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ORIGINAL ARTICLE

Neuromuscular response between individualization and standardization of the height of the hurdle in single-leg jumps

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ABSTRACT

The aim of this study was to compare the neuromuscular response between unipedal jumps over different hurdle heights. Thirty-eight students were evaluated during continuous unipedal forward jumps with fixed hurdles (FH-20cm) and individualized hurdles (IH-60% of maximum vertical jump). Subjects were instructed to jump over four hurdles as quickly and powerfully as possible. Contact time (CT), vertical force and horizontal force were measured and then used to calculate rate of force development (RFD) and vertical stiffness (Kvert). Electromyography was measured in tibialis anterior and medial gastrocnemius muscles. CT was lower in FH (p < .002) and Kvert was higher in FH (p < .004) compared to IH. No differences were found in RFD or electromyographic responses. No significant differences were found in eccentric or concentric vertical peak forces, or the horizontal concentric peak force. Subjects in the 4th quartile had a shorter contact time (p < .008 – p < .001), a higher Kvert (p < .001 – p < .001), generated a higher concentric horizontal peak force (p < .001 – p < .001), a higher concentric vertical peak force (p < .001 – p < .001) and a higher RFD (p < .05 – p < .001) compared to those of the 1st quartile in IH and FH respectively. In the 4th quartile, FH had a lower contact time (p < .007), higher Kvert (p < .02) and RFD (p < .05). It is concluded that using a FH or IH in one-leg jumps over hurdles has a similar neuromuscular response in active subjects.

Keywords: performance analysis; plyometrics; EMG; stiffness; training.

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INTRODUCTION

Plyometric training is widely implemented across most sports because of its ability to generate high levels of muscular power, its ease of implementation, and its biomechanical similarity to sport-specific movements that contribute to competitive success (Markovic et al., 2007; Chelly et al., 2010). Coaches commonly incorporate plyometric exercises to enhance performance in key competitive actions, such as sprinting and changes of direction. Among these exercises, hurdle jumping most closely replicates the movement patterns required during these actions. Surveys conducted by Healy et al. (2019) and Loturco et al. (2023) among high-performance coaches revealed that 93% and 89%, respectively, identified hurdle jumping as the most frequently used exercise for plyometric training.

Despite its widespread use and perceived effectiveness in athletic training, research specifically examining the unilateral variant of hurdle jumping remains limited (Mero and Komi, 1987; Aura and Viitasalo, 1989; Cappa and Behm, 2011). Most studies have focused on the bilateral hurdle jump (Healy et al., 2019; Cappa and Behm, 2013; Kossow and Ebben, 2018). In general, these jumps are performed continuously, enabling a high level of muscle pre-activation and power output, which is facilitated by the stiffness generated by the neuromuscular system during the eccentric phase of muscle contraction (Cappa and Behm, 2013).

The wide variety of plyometric jumps makes it difficult to determine their relative intensity. To characterize exercise intensity, variables such as the magnitude of the applied force, ground contact time, mechanical power output, and the rate of force development can be evaluated. Jensen and Ebben (2007) proposed classifying jump intensity primarily on the basis of force production across several jumping exercises. However, most of the movements included in their analysis were initiated from a stationary standing position without a preceding flight phase.

The intensity exerted by the athlete during plyometric jumping is generally considered implicit, as maximal effort is expected in every repetition. However, in hurdle jumping, obstacle height represents an additional factor that influences exercise intensity. For example, Ronnestad et al. (2008) and Hariyanto et al. (2022) employed bilateral hurdle jumps but did not report the height of the hurdles. Hernández-Preciado et al. (2018) used a fixed hurdle height of 50 cm for all participants, whereas Van Lieshout et al. (2014) standardized hurdle height according to the height of the lateral femoral epicondyle. In contrast, Chelly et al. (2010) and Markovic et al. (2007) used both fixed and progressively increasing hurdle heights to increase training intensity.

Regarding hurdle height during bilateral hurdle jumps, Cappa and Behm (2011) demonstrated that when hurdle height exceeds 100–120% of the maximum height achieved during a countermovement jump (CMJ), power output, as reflected by the rate of force development (RFD), decreases. Similarly, Healy et al. (2020) investigated sprinters performing hurdle jumps over heights of 60, 75, and 90 cm and reported that increasing hurdle height resulted in longer ground contact times, indicating a decline in performance. More recently, Seki et al. (2023) evaluated bilateral hurdle jumps over hurdles measuring 76, 91, and 106 cm. Performance did not improve as hurdle height increased, and although hurdle height was increased by 30 cm, the athletes' centre of mass rose by only 5 cm. These findings suggest that obstacles substantially exceeding the maximum height attained during a CMJ are cleared primarily by increasing lower-limb flexion rather than by increasing the intensity of the movement.

Regarding unilateral hurdle jumps, Cappa and Behm (2011) examined performance using hurdle heights corresponding to 70%, 80%, and 90% of the maximum CMJ height. Ground contact time exceeded 250 ms

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at all hurdle heights, surpassing the threshold proposed by Schmidtbleicher (1992) for the fast stretch-shortening cycle (256, 259, and 262 ms, respectively). In addition, the rate of force development (RFD) decreased as hurdle height increased to 90% of CMJ height and was significantly lower than that observed during bilateral hurdle jumps. The coefficient of variation was 32%, indicating considerable inter-individual variability and suggesting that performance responses were not consistent across athletes. Based on these findings, a lower hurdle height of 60% of CMJ height was selected in the present study to investigate whether reducing the relative hurdle height could promote shorter ground contact times and a faster stretch-shortening cycle. Thus, the 60% value was not intended to represent a universally optimal percentage, but rather a theoretically informed reduction from the previously investigated 70–90% range. These findings highlight the need to determine whether hurdle height should be individualized during training. In practice, many plyometric training programs use hurdles of a fixed height, resulting in different relative exercise intensities among athletes. Therefore, the aim of the present study was to compare the neuromuscular responses to unilateral hurdle jumps performed over fixed hurdles of 20 cm (FH) and individualized hurdles set at 60% of the maximum countermovement jump (CMJ) height (IH).

MATERIALS AND METHODS

Continuous unilateral hurdle jumps were evaluated under two experimental conditions: fixed-height hurdles of 20 cm (FH) and individualized hurdle heights corresponding to 60% of each participant's maximum countermovement jump (CMJ) height (IH).

Participants

Thirty-eight healthy adults (19 women and 19 men) participated in this study (age: 25.9 ± 8.82 years; body mass: 69.3 ± 14.05 kg; height: 168.5 ± 11.06 cm; countermovement jump [CMJ] height: 34.5 ± 8.05 cm). Participants were recruited through an open invitation at the Instituto Universitario de Actividad Física y Deportes "*Dr. Jorge Coll*", Mendoza, Argentina.

Participants had no history of musculoskeletal injury within the six months preceding the study and were free of pain that could have limited maximal jumping performance. Individuals who had participated in organized competitive sports during the previous year were excluded. All participants regularly engaged in the physical training required as part of the Physical Education Teacher and Personal Trainer academic programs. The study was approved by the Ethics Committee of the National University of Catamarca, Argentina. Written informed consent was obtained from all participants in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013).

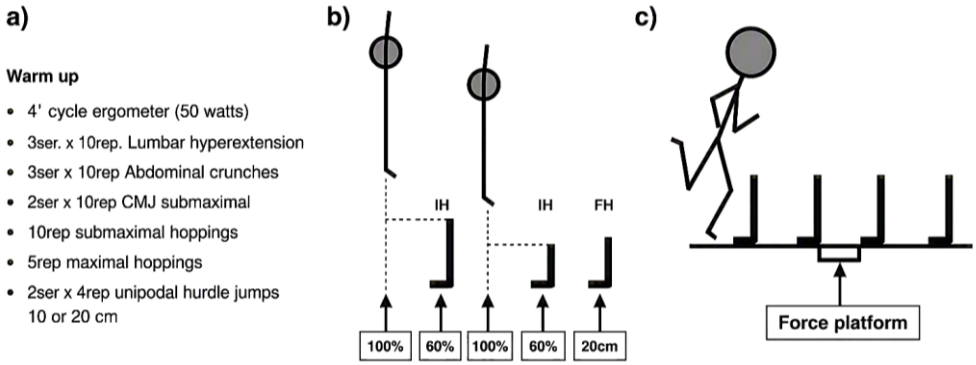
Procedures

Upon arrival at the laboratory, participants received a verbal explanation of the experimental protocol, completed the informed consent process, and underwent the collection of demographic information and basic anthropometric measurements.

Before jump testing, participants completed a standardized warm-up protocol (Figure 1A). The jumping leg and the spacing between hurdles were determined during two to three familiarization sets, in which participants selected the configuration that allowed them to perform the jumps at maximal execution speed while minimizing ground contact time. Subsequently, surface electrodes (FS-TC1/10 SKINTACT, Euroswiss S.A., Innsbruck, Austria) were placed over the mid-belly of the tibialis anterior and medial gastrocnemius muscles. Electromyographic activity was recorded in millivolts (mV) using a wireless electromyography system (Biosignalsplux Explorer, Lisbon, Portugal).

To record electromyographic activity, pre-gelled Ag/AgCl surface electrodes (3M) were used and positioned according to the SENIAM recommendations (Stegeman et al., 2007). The raw electromyographic signal was recorded at 1000 Hz using OpenSignals (r)evolution software and subsequently processed using MATLAB software. The signal was filtered using a sixth-order Butterworth filter with a 50 Hz cut-off frequency. Subsequently, the root mean square (RMS) value was calculated, and the mean activation value for each muscle was obtained during each exercise condition. Muscle activation was analysed throughout the contact phase of the jumps. Electromyographic data were normalized according to the muscle activation recorded during the CMJ, considering the peak RMS value obtained during the CMJ as 100%. Activation values during unilateral hurdle jumps were then expressed as a percentage relative to this reference value (%CMJ).

Participants performed two maximal countermovement jumps (CMJs) with arm swing on a two-axis force platform (PASCO PS-2142, Roseville, USA; resolution: 0.1 N; sampling frequency: 1000 Hz) to record ground reaction forces. Subsequently, four hurdles were positioned, and participants were instructed to perform four consecutive unilateral hurdle jumps as rapidly as possible, contacting the force platform located between the second and third hurdles (Figure 1C). Two trials were performed using individualized hurdle heights corresponding to 60% of the mean CMJ height, and two trials were performed using fixed-height hurdles of 20 cm (Figure 1B). Vertical and horizontal ground reaction forces (N) and ground contact time (s) were recorded. To minimize the potential effects of fatigue and order bias, the sequence of the two hurdle conditions was counterbalanced across participants. Inter-jump rest intervals of 1–2 min were provided between trials to minimize muscle fatigue. The mean of the two trials was used for analysis. If the vertical force values differed by more than 5% between trials, a third trial was performed, and the median value was used for statistical analysis.



Note. a) Warm up. b) Heights of the individualized hurdle with respect to the CMJ and the fixed hurdle; IH = Individual Hurdle. FH = Fixed Hurdle. C) Hurdle and force platform disposition.

Figure 1. Description of warm up, CMJ and hurdle jumps.

Several variables were calculated to characterize neuromuscular performance during the jumping tasks. Peak vertical and horizontal ground reaction forces were analysed separately during the eccentric and concentric phases. The transition between phases was defined as the instant at which the horizontal ground reaction force changed from negative to positive values. The rate of force development (RFD; $N \cdot s^{-1}$) was calculated as the ratio of peak vertical force to the time elapsed from initial ground contact to peak force. Oscillation frequency (ω) was calculated using the following equation: $\omega = (2 \cdot Pi)/(\text{effective contact time (s)} \cdot 2)$. Vertical stiffness (Kvert; $N \cdot m^{-1}$) was calculated according to the equation proposed by McMahon (1987): $Kvert = (mass \cdot \omega^2)/1000$.

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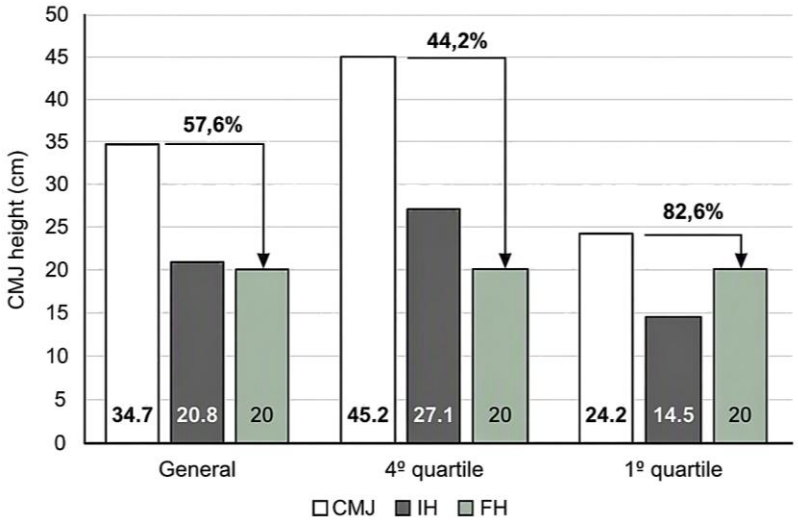
Electromyographic activity during hurdle jumps was analysed across three phases: pre-activation (100 ms prior to ground contact), eccentric phase, and concentric phase (defined according to the horizontal ground reaction force profile). Finally, electromyographic data were normalized to the CMJ values and expressed as percentages.

Statistical analysis

The statistical software JASP 0.18.3.0 (University of Amsterdam) was used for all analyses. Descriptive statistics were performed for all variables to characterize neuromuscular performance. Differences between the mean values of the two hurdle conditions (IH vs. FH) were assessed. Subsequently, to determine whether performance level influenced the results, participants in the first and fourth quartiles of CMJ height performance were compared. This analysis was conducted because initial performance level frequently influences acute and chronic neuromuscular physiological adaptations. The Shapiro–Wilk test was applied to assess the normality of all variables. A logarithmic transformation was applied to variables that did not meet the assumption of normal distribution. Student's t-test was used to identify differences among the analysed variables. A minimum significance level of $p < .05$ was adopted. Cohen's d was used to assess effect size (ES), with a 95% confidence interval (95% CI).

RESULTS

Participants in the first quartile presented the following characteristics: age = 26.3 ± 10.8 years; body mass = 65.5 ± 10.85 kg; height = 159.2 ± 5.81 cm. Participants in the fourth quartile showed the following characteristics: age = 28.5 ± 11.3 years; body mass = 77.32 ± 11.37 kg; height = 177.15 ± 5.39 cm. The mean height of the individualized hurdles set at 60% of CMJ height was 20.8 ± 5.1 cm. When the sample was divided into the first and fourth quartiles, the relative hurdle height expressed as a percentage of CMJ height differed between groups (Figure 2).

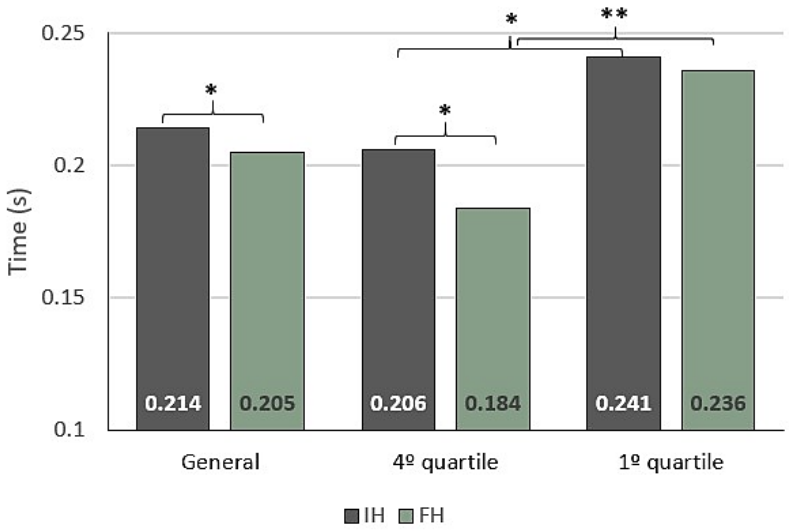


Note. CMJ = Countermovement Jump. IH = Individual Hurdle. FH = Fixed Hurdle.

Figure 2. Comparison of the hurdle height respect to the CMJ.

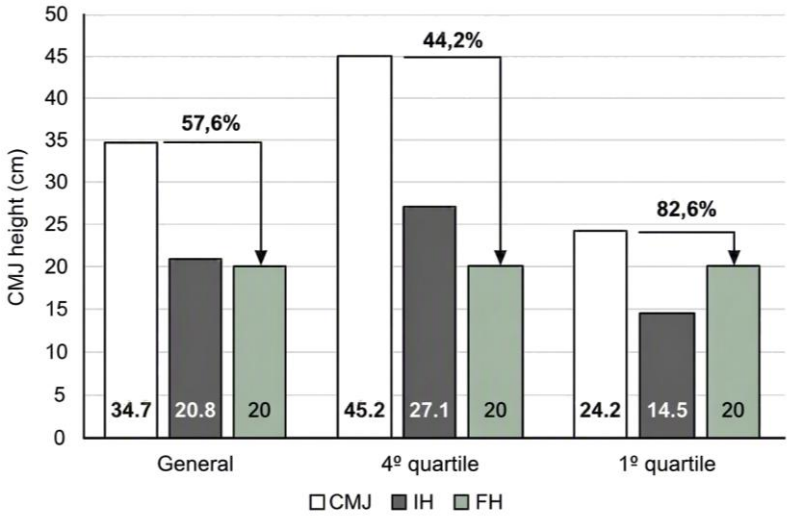
When comparing contact time (CT) between fixed-height hurdles and individualized hurdles, significant differences were observed in favour of the fixed-height hurdle condition ($p < .002$; ES = 0.547; 95% CI [0.203, 0.886]; t = 3.374). Regarding CT comparisons between the fourth and first quartiles, significant differences

were found for the individualized hurdle condition (p < .008; ES = 1.068; 95% CI [0.263, 1.838]; t = 3.378) and the fixed-height hurdle condition (p < .001; ES = 1.546; 95% CI [0.591, 2.466]; t = 4.890), with better performance observed in the fourth quartile. Significant differences were also found among participants in the fourth quartile between hurdle conditions (p < .007; ES = 1.095; 95% CI [0.282, 1.872]; t = 3.462), favouring the fixed-height hurdle condition (Figure 3).



*Note. * p < .05; ** p < .001. IH = Individual Hurdle. FH = Fixed Hurdle.*

Figure 3. Comparison of contact time between individualized and fixed hurdle.



*Note. ** p < .001. IH = Individual Hurdle. FH = Fixed Hurdle.*

Figure 4. Comparison of stiffness (Kvert) between individualized and fixed hurdle.

Regarding vertical stiffness (Kvert), significant differences were observed in favour of the fixed-height hurdle condition (p < .004; ES = 0.504; 95% CI [0.163, 0.838]; t = 3.104). Comparisons between the fourth and first quartiles showed significant differences in favour of the fourth quartile for both individualized hurdles (p < .001; ES = 1.483; 95% CI [0.549, 2.381]; t = 4.69) and fixed-height hurdles (p < .001; ES = 1.466; 95% CI

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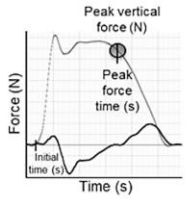
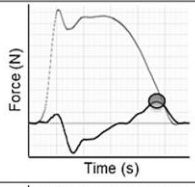
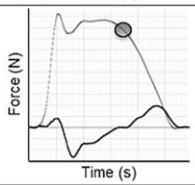
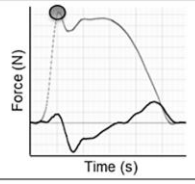
[0.538, 2.358]; t = 4.636). Significant differences were also observed in favour of the fixed-height hurdle condition among participants in the fourth quartile (p < .02; ES = 0.855; 95% CI [0.106, 1.570]; t = 2.703) (Figure 4).

When analysing the rate of force development (RFD), no significant differences were observed in the overall sample. However, significant differences were found in the fourth quartile (p < .01; ES = 0.916; 95% CI [0.152, 1.645]; t = 2.895), favouring the fixed-height hurdle condition. Participants in the fourth quartile achieved significantly higher performance values than those in the first quartile in both the fixed-height hurdle condition (p < .001; ES = 1.713; 95% CI [0.700, 2.690]; t = 5.416) and the individualized hurdle condition (p < .007; ES = 1.100; 95% CI [0.285, 1.878]; t = 3.478).

No significant differences were observed in eccentric peak force, vertical concentric peak force, or horizontal concentric peak force when comparing the fixed-height hurdle condition (FH) and individualized hurdle condition (IH). However, participants in the fourth quartile demonstrated significantly higher values than those in the first quartile when performing fixed-height hurdle jumps, both for horizontal concentric peak force (p < .001; ES = 1.477; 95% CI [0.545, 2.372]; t = 4.670) and vertical concentric peak force (p < .001; ES = 1.553; 95% CI [0.596, 2.475]; t = 4.912). Similar differences were observed during individualized hurdle jumps for horizontal concentric peak force (p < .001; ES = 1.968; 95% CI [0.864, 3.039]; t = 6.224) and vertical concentric peak force (p < .001; ES = 1.539; 95% CI [0.587, 2.456]; t = 4.868). Descriptive values and the force curve analysis methodology are presented in Table 1.

Table 1. Comparison of strength parameters between fixed and individualized hurdle jumps in quartiles.

		Fixed Hurdle		Individualized Hurdle	
		4º quartile (M±SD)	1º quartile (M±SD)	4º quartile (M±SD)	1º quartile (M±SD)
Rate of Force Development (RFD) (N·s)		27726 ± 7855	10757 ± 2881	21951 ± 5889	13906 ± 4574
Horizontal Concentric Peak Force (N)		229,5 ± 44,5	143,8 ± 23,2	209,1 ± 21,3	142,6 ± 19,8
Vertical Concentric Peak Force (N)		2341 ± 320	1517 ± 297	2302 ± 355	1696 ± 222
Vertical Eccentric Peak Force (N)		2524 ± 351	2276 ± 229	2694 ± 379	2042 ± 485

*Note. p < .05 = *; p < .001 = **. IH = Individual Hurdle; FH = Fixed Hurdle. Vertical Force − Horizontal Force.*

No significant differences were observed in medial gastrocnemius or tibialis anterior muscle activation during any phase of the jump when comparing fixed-height and individualized hurdle conditions in the overall sample. Table 2 presents the percentage of normalized muscle activation relative to the CMJ.

Table 2. Comparison of electromyographic parameters between jumps with fixed and individualized hurdles in the general group.

Variable	Individualized hurdle (M ± SD)	Fixed hurdle (M ± SD)	*p*
% Gastrocnemius pre-activation	149.0 ± 58.60	148.3 ± 55.25	.905
% Tibialis anterior pre-activation	106.6 ± 71.12	96.5 ± 54.78	.200
% Gastrocnemius eccentric phase	163.4 ± 52.30	167.8 ± 62.67	.550
% Tibialis anterior eccentric phase	103.0 ± 83.14	100.8 ± 71.64	.640
% Gastrocnemius concentric phase	142.1 ± 54.31	129.8 ± 52.63	.136
% Tibialis anterior concentric phase	131.1 ± 47.33	137.4 ± 44.10	.347
% Gastrocnemius total contact	163.0 ± 36.86	158.8 ± 40.86	.283
% Tibialis anterior total contact	124.0 ± 58.93	123.1 ± 51.90	.821

Note. Values are expressed as a percentage relative to 100% activation of the gastrocnemius and tibialis anterior during the CMJ. $p < .05$.

DISCUSSION

The aim of this study was to analyse the neuromuscular characteristics of continuous unilateral hurdle jumps, which, to the best of our knowledge, have not yet been described in the literature despite being widely used in training settings. The main finding of this study was that when hurdle height was individualized according to CMJ performance or when a fixed height of 20 cm was used, performance outcomes were very similar among participants with different performance levels.

For the present study, relatively low hurdle heights were selected because our laboratory had previously investigated considerably higher hurdle heights relative to CMJ performance. In that study, the vertical force curve exhibited a double-peak pattern accompanied by very long contact times (Cappa and Behm, 2011). This double force peak corresponds to a pronounced heel drop during the stance phase, which prolongs the eccentric phase of the movement and consequently results in extended ground contact times. This concept had previously been investigated during bilateral drop jumps by Young et al. (1995), who reported that increasing drop height resulted in longer contact times due to a greater contribution of the plantar surface of the foot during ground support.

A very high force peak at the beginning of the eccentric phase represents a neural system response aimed at decelerating the movement and initiating the concentric phase. Cormack et al. (2008) analysed continuous vertical CMJs and observed that these jumps generate very high vertical eccentric peak forces (4000–5000 N). This type of force curve morphology is not consistent with explosive actions such as sprinting (Kyröläinen et al., 2005) and more closely resembles the mechanical characteristics of change-of-direction movements (Bencke et al., 2000). It is possible that this eccentric peak force contributes to improving neural system capacity, as it is preceded by a high level of muscle activation prior to ground contact (Aura and Viitasalo, 1989; Mero and Komi, 1994). Unilateral hurdle jumps do not generate such a large, eccentric force peak (Table 1), as only the forefoot is supported and the ankle joint functions as a spring-like mechanism to attenuate impact forces. In fact, the vertical force produced during unilateral hurdle jumps by the best performers in our group showed similar concentric force values compared with sprinters assessed at maximal velocity (2366 vs. 2341 N) (Kyröläinen et al., 2005). This similarity provides unilateral hurdle jumps with a high level of specificity when the goal is to improve forward sprinting speed.

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However, when analysing horizontal concentric force during the unilateral hurdle jumps performed in the present study, values tended to be lower compared with those reported during sprinting by Kyröläinen et al. (2005), single-leg grouper jumps, and single-leg jumps by Aura and Viitasalo (1989) (229 vs. 820 vs. 354 vs. 1000 N, respectively). This difference may be explained by the horizontal velocity associated with each exercise modality, as greater forward velocity requires higher levels of horizontal force production. Unilateral hurdle jumps are not performed at high horizontal velocities because the obstacle must be cleared, a condition that appears to prioritize vertical force production over horizontal force production.

To generate high levels of mechanical power, a high level of muscle stiffness is required. This characteristic is achieved through jumping actions involving a previous flight phase and a short force application time. Cappa and Behm (2013) showed that CMJ performance presents considerably lower stiffness compared with bipedal hurdle jumps, while Farley and Morgenroth (1999) reported that increasing jump frequency and reducing stance time markedly increase stiffness. Similarly, Arampatzis et al. (1999) demonstrated that higher sprinting velocities are associated with greater stiffness levels, and that voluntarily reducing contact time during drop jumps increases muscle stiffness but decreases mechanical power (Arampatzis et al., 2001). In the present study, participants with higher stiffness levels were the best performers (fourth quartile), who also exhibited shorter contact times. When performing the lowest hurdle height, these participants showed values almost 20% higher than those obtained with a hurdle height corresponding to 60% of CMJ height. Furthermore, the Kvert observed during unilateral hurdle jumps represented 80% of the values reported for bipedal hurdle jumps performed at 100% of CMJ height (Cappa and Behm, 2011) and reached similar levels to high-frequency bipedal hopping in place (Farley and Morgenroth, 1999). These findings suggest that unilateral hurdle jumps may represent an effective alternative for power training when the appropriate exercise modality and obstacle height are selected.

Although no video recordings were obtained in the present study, visual observation suggested that jump frequency was higher when lower hurdle heights were used. Therefore, participants in the fourth quartile demonstrated better performance when performing the fixed-height hurdle condition, whereas results for participants in the first quartile were very similar between conditions. These findings may indicate that using CMJ height as a criterion for individualizing hurdle height may not represent an optimal approach for this type of training task.

Our results showed high levels of gastrocnemius pre-activation during unilateral hurdle jumps. These findings are similar to those reported by Cappa and Behm (2013), who observed high pre-activation levels during bipedal hurdle jumps performed at a height corresponding to 100% of CMJ height. Similarly, Aura and Viitasalo (1989) reported that unilateral hurdle jumps are characterized by high levels of quadriceps pre-activation. This high level of pre-activation precedes the expected increase in eccentric force production, as the myotatic reflex contributes during the initial milliseconds of muscle contraction (Ishikawa and Komi, 2007).

Kyröläinen et al. (2005) reported that, during pre-activation in maximal velocity sprinting, gastrocnemius activity reached 174% of maximal isometric voluntary contraction. In the present study, gastrocnemius pre-activation represented approximately 150% of CMJ values in participants from the fourth quartile. This difference may be explained by the fact that the present study normalized EMG data using a more dynamic task, such as the CMJ. However, this type of analysis alone is insufficient to determine whether unilateral hurdle jumps present neuromuscular characteristics similar to sprinting. Dorn et al. (2012) reported that, during maximal velocity sprinting, the ankle joint contributes the greatest proportion of propulsive force. In the present study, total gastrocnemius activation represented 158–163% of CMJ values, indicating a high

level of activation, considering that during CMJ performance the gastrocnemius is highly involved during the final phase of concentric action.

Many plyometric exercises are used to improve sprint performance. During the acceleration phase, Schache et al. (2019) showed that ankle joint action represents a key contributor to propulsive work during the stance phase. The ankle joint contributes approximately 50% of the total effort during the first step and increases to 60.8% as sprinting progresses. In the present study, tibialis anterior activation during unilateral hurdle jumps demonstrated high activation levels, reaching approximately 35% above CMJ values. This coactivation pattern may contribute to maintaining optimal levels of muscle stiffness during the stance phase.

No correlation was found between CMJ height and the stiffness levels achieved in any group or in any jumping condition, regardless of hurdle type. This finding may be explained, similarly to what occurs with contact time, by the different biomechanical characteristics of the two jump modalities. Cappa and Behm (2011) reported an average contact time of .809 s during CMJ performance, whereas unilateral hurdle jumps performed at 70%, 80%, and 90% of CMJ height showed contact times of .256, .259, and .262 s, respectively. In the present study, the average CMJ contact time was .950 s, while all hurdle jump conditions showed contact times below .250 s. These findings suggest that using CMJ height as a criterion for individualizing hurdle height in horizontal jumps may not be an appropriate parameter.

CONCLUSION

It can be concluded that, when performing continuous unilateral hurdle jumps with the aim of maximizing muscle power production, the neuromuscular performance response is similar when using fixed-height commercial hurdles of 20 cm or individualized hurdles corresponding to 60% of CMJ height in active participants with different performance levels. However, participants in the fourth quartile demonstrated better performance when using fixed-height hurdles. Finally, the results suggest that a CMJ-normalized system does not provide additional precision for determining hurdle height in this type of jumping task; therefore, CMJ-based individualization may not be necessary for unilateral hurdle jumps.

It can be concluded that, during continuous unilateral hurdle jumps performed with the aim of maximizing power production, similar neuromuscular responses are obtained when using fixed-height hurdles of 20 cm or individualized hurdles corresponding to 60% of CMJ height in active individuals with different performance levels. However, participants with higher performance levels (fourth quartile) demonstrated superior neuromuscular outcomes when using fixed-height hurdles. These findings suggest that CMJ-based hurdle height individualization does not provide additional benefits for this type of jumping task, and fixed low-height hurdles may represent a practical alternative for unilateral plyometric training.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. Contributions are specified according to the CRediT (Contributor Roles Taxonomy) as follows:

Conceptualisation: Cappa Darío, Godoy Santiago, Arbach Nahir, Arcuri Carlos, Rodriguez Clarisa, Morales Emanuel, Ramos Marcos. Methodology: Cappa Darío, Godoy Santiago, Arbach Nahir. Formal analysis: Godoy Santiago, Morales Emanuel, Arbach Nahir. Investigation: Cappa Dario, Godoy Santiago, Arbach Nahir, Ramos Marcos. Data curation: Morales Emanuel, Godoy Santiago, Arbach Nahir, Arcuri Carlos.

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Writing – original draft: Godoy Santiago, Lopez José Luis, Arbach Nahir. Writing – review & editing: Cappa Darío, Rodriguez Clarisa. Supervision: Cappa Darío.

All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

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