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Do Vertical Stiffness or Dynamic Joint Stiffness Have Footedness-related Differences?

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Authors' contributions

This work was carried out in collaboration between all authors. Author TA designed the study, performed the literatures searches and statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author JMCSA designed the study and managed the analyses of the study. Author ACC managed the analysis of the study. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Aims: Unilateral hopping (UH) is one of the common tests for footedness assessment. Inter-limb differences between vertical stiffness (KVERT), ankle dynamic joint stiffness (ADJS) and knee dynamic joint stiffness (KDJS) are expected to exist between the dominant and non-dominant limb. Thus the objective of the present study is to verify those differences, denoting KVERT, ADJS and KDJS as indicators of footedness.
Study Design: Comparative study.
Place and Duration of Study: MovLab/ CICANT/ Universidade Lusófona de Humanidades e Tecnologias, between November 2013 and June 2014.

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Methodology: A total of 31 participants (20 female and 11 male) presenting different footedness (right and left) were assessed. Using a 3D motion capture system and a force platform, 10 seconds of UH (for each side) were recorded. Synchronised ankle and knee sagittal moment of force-angular position were used to calculate ADJS and KDJS for the support phase of all hops recorded by participant, divided into two sub-phases: controlled dorsiflexion (CDF) and powered plantar flexion (PPF). The same criteria was used to analyse the synchronised vertical component of ground reaction force (GRFz)-centre of mass (CoM) displacement used for KVERT computation. A paired samples t-test was used to assess inter-limb differences.
Results: No significant differences were found between the dominant and non-dominant limb with the exception of the ADJS in the PPF stance sub-phase ($p<0.05$).
Conclusion: Footedness does not seem to influence KVERT or KDJS during a hopping task, whereas ADJS presents differences in PPF stance sub-phase.

Keywords: Unilateral hopping; vertical stiffness; dynamic joint stiffness; joint stability; footedness.

1. INTRODUCTION

The systematic selection of one lower limb to be used in a task in contrast to the opposite one is usually defined as footedness or foot preference [1,2]. This difference in limb selection has been considered to be an important aspect of human movement analysis but research had produced few reports addressing this issue [1,3-7], even though some studies consider footedness a better predictor of cerebral dominance assessment than handedness, due to less cultural influence [7,8]. Considering this preference for one lower limb in respect to the contralateral one, functional asymmetries of human movement are expected to occur [1,2,7], thus differences should be present between the dominant and non-dominant lower limb in different variables [2,9]. To assess lower limb preference, methods vary from questionnaires to performance tasks, with no consensus regarding the better association of those measures, regardless of the satisfactory results reported for any of these approaches [6,8,10,11]. Jumping tasks are often used to assess footedness, which includes hopping [8,12-14], hopping forward [15,16], single-leg long jump [17,18] and single-leg triple jump for distance [19]. These tests are also considered good enough for the assessment of functional and neuromuscular control [20-22], and are used additionally for the assessment of joint stability and moment of force differences between lower limbs [20]. During a functional task, such as jumping or hopping, ankle joint stability consists of maintaining the alignment of the joint segments at a right angular position during the performance of the task, respecting the joint's normal passive constraints [2,23,24]. The observed response during the task is the result of the individual contribution of the active and passive joint components, and this demonstrates an answer to the specific stability needs of that task, allowing the study of the body's modulation and adaptation mechanisms [23].

Joint stability can be studied by the use of the dynamic joint stiffness (DJS) concept, as this is considered to be a joint stability indicator [23]. DJS is defined as the resistance offered by muscles and other joint structures to the displacement of the joint's segments and as a reaction to the external moment of force [23,25, 26]. DJS can be assessed by the analysis of the behaviour of joint moments-angles relations [27-29]. This analysis allows the study of the spring-like behaviour of the joint which is needed to calculate DJS, and the mechanical energy exchanges [27,29].

Another measure used to assess stiffness in hopping tasks is vertical stiffness (KVERT) [26,30]. KVERT is calculated by the quotient of maximum ground reaction force (Fmax) and the vertical displacement of the body's centre of mass (CoM) [26,31]. This parameter is used in jump tasks performed without horizontal displacement [26,32].

Unilateral hopping (UH) is one of the common tests for footedness assessment [8,12-14]. Inter-limb differences between KVERT, ADJS and KDJS are expected to exist between the dominant and non-dominant limb. Thus the objective of the present study is to address whatever differences are found in those parameters between the dominant and non-dominant limb. If this is shown to be true, KVERT, ADJS and KDJS can serve as a indicator of footedness, contributing to better footedness assessment.

2. METHODOLOGY

2.1 Participants and Procedures

A sample of 31 volunteers was selected from a total of 164 participants who agreed to fill an online version of the Lateral Performance Inventory (LPI) [10]. The use of the LPI was due to its reliability in the assessment of the lateral profile composed by handedness, footedness, eyedness and eardness [10]. The online version of the LPI allowed us to reach more participants to answer the questions, as online questionnaires prove to be reliable [33]. The sample selection was made by the application of some inclusion criteria consisting of: age between 18-40 years and no recent or past history of ankle injury that could affect the outcomes. The participants were clinically assessed for ankle and knee instability prior to the data collection. The sample was composed of 20 females (mean age 23.0±2.98 years; mean weight = 60.3±9.8 kg; mean height = 163±6.3 cm) and 11 males (mean age 23,64±2,25 years; mean weight = 74.4±11.6 kg; mean height = 176.1±5.1 cm). The footedness distribution was 81.8% right-footed and 18.2% left-footed. Footedness indexes were calculated in accordance with the inventory instructions [10].

In the experimental setup, one examiner again passed the LPI to all participants prior to the data collection process. This allowed for the confirmation of the footedness as well as the other lateral indexes presented in the inventory. To effect this, instead of verbal answers, participants were asked to perform each task whilst the examiner observed their behaviours. Biomechanical data were collected at MovLab (Universidade Lusófona de Humanidades e Tecnologias, Lisbon, Portugal). Kinematic data were recorded at 200Hz using a 3D motion capture system (Vicon® Motion Capture MX System, Oxford UK), composed of 9 MX (7*1.3 Gb; 2*2.0 Gb) which were connected to the MX Ultranet control hardware and used to track the motion of the 41 spherical reflexive markers (9.5mm diameter) that make up the plugin Gait-Full Body model. Anthropometric data, needed for the plugin Gait-Full Body model, were collected using the SECA 764 scale and Siber Hegner anthropometric measurement instruments. Synchronised kinetic data were recorded at 1000 Hz using a force platform (AMTI BP400600-2000, USA) connected to a strain gauge amplifier (AMTI MSA-6 Mini Amp). The participants were instructed to perform UH for 15 seconds on the force platform. From the 15 seconds performed, we selected only 10 seconds, rejecting the first seconds to assure stable hopping frequency. A total of 20 seconds (10 seconds each side) was analysed.

2.2 Data Processing

Data processing for DJS computation on jumping tasks commonly uses the slope score of one regression line that includes both the eccentric and concentric sub-phases [30,34]. The present study applies an adapted criteria from the one used by several authors in respect of gait stance phase analysis [2,27,29], where authors divided the stance phase into three sub-phases with respect to the type of muscle action associated. Applying this criteria to the UH stance phase, a controlled dorsiflexion phase (CDP) and a power plantar flexion phase (PPF) can be defined. The former is associated with eccentric muscle action and the latter is associated with concentric muscle action. ADJS and KDJS in each sub-phase were calculated using the standard formula $DJS=dM/d\theta$, where M is the ankle moment of force (normalised to body weight) and θ is the ankle sagittal angle [2,29]. Least-squares regression models were used to calculate regression lines for each of the sub-phases [2,29]. The ADJS and KDJS calculation was performed for every trial of every participant. Mean values for each participant were used in the statistical analysis. Fig. 1 shows the moment of force-ankle angle plot with the two sub-phases and corresponding regression lines used for ADJS calculation. Fig. 2 shows the same loop but for the KDJS.

The KVERT was computed using the expression $KVERT = Fmax/\Delta y$, where Fmax = maximum vertical ground reaction force (GRFz) and Δy= maximum vertical displacement of the centre of mass [31,35]. KVERT was obtained from the regression slope of the plot GRFz-CoM displacement as proposed by Granata et al. [25], with an example shown in Fig. 3.

Statistical results were obtained by the application of the paired samples t-test, with the objective of identifying significant differences attributed to footedness in KVERT, ADJS and KDJS scores. Statistical calculation was assured by the Statistical Package for Social Sciences software (SPSS version 20, IBM, USA).

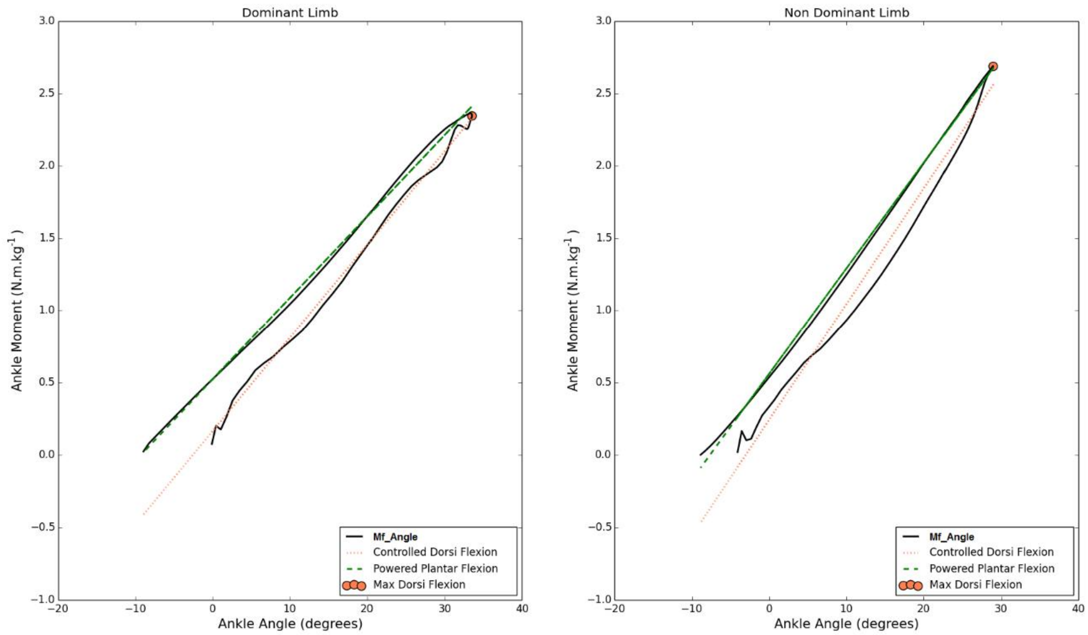

Fig. 1. Ankle joint moment-angle loop for the dominant and non-dominant lower limb with the regression lines for each one of the loop sub-phases

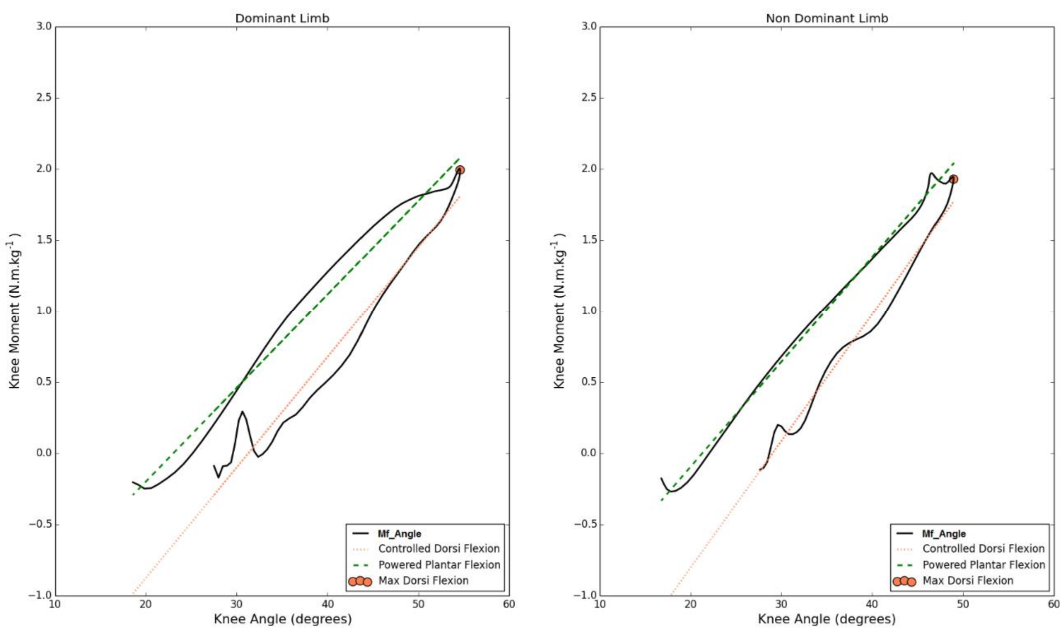

Fig. 2. Knee joint moment-angle loop for the dominant and non-dominant lower limb with the regression lines for each one of the loop sub-phases

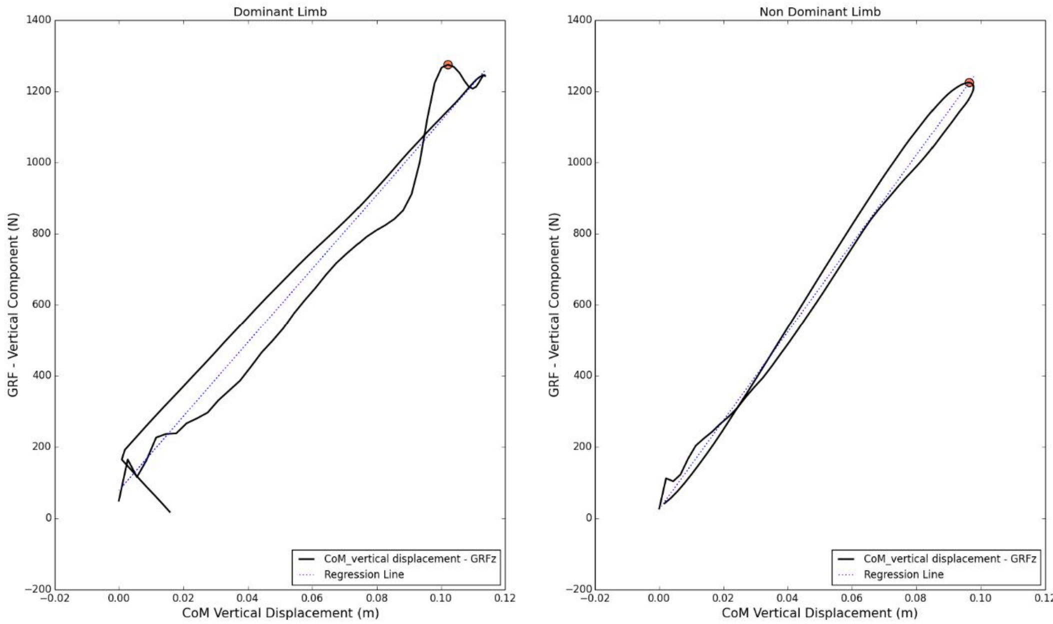

Fig. 3. GRFz vs CoM vertical displacement loop for the dominant and non-dominant lower limb with the regression line used for KVERT calculation

3. RESULTS AND DISCUSSION

Table 1 shows the individual and sample values for all the variables studied. KVERT mean score of 12.07±2.92 was obtained for the dominant limb and values of 12.43±2.81 for the non-dominant limb. The scores of ADJS and KDJS are grouped according to the sub-phases defined for the present study. On the dominant side, mean values of ADJS in each sub-phase were CDF: 1.08±0.30 and PPF: 0.92±0.26. On the non-dominant side mean ADJS values were CDF: 1.36±1.28 and PPF: 0.99±0, 26. The KDJS presented for the dominant side were: 88.72±41.70 in CDF and: 71.44±22.00 in PPF. The non-dominant side had mean KDJS values in CDF of: 80.59±27.99 and in PPF of: 64.07±19.27. R2 values obtained for each of the regression lines used to calculate KVERT, ADJS and KDJS presented a mean value between 0.92 on both sides. For the ADJS the mean values of R2 were between 0.93 and 0.98 and for the KDJS between 0.80 and 0.96.

The inter-limb differences are shown in Table 2. The significance of these differences can be analysed in the paired samples t-test results presented in Table 3.

Similar KVERT can be observed for each dominant and non-dominant limb with no statistical difference reported. The same occurs for the KDJS and hop frequency (Hop_Hz). Considering the ADJS scores, a significant difference ($p<0,05$) was detected in the PPF sub-phase, where dominance seems to be related to the difference of ADJS demonstrated. Observing Table 2, it can be seen that the differences in the case of ADJS in the PPF stance sub-phase are negative for the majority of the participants. This means that the non-dominant limb presents higher values of ADJS than the dominant one. The same behaviour can be observed in the case of the other sub-phase (CDF) for the ADJS and in many cases of both sub-phases in the case of KDJS, even without statistically significant differences.

Unilateral hopping (UH) is one of the common tasks used to address limb dominance [12-14]. Thus, the preferable use of one limb should have as a consequence differences in the way limb stability is produced, as stability is directly related to motor control and balance [23,25]. In that way, differences between limbs associated with functional asymmetries are expected to be present [17].

Table 1. Individual and sample mean scores for KVERT ADJS and KDJS, with respective coefficient of regression (R2) grouped according to jump stance sub-phase

Participants	Dominant																Non-dominant															
	Vertical Stiffness			Ankle Dynamic Joint Stiffness						Knee Dynamic Joint Stiffness							Vertical Stiffness			Ankle Dynamic Joint Stiffness						Knee Dynamic Joint Stiffness						
	Mean KVERT	Mean R^2	St Dev	Mean ADJS_CDF	Mean R^2	St Dev	Mean ADJS_PPF	Mean R^2	St Dev	Mean KDJS_CDF	Mean R^2	St Dev	Mean KDJS_PPF	Mean R^2	St Dev	Hop Hz	Mean KVERT	Mean R^2	St Dev	Mean ADJS_CDF	Mean R^2	St Dev	Mean ADJS_PPF	Mean R^2	St Dev	Mean KDJS_CDF	Mean R^2	St Dev	Mean KDJS_PPF	Mean R^2	St Dev	Hop Hz
P01	9,35	0,89	0,08	1,12	0,96	0,03	1,01	0,99	0,01	83,76	0,83	0,09	77,50	0,99	0,01	1,88	11,32	0,94	0,04	1,29	0,98	0,02	0,98	0,99	0,01	99,04	0,90	0,07	71,71	0,95	0,02	2,01
P02	7,98	0,92	0,04	1,10	0,86	0,06	0,81	0,90	0,04	97,15	0,93	0,05	68,43	0,98	0,01	1,86	10,23	0,95	0,04	1,19	0,95	0,03	1,13	0,97	0,02	74,37	0,80	0,14	63,19	0,97	0,02	1,92
P03	11,57	0,96	0,03	0,80	0,96	0,02	0,72	0,99	0,01	51,33	0,90	0,09	50,35	0,97	0,02	1,83	12,97	0,98	0,01	0,63	0,87	0,03	0,67	0,96	0,02	79,52	0,84	0,25	77,07	0,96	0,04	1,93
P04	11,91	0,93	0,03	1,32	0,94	0,03	1,07	0,99	0,01	118,06	0,86	0,08	91,31	0,93	0,03	2,01	12,81	0,89	0,08	1,32	0,93	0,04	1,12	0,99	0,01	98,06	0,87	0,07	72,61	0,90	0,04	2,00
P05	18,58	0,87	0,29	0,87	0,94	0,02	0,74	0,93	0,01	62,44	0,81	0,14	59,91	0,97	0,02	2,00	15,33	0,96	0,04	0,62	0,93	0,01	0,59	0,98	0,01	42,17	0,77	0,12	43,37	0,94	0,03	1,87
P06	16,05	0,84	0,06	1,04	0,96	0,02	0,79	0,98	0,01	125,78	0,81	0,08	97,14	0,94	0,04	1,96	16,84	0,84	0,06	1,12	0,93	0,03	0,77	0,98	0,01	110,11	0,72	0,08	70,31	0,93	0,04	1,96
P07	17,42	0,86	0,09	1,74	0,94	0,07	0,95	0,93	0,03	277,17	0,95	0,06	156,90	0,98	0,01	1,99	16,60	0,91	0,08	1,73	0,95	0,03	1,27	0,99	0,02	130,99	0,79	0,18	75,70	0,91	0,03	1,97
P08	12,56	0,91	0,23	1,58	0,94	0,03	1,45	0,94	0,02	102,13	0,92	0,04	85,94	0,92	0,23	2,47	11,62	0,98	0,02	1,64	0,99	0,02	1,34	1,00	0,01	109,10	0,94	0,04	83,87	0,98	0,03	2,30
P09	12,34	0,94	0,07	1,15	0,95	0,03	1,04	0,96	0,03	83,50	0,76	0,26	69,51	0,92	0,04	2,09	13,01	0,94	0,06	1,26	0,98	0,02	1,16	0,99	0,02	131,49	0,92	0,05	89,59	0,96	0,02	1,96
P10	8,76	0,95	0,04	1,19	0,93	0,04	0,90	0,99	0,01	97,31	0,89	0,10	70,70	0,98	0,01	1,99	9,39	0,95	0,03	1,13	0,92	0,03	0,93	0,98	0,01	64,46	0,80	0,12	53,52	0,92	0,05	2,04
P11	14,60	0,97	0,02	1,08	0,95	0,01	1,06	0,99	0,01	54,58	0,79	0,09	62,93	0,96	0,02	1,86	14,83	0,97	0,03	1,71	0,98	0,07	1,02	1,00	0,01	66,64	0,60	0,14	56,47	0,91	0,07	1,82
P12	8,20	0,96	0,02	1,29	0,96	0,03	1,06	0,99	0,01	64,97	0,86	0,06	50,45	0,97	0,02	1,90	8,61	0,98	0,01	1,31	0,99	0,02	1,17	1,00	0,01	52,52	0,80	0,20	41,96	0,89	0,20	1,95
P13	9,85	0,98	0,02	1,09	0,95	0,02	1,03	0,99	0,01	85,07	0,91	0,05	76,56	0,98	0,01	2,05	11,17	0,98	0,01	1,15	0,94	0,03	1,05	0,99	0,01	96,80	0,88	0,11	91,12	0,98	0,01	2,12
P14	10,90	0,92	0,06	0,65	0,92	0,02	0,57	0,92	0,02	68,55	0,87	0,21	63,89	0,94	0,09	1,96	12,00	0,93	0,04	0,99	0,96	0,03	0,86	0,98	0,02	71,93	0,86	0,11	75,07	0,97	0,02	2,04
P15	13,93	0,91	0,07	1,09	0,91	0,03	0,83	0,99	0,01	93,65	0,87	0,17	71,39	0,90	0,23	1,74	8,92	0,85	0,05	0,58	0,86	0,03	0,55	0,95	0,02	53,08	0,74	0,26	46,04	0,90	0,21	1,56
P16	12,06	0,91	0,08	1,39	0,96	0,03	1,32	0,98	0,02	73,73	0,67	0,22	70,46	0,92	0,05	1,97	11,67	0,96	0,03	1,12	0,97	0,02	1,13	0,98	0,02	66,65	0,81	0,11	55,60	0,93	0,04	1,96
P17	16,42	0,91	0,10	0,81	0,94	0,02	0,67	0,98	0,01	85,07	0,86	0,09	72,68	0,96	0,03	2,23	12,50	0,95	0,05	0,71	0,94	0,02	0,65	0,96	0,02	52,98	0,93	0,05	43,84	0,97	0,02	1,98
P18	8,15	0,92	0,06	1,00	0,96	0,02	1,05	1,00	0,01	75,04	0,88	0,10	69,51	0,99	0,01	1,79	10,38	0,95	0,05	1,31	0,97	0,03	1,22	0,99	0,01	100,79	0,89	0,12	72,98	0,96	0,07	2,02
P19	10,90	0,95	0,05	0,54	0,78	0,03	0,56	0,81	0,03	100,15	0,95	0,02	84,02	0,99	0,01	2,11	11,69	0,95	0,02	0,91	0,96	0,02	0,77	0,96	0,02	109,27	0,92	0,05	83,86	0,98	0,01	2,04
P20	13,33	0,94	0,11	1,59	0,97	0,04	1,33	0,98	0,03	137,40	0,93	0,05	97,32	0,98	0,01	1,93	11,42	0,94	0,05	1,41	0,97	0,02	1,25	1,00	0,01	79,32	0,84	0,12	52,14	0,96	0,03	1,76
P21	6,23	0,75	0,17	1,06	0,88	0,04	0,77	0,93	0,02	70,02	0,87	0,08	42,99	0,98	0,02	1,65	3,44	0,44	0,29	0,55	0,51	0,06	0,64	0,86	0,05	27,77	0,53	0,30	20,17	0,75	0,23	1,66
P22	11,86	0,94	0,04	0,78	0,95	0,02	0,81	0,99	0,01	102,41	0,87	0,21	91,16	0,99	0,01	2,04	14,11	0,96	0,05	1,30	0,99	0,01	1,13	0,99	0,01	133,29	0,94	0,05	103,46	0,98	0,02	2,09
P23	11,50	0,95	0,03	0,91	0,96	0,02	1,06	0,99	0,01	82,45	0,85	0,09	76,78	0,97	0,02	1,66	13,54	0,95	0,08	1,31	0,94	0,03	1,33	0,99	0,02	97,20	0,90	0,04	88,30	0,96	0,04	1,72
P24	12,59	0,94	0,03	0,92	0,98	0,02	0,82	0,99	0,01	58,99	0,78	0,06	53,18	0,90	0,08	2,00	14,59	0,95	0,05	8,06	0,99	0,02	1,11	0,99	0,02	60,00	0,66	0,21	56,19	0,92	0,17	2,09
P25	11,51	0,89	0,06	0,93	0,94	0,02	0,81	0,99	0,01	82,07	0,90	0,05	62,21	0,98	0,01	1,96	15,11	0,84	0,17	1,00	0,80	0,05	0,95	0,94	0,02	73,15	0,65	0,19	40,39	0,95	0,06	2,27
P26	11,65	0,90	0,10	0,79	0,90	0,02	0,67	0,99	0,01	81,59	0,77	0,29	69,57	0,99	0,01	1,87	12,92	0,90	0,21	1,15	0,94	0,02	0,96	0,96	0,01	101,53	0,87	0,08	73,68	0,97	0,05	2,08
P27	11,51	0,90	0,05	0,59	0,90	0,02	0,56	0,98	0,01	63,78	0,88	0,07	51,32	0,98	0,01	1,65	10,76	0,85	0,15	0,63	0,92	0,02	0,54	0,98	0,01	72,62	0,82	0,25	62,39	0,91	0,22	1,67
P28	9,01	0,91	0,05	1,01	0,93	0,04	0,78	0,98	0,01	75,28	0,94	0,02	54,35	0,95	0,03	1,82	11,85	0,94	0,06	1,29	0,95	0,03	1,19	0,99	0,01	71,72	0,85	0,12	69,80	0,92	0,07	1,99
P29	14,71	0,98	0,01	1,07	0,99	0,01	0,93	0,99	0,01	53,24	0,90	0,04	53,13	0,98	0,02	2,17	17,73	0,95	0,06	1,23	0,99	0,02	0,98	0,99	0,01	76,27	0,80	0,15	58,85	0,95	0,03	2,16
P30	15,50	0,96	0,04	1,63	0,98	0,02	1,65	0,98	0,04	35,39	0,34	0,17	36,95	0,94	0,04	2,06	14,48	0,96	0,02	1,44	0,98	0,02	1,52	0,98	0,03	26,34	0,28	0,19	26,51	0,66	0,21	1,93
P31	13,23	0,83	0,09	1,42	0,96	0,06	0,77	0,99	0,01	108,30	0,87	0,06	76,24	0,96	0,03	1,87	13,66	0,90	0,07	1,06	0,92	0,03	0,82	0,99	0,01	69,01	0,80	0,09	66,34	0,93	0,04	2,01
Mean	12,07	0,92		1,08	0,94		0,92	0,97		88,72	0,85		71,44	0,96		1,95	12,43	0,92		1,36	0,93		0,99	0,98		80,59	0,80		64,07	0,93		1,96
StDev.	2,92	0,05		0,30	0,04		0,26	0,04		41,70	0,11		22,00	0,03		0,17	2,81	0,10		1,28	0,09		0,26	0,03		27,99	0,14		19,27	0,07		0,17

Table 2. Inter-limb differences

Participants	Interlimb differences										
	Vertical stiffness		Ankle dynamic joint stiffness				Knee dynamic joint stiffness				Hop Hz
	KVERT	R2	ADJS_CDF	R2_CDF	ADJS_PPF	R2_PPF	KDJS_CDF	R2_CDF	KDJS_PPF	R2_PPF	
P01	-1,97	-0,06	-0,18	-0,02	0,03	0,00	-15,28	-0,06	5,80	0,04	-0,13
P02	-2,25	-0,03	-0,10	-0,09	-0,32	-0,07	22,78	0,14	5,24	0,02	-0,07
P03	-1,41	-0,03	0,17	0,09	0,05	0,03	-28,19	0,06	-26,71	0,01	-0,10
P04	-0,90	0,04	0,00	0,01	-0,05	0,00	20,00	-0,01	18,70	0,03	0,01
P05	3,25	-0,10	0,25	0,02	0,15	-0,05	20,27	0,05	16,54	0,03	0,12
P06	-0,79	0,01	-0,08	0,02	0,02	0,00	15,67	0,09	26,83	0,01	0,01
P07	0,82	-0,05	0,02	-0,01	-0,33	-0,06	146,18	0,16	81,20	0,07	0,03
P08	0,94	-0,07	-0,06	-0,05	0,12	-0,06	-6,97	-0,02	2,07	-0,06	0,17
P09	-0,67	-0,01	-0,11	-0,03	-0,12	-0,02	-47,99	-0,16	-20,08	-0,03	0,13
P10	-0,63	0,00	0,06	0,00	-0,02	0,01	32,84	0,09	17,18	0,06	-0,06
P11	-0,23	0,01	-0,63	-0,03	0,04	0,00	-12,06	0,19	6,46	0,05	0,04
P12	-0,41	-0,02	-0,02	-0,03	-0,11	-0,01	12,45	0,06	8,50	0,08	-0,05
P13	-1,33	0,00	-0,06	0,01	-0,02	-0,01	-11,74	0,03	-14,55	0,00	-0,07
P14	-1,09	-0,02	-0,34	-0,05	-0,29	-0,07	-3,39	0,01	-11,18	-0,03	-0,08
P15	5,01	0,06	0,51	0,06	0,28	0,04	40,57	0,13	25,35	0,01	0,18
P16	0,39	-0,05	0,28	-0,02	0,19	0,00	7,08	-0,14	14,86	-0,01	0,02
P17	3,92	-0,03	0,10	0,01	0,02	0,02	32,08	-0,08	28,84	-0,01	0,25
P18	-2,23	-0,03	-0,31	-0,02	-0,16	0,00	-25,75	-0,01	-3,48	0,03	-0,23
P19	-0,79	0,00	-0,37	-0,17	-0,21	-0,15	-9,12	0,03	0,16	0,01	0,06
P20	1,92	0,01	0,18	0,00	0,08	-0,02	58,08	0,09	45,18	0,01	0,17
P21	2,78	0,31	0,51	0,37	0,13	0,07	42,26	0,33	22,83	0,22	-0,01
P22	-2,25	-0,02	-0,52	-0,04	-0,32	0,00	-30,87	-0,07	-12,31	0,01	-0,05
P23	-2,04	0,00	-0,40	0,03	-0,27	0,00	-14,74	-0,05	-11,52	0,01	-0,06
P24	-2,00	0,00	-7,13	-0,01	-0,29	0,00	-1,01	0,11	-3,00	-0,02	-0,08
P25	-3,60	0,06	-0,06	0,14	-0,14	0,05	8,92	0,25	21,83	0,03	-0,30
P26	-1,26	-0,01	-0,36	-0,04	-0,29	0,04	-19,94	-0,10	-4,11	0,01	-0,21
P27	0,75	0,05	-0,04	-0,02	0,03	0,00	-8,84	0,06	-11,07	0,06	-0,02
P28	-2,84	-0,03	-0,28	-0,03	-0,41	-0,01	3,56	0,09	-15,45	0,03	-0,18
P29	-3,02	0,03	-0,16	0,00	-0,05	0,00	-23,03	0,10	-5,72	0,03	0,01
P30	1,03	-0,01	0,19	-0,01	0,13	-0,01	9,06	0,06	10,44	0,28	0,12
P31	-0,43	-0,08	0,36	0,04	-0,05	-0,01	39,29	0,06	9,90	0,03	-0,13
Mean	-0,37	0,00	-0,28	0,00	-0,07	-0,01	8,13	0,05	7,38	0,03	-0,02
StDev	2,07	0,07	1,30	0,09	0,18	0,04	35,74	0,11	21,47	0,07	0,13

Table 3. Paired samples t-test results

		Paired differences					t	df	Sig. (2-tailed)
		Mean	Std. deviation	Std error mean	95% confidence interval of the difference				
					Lower	Upper			
Pair 1	KVERT_DOM&KVERT_NDOM	-.36532	2.07210	.37216	-1.12538	.39473	-.982	30	.334
Pair 2	ADJS_CDF_DOM&ADJS_CDF_NDOM	-.27742	1.30345	.23411	-.75553	.20069	-1.185	30	.245
Pair 3	ADJS_PPF_DOM&ADJS_PPF_NDOM	-.07129	.17948	.03223	-.13712	-.00546	-2.212	30	.035
Pair 4	KDJS_CDF_DOM&KDJS_CDF_NDOM	8.13390	35.74303	6.41964	-4.97675	21.24454	1.267	30	.215
Pair 5	KDJS_PPF_DOM&KDJS_PPF_NDOM	7.37779	21.47326	3.85671	-.49866	15.25425	1.913	30	.065
Pair 6	Hop_Hz_DOM&Hop_Hz_NDOM	-.01645	.12978	.02331	-.06406	.03115	-.706	30	.486

Three variables were used to describe the lower limb stability process during the hopping task: KVERT, ADJS and KDJS. DJS is considered to be a joint stability indicator as it demonstrate the resistance imposed by the joint to the external forces applied to it [23]. On the other hand, KVERT presents a more global stiffness behaviour, as it describes total body resistance to a change in length [36]. As we used a UH task, the KVERT score indicates the body stiffness achieved by the supporting limb, and differences between the dominant and non-dominant limb should be present for the same reasons pointed out for ADJS or KDJS.

The only case in which significant differences (p<0,05) between limbs were found was in the ADJS scores at the PPF sub-phase. The difference indicates that the non-dominant lower limb demonstrated a higher ADJS score than the dominant one. Considering that the dominant limb is the one used for action [1,37], and the take-off limb on a high jump [1], it can also be considered as the hopping limb in the unilateral hopping task [1]. Thus, a degree of controversy continues to exist in the definition of footedness [7]. If the definition of dominance can be task-dependent, as functional tasks can be essentially manipulative, essentially stabilizing or both (on a bilateral context task) [38], and a tendency to use the dominant foot in unilateral tasks is reported [7], then the concept of footedness can be reduced to the idea that no dominance exists [1,39]. Some reports confirm this hypothesis as no inter-limb differences were reported in the jump height of both vertical and horizontal unilateral jumps [40] and no differences were found in muscle force and gait parameters [2,6]. On the other hand, some differences were found in the CoM sway in stability tasks, with the dominant lower limb presenting higher sway values than the non-dominant one [41]. Taking this into account, the present study results can be explained by understanding the dominant limb lower ADJS score in the PPF sub-phase, as a result of its orientation from mobilising to stabilising tasks. If so, the dominant limb as assessed by the LPI can be the one less prepared for a task where whole body balance control is needed, such as in the case of unilateral hopping. This contributes to the lack of consensus regarding the definition of the dominant limb in the case of the lower limb. The concept of footedness is not as obvious as the concept of handedness [42]. This is due to the specific activities that the lower limb or the upper limb control. If one of the main tasks of the lower limb is support, then the complete acceptance of footedness as the mobilising limb is difficult. The support task is then as important as the mobilising task, as the limb needs sufficient support to allow for mobilisation [6,43].

One aspect to highlight is that significant differences on ADJS only appear on the PPF sub-phase. This is important if the fact that no significant differences were found in the CDF sub-phase is considered. As DJS is commonly calculated by the use of a single regression line that includes both sub-phases presented in our study [25,44], the differences reported in the ADJS behaviour could possibly be associated with the type of muscle action being produced by the participant. Thus, the adaptation proposed by our study could serve as an option for future studies searching for a deeper understanding of DJS behaviour on different joints and tasks.

This study only used a self-selected hopping frequency, and did not impose higher frequencies as in other studies [25,44], as the goal was not to influence the participants' choices of limb and motor strategy. This was due to the fact that no studies were found in our search that addressed the influence of footedness in KVERT, ADJS and KDJS. Therefore this study is one of the first to have attempted to verify that

4. CONCLUSION

The aim of the present study was to verify if differences exists between dominant and non-dominant lower limb, in the measures of KVERT, ADJS and KDJS, as they are expected to occur. The obtained results were negative for all the variables studied, with exception made to the ADJS in the PPF sub-phase of the stance phase of the UH (P<0.05). This positive relation can indicate that stiffness could be an indicator of footedness if the preferred limb is understood to be the supporting one rather than the mobilising one for hopping tasks. The lack of significant differences on the other variables can, by other hand, give strength to the theory that no dominance exist in the lower limb. Further reflections on preferred limb interpretation should be addressed in future studies on footedness. The adaptations performed in this study for DJS calculation could lead to future research highlighting DJS behaviour on jumping tasks like hopping.

CONSENT

All authors declare that written informed consent was obtained from the patient (or other approved parties) for publication of this case report and accompanying images.

ETHICAL APPROVAL

All authors hereby declare that all procedures have been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. The present study was approved by the ethical board of the Escola Superior de Saúde da Cruz Vermelha Portuguesa.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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