BDJ showed significantly higher stiffness values than the CDJ, supporting previous data by Sugimoto et al. [41], who revealed a correlation between Tc and leg stiffness. Furthermore, stiffness differs significantly between the two types of jumps in the FREE ($p < 0.001$) and VEST ($p < 0.001$) conditions, showing that the condition does not affect this parameter. In terms of velocity, the condition significantly differentiates this DV with BDJ FREE showing significantly higher values than BDJ VEST. Nevertheless, the per cent reduction of stiffness between the two conditions differs significantly in the BDJ (23.86%, $p < 0.05$), while the corresponding in the CDJ was 16.97% ($p < 0.05$) (Figure 2). Finally, RSI differs significantly between the two types of jumps, displaying higher values in the BDJ FREE than in the BDJ VEST condition, while in the VEST condition, the CDJ is superior compared to BDJ FREE. As the findings by Struzik et al. [40] revealed, significant differences in JH and velocity between BDJs and CDJs induce significant differences, including in the RSI value. The percentage reduction in BDJ FREE is 20.14%, while the corresponding in CDJ FREE is 16.75% (Figure 2). However, although there are no significant differences in RSI regarding the DBH, it is noteworthy that at DBH 30, there is an increase in RSI compared to the other DBHs (20, 25, 35) on the BDJ due to the higher velocity values. This may lead us to speculate that BDH 30 is the optional DBH from which these participants achieved the highest values in JH, velocity, and RSI. Lastly, referring to the results of the regression analysis, it is emphasised that velocity is the most important factor than contributes to the JH. In this area, trainers and participants should focus on performing jumps in which they will be able to achieve the maximum possible take-off velocity, taking into account the DBH and type of jump, emphasising the short Tc that will lead to RSI improvement. Training-wise, based on the finding of the present study, it can be suggested to incorporate jumps from 20 to 25 cm of DBH in order to improve jumping ability.

Conclusions

Due to the SSC, the CDJ causes less reduction in the JH in either the FREE or VEST condition when performed from different DBHs. Stiffness can be improved with both types of jumps. RSI does not differ in the BDJ regardless of the condition, while the CDJ is significantly affected by the VEST condition, and for this reason, it is not recommended for RSI improvement. Furthermore, for gymnasts in this age group (10–12 aged), it is recommended to perform jumps from a DBH of 20–25 cm. Conclusively, the type of jump (BDJ/CDJ) and DBH are determinants of JH, while the take-off velocity is the most important factor than contributes to the JH.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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