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Kinetic Comparison between Drop Jumps and Horizontal Drop Jumps in Elite Jumpers and Sprinters

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Abstract: Previous research addressed the spatiotemporal variables of the drop jump (DJ) versus the horizontal drop jump (HDJ). This study compared the kinetic variables of the DJ versus the HDJ in elite jumpers and sprinters. In a single session, sixteen elite jumpers and sprinters performed two DJ attempts with three different fall heights (0.30 m, 0.40 m, and 0.50 m), and after 2 h, performed two HDJ attempts from the same fall heights (0.30 m, 0.40 m, and 0.50 m). Kinetic variables: eccentric ground reaction forces (GRFE) and concentric ground reaction forces; eccentric impulse (PE) and concentric impulse (PC); peak power in the concentric phase; and rate of force decrease (RFDe) were measured using a research-grade force plate. The Wilcoxon test was used to compare the vertical and anteroposterior axes. GRFE was significantly higher ($p \leq 0.05$) in the DJ vs the HDJ with large effect sizes. The PE ($p \leq 0.006$) and PC ($p = 0.002$) were significantly lower in the DJ than in the HDJ. The RFDe was also significantly lower in the DJ at 0.30 m vs. the HDJ at 0.30 m ($p = 0.002$). In summary, elite jumpers and sprinters may benefit from incorporating both the DJ and the HDJ into their training regimens, with the DJ being particularly advantageous for enhancing power metrics and RFDe.

Keywords: ground reaction force; impulse; power output; concentric phase; eccentric phase; bilateral jumps

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1. Introduction

The kinetic evaluation of plyometric activity is essential for optimizing performance by identifying which exercises generate the most ground reaction force (GRF) [1–3], eccentric (EP) and concentric (CP) impulses [4–6], and rate of force development (RFD) [2], as well as the adequacy of fall height (FH) for maximal power output (Pw) [4]. Thus, kinetic assessment could be a helpful way to make practical decisions about including vertical or horizontal projection exercises at specific points in sports preparation.

The kinetic evaluation of the drop jump (DJ) and the horizontal drop jump (HDJ) has been reported in the literature [7,8]. Researchers have attempted to quantify exercise intensity [2,9–12], establish differences between a limited number of plyometric activities [8,12–14], and determine the best technique. For example, science considers that during rebound DJs, GRF can be 1.5 higher than that produced during countermovement DJs [15]. On the other hand, it was reported that the GRF is greater in the DJ than in the HDJ when the drop height is 40 cm [16]. The authors also report that, for unilateral DJs from the 20 cm box, there is no difference between vertical and horizontal impulses. Although we presume that the low value refers to the anteroposterior forces, in this research, it is unclear whether the mean GRF of the horizontal jump (714.6 ± 167.2 N) is a measure of the anteroposterior forces of HDJs, or a measure of the vertical forces of HDJs; these aspects should be clarified in future scientific reports. A previous study [17] found that the time to the concentric peak of the GRF can account for 45–55% of the total jump time, meaning that the muscles still have significant time to continue to produce force after the concentric peak. In this regard, we have not found a report of the temporal phase of force production after reaching the maximum concentric peak. It has also not been reported how the muscle continues to apply force after reaching this maximum peak.

In this context, it is known that several sporting movements are highly dependent on the application quality of Pw and RFD [18–20]. These are essential physical requirements [21] during plyometric exercises, especially when FH induces short contact times. Therefore, it is unsurprising that many scientists include these assessments in plyometric control to monitor their performance. Previous reports have assessed maximal eccentric and concentric Pw [19] and RFD [22] concerning vertical force tracing during jumps. They are based on two criteria: (I) that RFD is measured from the onset of contraction to any point on the force–time curve or between any two points on the curve [23,24], and (II) that a subject can have as many RFD values as the number of time intervals within the force curve [21]. Thus, it could be interesting to know the RFD values, especially when the slope of the curve displays negative behavior after reaching the maximum peak of concentric force, i.e., the rate of force decrease (RFDe) of the DJ and HDJ in sprint and jumping athletes. To the best of our knowledge, this metric has not been previously reported, and there is a lack of knowledge about how muscles continue to develop force from peak concentric force to the take-off instant. As previously reported, no comprehensive study has yet been conducted to determine the relationship between kinetic variables and certain types of bilateral jumps [25]. Furthermore, we did not find any comprehensive studies of DJs and HDJs that show whether the eccentric impulse (PE) and concentric impulse (PC) are modified or tend to differ with increasing FH. Also, little has been reported on Pw in HDJs and whether it differs concerning DJs, though it could be considered that these variables constitute a key physical component in the performance of these sports disciplines. Therefore, the present study aimed to compare the kinetic variables of the DJ versus the HDJ in elite jumpers and sprinters.

2. Materials and Methods

2.1. Experimental Approach to the Problem

A repeated measures experimental design was applied to test the hypothesis that differences exist between the DJ and HDJ plyometric exercises, with the exercise mode as the independent variable and the GRFE, GRFC, PE, PC, PW, and RFDe as the dependent variables. Previously, the standing long jump (SLJ) was applied to test whether there are differences between the covered jump distances and the FT compared to the HDJ.

2.2. Subjects

Sixteen male athletes (mean ± SD; age = 24.31 ± 2.24 years, body mass = 81.11 ± 5.10 kg, height = 1.86 ± 0.06 m, BMI = 23.44 ± 2.21 kg m2, and SLJ = 3.05 ± 0.07 m) consisting of triple jumpers (n = 4), long jumpers (n = 3), 100 m sprinters (n = 6), and 110 m hurdlers (n = 3) were recruited, all belonging to their national team. Subjects had participated in World (9/16) and European or Pan-American (16/16) championships. All had experience in performing plyometric exercises, but abstained from plyometric or strength training in the three days before the assessment. They had no history of injuries within the three months preceding the measurements, nor did they report orthopaedical disorders or medical contraindications to avoid plyometric training. All athletes were informed of the risks associated with the measurements and gave written informed consent. The study was conducted following the Declaration of Helsinki (October 2013) and approved by the Institutional Ethics Committee of the Faculty of Sport Sciences and Physical Education of the University of Coimbra (code—CE/FCDEF-UC/00802021 6 July 2021).

2.3. Testing Procedures

The testing procedures and instrumentation followed previously applied criteria in the first part of this study, which analyzed the spatiotemporal variables [17].

The height, body mass, and age of each participant was recorded prior to the assessment session. Height was determined using a stadiometer with a precision of 0.1 cm (Bodymeter 206, SECA, Hamburg, Germany). Body mass was measured using a SECA scale (Hamburg, Germany), and body mass index was computed following established protocols [26]. Each athlete underwent a warm-up tailored to their individual needs. The warm-up lasted an average of 50 min and consisted of two segments. The initial segment, termed the general warm-up, included activities such as joint mobility exercises, approximately 5 min of running, and dynamic flexibility work. The subsequent segment, known as the specific warm-up, involved exercises relevant to each athlete's respective specialty sport. Following the warm-up, all participants had a 5-min recovery period.

Participants executed two DJ attempts from three distinct FHs to assess the dependent variables. All athletes were accustomed to the procedure. They completed two DJ attempts at 0.3 m (DJ30), two at 0.4 m (DJ40), and two at 0.5 m (DJ50). Following an active rest period, comprising dynamic stretching exercises, a 30-m progressive sprint, and an SLJ ensuring full recovery, they performed two HDJ attempts at 0.3 m (HDJ30), two at 0.4 m (HDJ40), and two at 0.5 m (HDJ50). The best jump from each height was selected for data analysis. The DJ was executed with rebounding [15], and both DJs and HDJs retained consistent arm swinging. For HDJ attempts, it was stipulated that athletes maintain a vertical displacement during the eccentric phase, transitioning to a horizontal movement only after reaching the lowest point. This criterion ensured that the eccentric phase of both exercises was determined based on zero velocity parameters. Jumps were eliminated if they displayed asymmetric contacts, had a Ground Contact Time (GCT) exceeding 250 ms during the DJ (excluding HDJs), or lacked contact with the force platform. This resulted in the elimination of four jumps. The SLJ was performed with both feet to maximize horizontal jump distance. A reference line was placed on the force platform for initial alignment, and jump length was measured using a metallic tape measure, with the distance recorded from the line to the point where the heel landed closest to the starting line, as previously outlined [27]. During HDJs, athletes were instructed to contact the force plate as close to the SLJ reference line as possible. The covered jump distance was measured following the same guidelines as an SLJ. A rest interval of 1 min was provided between jumps of the same drop height, and 4 min between different drop heights.

2.4. Instrumentation and Data Processing

The exercises were conducted utilizing a force plate (Kistler Model 9260AA6, Winterthur, Switzerland) with dimensions of 0.6 m $\times$ 0.4 m $\times$ 0.05 m, which was positioned flush with a custom-made wooden platform. The force plate was set up to capture data at a sampling rate of 1000 Hz via an interface box (Kistler Model 9260AA6). Data analysis was performed using Bioware 5.3.2.9 software (Winterthur, Switzerland) in accordance with the manufacturer's guidelines. Additionally, an Optojump-nexX30 (Bolzano, Italy) optical contact measurement system (OPT) was configured to acquire and display real-time data at a sampling rate of 1000 Hz through an interface. This device was affixed to both edges of the wooden platform, which recorded the flight time during HDJs.

GRF measurements were collected from when 10 N was exceeded until 10 N was lost during contact [28]. PE and PC were delimited using Equation (1). GRFE was the maximal peak of force during the eccentric phase, and GRFC was the maximal force peak during the concentric phase. Peak Pw was calculated by multiplying force by instantaneous velocity [18]. RFDe was modified from previous references [2,21] and obtained using Equation (2). The RFDe data were extracted from the slope of the force–time curve on the vertical axis, starting from the maximum peak of the GRFC, up to the highest force reached 30 ms before take-off (Fl30 ms) [29].

$$P_x(t) = m \times \mathrm{v_x}(t) \tag{1}$$

where P is impulse, m is the subject's body mass, and v is the velocity.

$$RFDe = \frac{CPF - Fl30\ \mathrm{ms}}{\Delta t} = N/S \tag{2}$$

where RFDe was described above as the rate of force development during take-off, CPF is the peak force of the concentric phase, Fl30 ms is the last force recorded 30 ms before take-off, and Δt is the elapsed time between CPF and Fl30 ms.

2.5. Statistical Analyses

Descriptive statistics (mean ± SD) were calculated for each variable (GRFE, GRFC, PE, PC, PW, and RFDe). Comparisons between the two jump exercises were organized in correspondence with the vertical and anteroposterior component of the force platform. The analyses were performed in three groups (A, B, and C). Group A: comparison between the vertical component of the DJ relative to (vs.) the vertical component of the HDJ (HDJV) between the same FH and different FHs; Group B: comparison between the vertical component of the DJ vs. the anteroposterior component of the HDJ (HDJa) between the same FH and different FHs; Group C: comparison between the HDJV vs. the HDJa between the same FH and different FHs. The normality and homogeneity assumptions of the data were not verified. The Wilcoxon test was used to test for statistical differences between DJs vs. HDJs for each jump height (pairs and sets). Kruskal Wallis ANOVA was used for within-group comparisons of FHs. Values were adjusted using Bonferroni post hoc and analyzed to identify statistically significant comparisons set at the α level of $p \leq 0.05$. Effect sizes were analyzed pairwise with G*Power software (v.3.1.9.7 Heinrich-Heine University of Dusseldorf, Dusseldorf, Germany). This was adjusted for the t-test, analyzing the means of two independent groups. The effect size convention was recognized as (small = 0.20; medium = 0.50; and large = 0.80) [30]. Data were analyzed with the statistical package IBM SPSS Statistics (version 27; IBM, Chicago, IL, USA), and graphs were produced with GraphPad (version 9.4.0., GraphPad Software; Boston, MA, USA).

3. Results

Data are presented as the mean ± SD (Table 1), significance level (p), effect size (ES) (Table 2), and Z-value. Figure 1 shows the typical GRF graph for both exercises. In group A's analysis, the PE revealed significantly lower results ($p \leq 0.006$) in the DJ than the HDJ, with medium to large ES. Pw was significantly lower in DJ30 vs. HDJ40v ($p = 0.002$), with medium ES, and in DJ30 vs. HDJ40v ($p = 0.001$), but the ES here was small. The RFDe was also significantly lower in DJ30 vs. HDJ40v ($p = 0.002$), with a small ES. The remaining variables (PC, GRFE, and GRFC) were significantly higher ($p \leq 0.009$) in the DJ than in the HDJ, with medium to large ES, whatever the FH.

Table 1. Mean (± SD) of each of the variables related between the drop jump and the horizontal drop jump.

	DJ30	HDJ30v	DJ40	HDJ40v	DJ50	HDJ50v	HDJ30a	HDJ40a	HDJ50a
PE (N.s)	264.57 ± 27.31	298.03 ± 34.34	283.17 ± 29.79	310.90 ± 40.71	315.78 ± 43.47	345.23 ± 58.50			
PC (N.s)	345.63 ± 27.31	307.79 ± 27.31	329.63 ± 62.40	278.76 ± 60.52	348.86 ± 89.45	297.38 ± 55.37	106.90 ± 36.03	102.83 ± 35.09	134.21 ± 65.63
GRFE (N)	4613.5 ± 1132.1	3019.3 ± 463.71	5288.1 ± 683.95	3510.1 ± 524.14	5574.0 ± 695.70	3492.3 ± 470.59	-	-	-
GRFC (N)	3892.3 ± 710.23	2634.4 ± 427.45	3942.1 ± 683.83	2971.4 ± 409.50	3693.6 ± 600.34	2700.3 ± 736.37	877.2 ± 223.06	960.05 ± 249.46	1074.8 ± 453.60
Pw (W)	7159.9 ± 2009.3	6706.8 ± 1248.2	10,840.6 ± 1820	8171.5 ± 459.5	10,526.7 ± 1253	7696.06 ± 1424	-	-	-
RFDe (N/s)	18,584.5 ± 7680	13,788.1 ± 4252	24,726.2 ± 7681	21,166.6 ± 7845	22,990.2 ± 9438	13,153.5 ± 4346	-	-	-

DJ30 = drop jump from 0.30 m; DJ40 = drop jump from 0.4 m; DJ50 = drop jump from 0.5 m; HDJ30 = horizontal drop jump from 0.30 m; HDJ40 = horizontal drop jump from 0.4 m; HDJ50 = horizontal drop jump from 0.5 m; PE = eccentric impulse; PC = concentric impulse; GRFE = ground reaction force eccentric phase; GRFC = ground reaction force concentric phase; Pw = maximum power; RFDe = the rate of force decrease.

Table 2. Summary of the significance levels of the differences between the drop jump and the horizontal drop jump.

*→	Groups	PE	ES	PC	ES	GRFE	ES	GRFC	ES	Pw	ES	RFDe	ES
DJ30 vs. HDJ30v	A	↓Y***	>1.0	↑Y***	>1.0	↑Y****	>1.0	↑Y****	>1.0	↑Y***	0.27	↑Y***	>1.0
DJ40 vs. HDJ40v		↓Y***	0.77	↑Y***	0.82	↑Y****	>1.0	↑Y****	>1.0	↑Y***	0.71	↑Y***	0.25
DJ50 vs. HDJ50v		↓Y***	0.57	↑Y***	0.69	↑Y****	>1.0	↑Y****	>1.0	↑Y****	>1.0	↑Y***	>1.0
DJ30 vs. HDJ40v		↓Y***	>1.0	↑Y***	>1.0	↑Y****	>1.0	↑Y****	>1.0	↓Y****	0.69	↓Y***	0.18
DJ30 vs. HDJ50v		↓Y***	>1.0	↑Y***	>1.0	↑Y****	>1.0	↑Y****	>1.0	↓Y****	0.30	↑Y***	0.87
DJ40 vs. HDJ50v		↓Y***	>1.0	↑Y***	0.54	↑Y****	>1.0	↑Y****	>1.0	↑Y****	>1.0	↑Y***	>1.0
DJ30 vs. HDJ30a	B	-		↑Y****	>1.0	-		↑Y****	>1.0	-		-	
DJ40 vs. HDJ40a		-		↑Y****	>1.0	-		↑Y***	>1.0	-		-	
DJ50 vs. HDJ50a		-		↑Y****	>1.0	-		↑Y****	>1.0	-		-	
DJ30 vs. HDJ40a		-		↑Y****	>1.0	-		↑Y****	>1.0	-		-	
DJ30 vs. HDJ50a		-		↑Y****	>1.0	-		↑Y****	>1.0	-		-	
DJ40 vs. HDJ50a		-		↑Y***	>1.0	-		↑Y****	>1.0	-		-	
HDJ30v vs. HDJ30a	C	-		↑Y****	>1.0	-		↑Y****	>1.0	-		-	
HDJ40v vs. HDJ40a		-		↑Y****	>1.0	-		↑Y****	>1.0	-		-	
HDJ50v vs. HDJ50a		-		↑Y****	>1.0	-		↑Y****	>1.0	-		-	
HDJ30v vs. HDJ40a		-		↑Y****	>1.0	-		↑Y****	>1.0	-		-	
HDJ30v vs. HDJ50a		-		↑Y****	>1.0	-		↑Y****	>1.0	-		-	
HDJ40v vs. HDJ50a		-		↑Y****	>1.0	-		↑Y****	>1.0	-		-	

DJ30 = drop jump from 0.30 m; DJ40 = drop jump from 0.4 m; DJ50 = drop jump from 0.5 m; HDJ30 = horizontal drop jump from 0.30 m; HDJ40 = horizontal drop jump from 0.4 m; HDJ50 = horizontal drop jump from 0.5 m; HDJa = anteroposterior axis of horizontal drop jump; HDJv = vertical axis of horizontal drop jump; PE = eccentric impulse; PC = concentric impulse; GRFE = ground reaction force eccentric phase; GRFC = ground reaction force concentric phase; Pw = maximum power; RFDe = rate force decrescent; * = the quantity 0 after the point. The arrow indicates that this column (*→) is significantly larger or smaller than the comparison column.

ANOVA comparisons of the DJs' PE showed that it was significantly lower in DJ30 vs. DJ50 ($p \leq 0.001$; Z = 3.802; ES = 1.34), and in the HDJs, DJ30 vs. DJ50 ($p \leq 0.026$; Z = 2.615; ES = 0.92). Also, GRFE was significantly lower in DJ30 vs. DJ50 ($p = 0.035$; Z = 2.513; ES = 0.68), in HDJ DJ30 vs. DJ40 ($p = 0.015$; Z = 2.791; ES = 0.98), and in DJ30 vs. DJ50 ($p \leq 0.035$; Z = 2.514; ES = 1.01). The Pw of the DJs was significantly lower in DJ30 vs. DJ40 ($p = 0.024$; Z = 2.722; ES = 1.91) and in DJ30 vs. DJ50 ($p = 0.019$; Z = 2.369; ES = 1.93), and for the HDJs, it was significantly lower in DJ30 vs. DJ40 ($p \leq 0.042$; Z = 3.238; ES = 1.33). The RFDe of the DJs was significantly higher in DJ30 vs. DJ40 ($p = 0.032$; Z = 2.692; ES = 0.39) and DJ30 vs. DJ50 ($p = 0.008$; Z = 2.369; ES = 0.38), and for the HDJs, DJ30 vs. DJ40 ($p \leq 0.036$; Z = 2.276; ES = 1.08) and DJ40 vs. DJ50 ($p \leq 0.032$; Z = 2.254; ES = 1.17). Finally, PC and GRFC revealed significantly higher results ($p \leq 0.002$) in the DJs over the HDJs, with large ESs in groups B and C. In contrast, ANOVA comparisons no showed significant differences ($p \leq 0.05$) between different FHs for the anteroposterior projection.

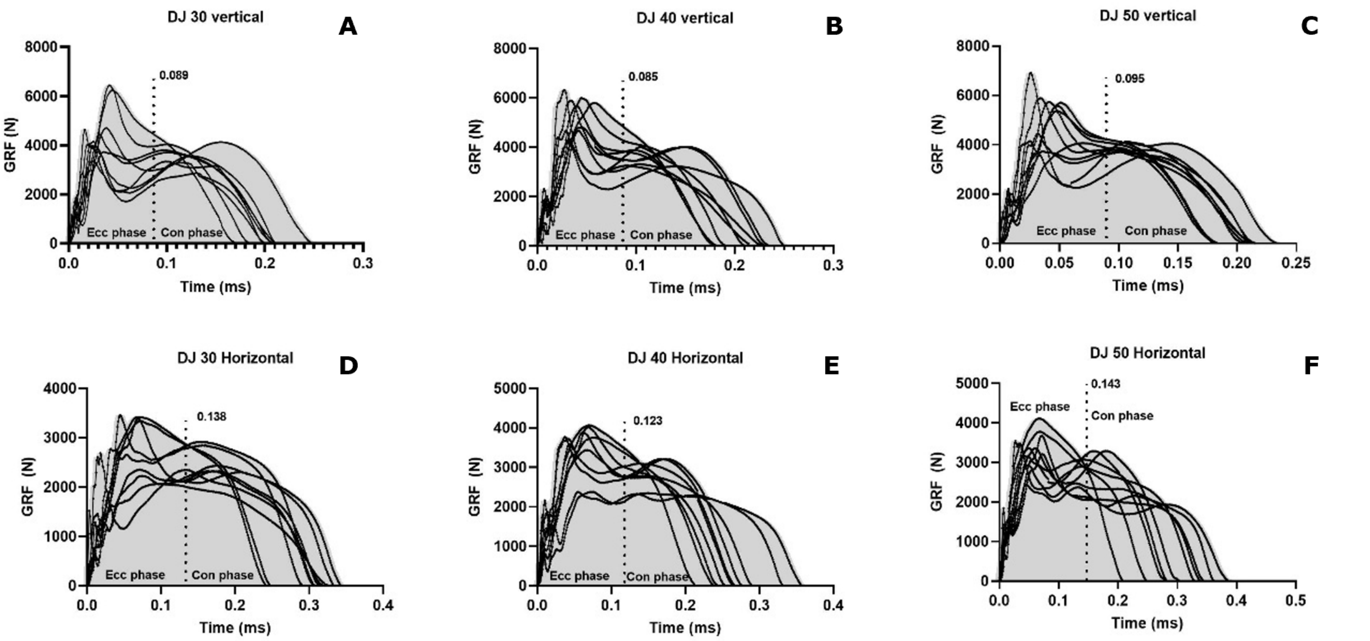

Figure 1. Comparison of GRFE and GRFC between the drop jump (DJ) and the horizontal drop jump (HDJ) with eccentric and concentric phase delineation starting at velocity = 0. (**A**) Force–time trace during DJ30, (**B**) force–time trace during DJ40, (**C**) force–time trace during DJ50, (**D**) force–time trace during HDJ30, (**E**) force–time trace during HDJ40, and (**F**) force–time trace during HDJ50.

4. Discussion

Here, we compared the kinetic variables of the DJ versus the HDJ in elite jumpers and sprinters. Furthermore, we tested the hypothesis that there are differences between these exercises. This is the first exhaustive study that seeks to quantify the existing differences between the DJ and the HDJ in six kinetic variables. We found differences centered mainly on the preponderance of vertical axis forces over the horizontal axis in both exercises. This phenomenon does not seem to be reversed during athletic exercises. As in other studies [13], we also noticed that P and GRF tend to always be lower on the anteroposterior axis than on the vertical axis.

The GRFE represents the landing forces, and it corresponds to the phase where the movement is still in its negative (eccentric) segment (see Figure 1) and can be heavily influenced by the fall strategy [2,15]. In contrast, GRFC represents the positive (concentric) phase of movement, starting when the velocity reverses direction and increases in value. It is unlikely that GRFC, under normal conditions, is influenced by external factors other than the purely concentric forces of the athlete. The most critical variables for analyzing DJ performance are derived from its measurement. This consideration is also based on the fact that within the SSC, the energy required to perform eccentric actions is significantly lower than that needed for concentric actions [31]. For this reason, although we recognize the benefits of the eccentric phase in increasing muscular stiffness, as well as its effects on the concentric phase function [32], we consider GRFC the most essential variable of GRF in the context of athletic performance assessment.

Overall, GRFE was significantly greater in the DJ vs. the HDJ, providing evidence that eccentric force production is higher in vertical jumps than in horizontal jumps. The GRFE found here is higher than the mean reported in previous research [2,15,16,33]. As the HDJ is affected by its countermovement activity, it is logical that it shows similar results to those of previous studies [15], where a decrease in force is evident with this technique. Another result we found is that, for both exercises, GRFE increased considerably with increasing FH, corroborating previous reports [34] and showing that eccentric forces are affected by FH. In another study [35] in which DJ landings from different heights were analyzed, it was found that with increasing FH, the amount of heel strikes during contact also increased. This behavior was equally observable in both DJ and HDJ exercises. Also, the representation of the initial peak force resulting from heel strikes is higher in the DJ than in the HDJ, but is less abrupt and with a longer time in the HDJ. Another study [36,37] indicates both a horizontal and a vertical component in the HDJ, while the DJ has only a vertical component. While their justification is based on video analysis, this criterion may be unfounded when analyzing the force traces of the DJ, where anteroposterior forces exist but with a visibly smaller component than in the HDJ.

During DJ50, we found an increase in PE, PC, and GRFE, but observed a decrease in GRFC, which reinforces the importance of separating the forces (eccentric and concentric) during ground contact. This behavior has been explained previously [38] and should represent a warning point for coaches seeking to work the intensity of plyometric exercise based on the concentric force production. In DJ50, a slight non-significant increase in ground contact time, flight time, and, therefore, jump height has been found [17]. The previous study also reports an increase in Pc, which could be evidence of more pronounced knee flexion to increase force production and achieve greater jump height. At this point, the athlete may begin to change the jumping technique [15] due to excessively increased eccentric loading, thus affecting reactive strength. It was also observed that when the vertical force graph is fully pointed, the maximum concentric force is reached at the beginning of the concentric phase; therefore, the eccentric phase duration is equal to the time in which the maximum concentric force is achieved. This behavior has not been previously reported in the research we reviewed.

This is the first study to compare the results of the GRFC on the vertical and horizontal axes of the DJ and HDJ. It was found that group A (the vertical axis of the DJ vs. the vertical axis of the HDJ) had significant differences in all sets of heights (Table 2), demonstrating that the vertical GRFC is always higher in DJs than in HDJs.

This may be explained by the fact that during HDJs, after the velocity reaches 0 m/s, the body simultaneously initiates both a vertical upward and a horizontal forward displacement, splitting force production into both components. However, a previous study [17] showed that the ground contact time is longer in HDJs than in DJs, which hinders the possibilities of reactive work with this exercise and the multiplicity of strategies for plyometric training. Behind these results, coaches may have a multiplicity of strategies for plyometric training. For a long time, plyometric understanding in athletics was limited only to vertical projection, but it is known that most of its activities include a horizontal component. Research has shown that horizontal plyometric exercises in the program design adhere to the principle of specificity. Numerous studies show improvements in plyometric training performance when exercises are biomechanically specific to the plane in which they are performed [13]. In this sense, as explained before [17], HDJs could be better used to train movements in which the ground contact times are longer and higher concentric components, such as the acceleration phases of a sprint, as well as to improve push-off capacity [39] during unilateral and bilateral horizontal jumps.

This study also underlines that the anteroposterior force peak in HDJ always occurs later than the maximum vertical force. In addition, the impulse showed significant differences with moderate to large ES. Furthermore, during the DJ, the PE is always lower than the PC, but for the HDJ this behavior tends to reverse with increasing height (Table 2). Another finding is that the vertical impulse of the concentric phase for both exercises does not seem to be affected by increasing height, which was also corroborated in previous studies [4,5]. Furthermore, as impulse increases, ground contact time also tends to increase. In this sense, the trainers should be careful because an increased impulse could affect reactive strength variables, depending on the technique used (e.g., Pc = 350 j with high force and short time vs. low force with a long time).

The power outputs were already expected, as power is a product of force times velocity, and their relationship has been widely documented [40]. The concentric power outputs found in this study were based on instantaneous peak power. Other studies [19] are unclear on whether power reports are made by calculating the maximum GRF multiplied by the maximum speed, where the results may be overestimated. Power outputs between different FHs showed significant differences. For DJs, the greater power was produced in DJ40, although the difference in means compared to DJ50, which is not as high, could be considered by coaches for optimal load determination. This slight difference in FH metrics has been explained above [17]. For HDJs, it can be observed (Table 1) that HDJ40 presents greater PW values and could be considered the optimal load for power production. In contrast, the HDJ50 PW drops drastically. This behavior is not entirely surprising, as the GRFC for HDJ50 is also affected, and it could be influenced by an increase in landing velocity. These results are consistent with other studies suggesting a FH between 40 and 60 cm for power output training [19]. Our results may also alert coaches seeking to train on power for heights above those recommended in the scientific literature.

Concerning RFD, studies have often focused on landing [12] around the first GRF peak [2,41,42], and only at the countermovement and squat jumps [43–46]. No previous studies have analyzed RFD at the take-off. Furthermore, in jumping assessments such as the countermovement jump, the RFD has been derived as the difference in the force–time curve from the point of peak concentric force minus the onset of the concentric phase, divided by time and expressed as newtons per second. Other researchers [44,45] also, with the countermovement jump, preferred calculating the mean RFD. To do so, the calculation considers (maximum GRF − minimum GRF)/Δt. Cormie et al., 2008 [47] were among the first to propose the assessment of RFD in the concentric phase. These assessments during the countermovement jump appear to be of little complexity due to the clarity with which the force curve can be observed during this jump. Nevertheless, while this is reasonable during the DJ, it may not make sense to assess RFD during first contact, especially knowing that fall strategies and jump height influence these results [2]. This study insists on evaluating the behavior of the concentric phase of the DJ, where the above formulas do not seem to fit the force curve plot. A possible strategy would have been to analyze the force from the beginning of the concentric phase to the concentric peak. But, as we stated before, the maximum force of the concentric peak coincides with the beginning of the concentric phase, so the calculation of the RFD would be null. Responding to the criterion that there are no reports on the behavior of the variation in force development after reaching the maximum peak of the concentric phase in the DJ, the strategy of calculating the RFDe is proposed in this study. This would solve the practical and fundamental problem of the training context. The RFDO describes to what extent the athlete can maintain high levels of strength after reaching the maximum concentric peak.

In general, for RFDe among the same FHs, DJs proved to be higher than HDJs, although this result was different in the DJ30 vs. HDJ30v set. In addition, the time to LF30 was lower in DJs compared to HDJs. Due to GRFC being higher during DJs than HDJs, it is justified that RFDC may tend to be significantly higher in DJs vs. HDJs. Our results support this behavior and reaffirm previous findings [17] on using the DJ as a component of special preparation and the HDJ as a component of general preparation. For DJs, the RFDe is characterized by a more remarkable ability to produce voluntary activation after reaching maximal strength, and could be explained by higher maintenance of the motor unit discharge rate [21,48]. Along with these findings, we report that the inter-individual variability of RFDe (demonstrated in SD) is so large that, for investigations where inter-individual comparison or measurement of the effects of training programs is required, it is recommended to normalize it to body mass. RFD-based training may be of most interest to coaches during the pre-competitive and competitive phases of the season. RFD is more sensitive to acute and chronic changes in neuromuscular function [48], so training based on it can guarantee a considerable reduction in training volume, optimizing the quality of performance and the maintenance of intensity similar to its maximum levels.

Our study has limitations. It could present greater validity if electromyographic delay data were added. The need for more randomization of participants and the non-inclusion of female data could also be limitations; however, they stem from the small number of high-level competitive athletes in these disciplines. These aspects also deserve future studies, allowing coaches to develop more specific training strategies.

5. Conclusions

Our results address the diversity of differences in the kinetic variables analyzed between the DJ and HDJ at different fall heights. The findings reported here constitute working tools to help coaches make decisions about using these exercises and at which stage they can be best utilized. These results report that: (I) Vertical impulses predominate over horizontal ones, regardless of the type of plyometric exercise; (II) in the DJ, the GRFE is superior to the GRFC; in this sense, strategies for the reduction of the first impact, seeking to enhance the GRFC during training, do not depend on this exercise; (III) the DJ guarantees better power metrics and RFDe, so its use in times of special preparation and tapering could be highly recommended. On the other hand, the HDJ can be used as a classic plyometric preparation exercise. However, its use in pre-competitive preparation is not ruled out due to its contribution to favoring acceleration during sprinting.

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