Journal of Scientific Research & Reports
6(5): 363-370, 2015; Article no.JSRR.2015.161
ISSN: 2320-0227

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Footedness-Related Differences in Dynamic Joint Stiffness and Leg Stiffness Measurements

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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.

Article Information

DOI: 10.9734/JSRR/2015/15820
Editor(s):
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Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=966&id=22&aid=8472

Original Research Article

Received 19th December 2014
Accepted 3rd March 2015
Published 16th March 2015

ABSTRACT

Aims: Single-leg triple jump for distance (SLTJD) is a common test used to assess footedness. Inter-limb differences in leg stiffness (KLEG), ankle dynamic joint stiffness (ADJS), and knee dynamic joint stiffness (KDJS) are expected to be present. The objective of the present study is to verify this.
Study Design: Comparative study.
Place and Duration of Study: MovLab/CICANT/Universidade Lusófona de Humanidades e Tecnologias, between November 2013 and June 2014
Methodology: A group of 31 participants (20 female and 11 male) presenting different footedness

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(right and left) was assessed. Six SLTJDs (three each side) were recorded using a 3D motion capture system and a force platform. KLEG was calculated for each of the trials recorded by each participant, and synchronised ankle sagittal moment of force and angular position were used to calculate ADJS and KDJS for the support phase of the last jump of the SLTJD, dividing it into two sub-phases: Controlled dorsiflexion and powered plantar flexion. A paired samples t-test was calculated to assess the influence of footedness on biomechanical variables.
Results: No significant differences were found between the dominant and non-dominant limb in the studied parameters.
Conclusion: Footedness does not seem to influence KLEG, ADJS, or KDJS in the SLTJD.

Keywords: Single-leg triple jump for distance; dynamic joint stiffness; leg stiffness; joint stability; footedness; laterality.

1. INTRODUCTION

Footedness is defined as the preference for using one foot with respect to its contralateral foot [1–2]. This difference in limb selection seems to be very important in the analysis of human activities and yet, the importance given to it by present research is low [1,3–7]. This is despite the fact that some studies consider footedness a better predictor of cerebral dominance assessment then handedness, due to less cultural influence [7–8]. Footedness then can contribute to the functional asymmetry of movement [1–2,7]; thus, differences should be expected between the dominant and non-dominant lower limb [2,9]. The methods used to assess footedness vary between questionnaires and performance tasks with no consensus regarding which is the better association of those measures, regardless of the good results reported for any of these approaches [6,8,10–11]. Jumping tasks are often used to assess footedness; these include hopping [8,12–14], hopping forward [15–16], single-leg long jump [17–18] and SLTJD [19]. These tasks are also used to assess functional and neuromuscular control because they prove to be reliable [20–22].

Joint stability and moment of force differences between the lower limbs are two of the biomechanical variables that can be assessed with these tests [20]. During a functional task, such as jumping or hopping, ankle joint stability consists of maintaining the alignment of the joint segments and their 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, which provide for the specific stability needs of that task, allowing study of the body's modulation and adaptation mechanisms [2,23]. The study of joint stability is possible by calculating dynamic joint stiffness (DJS) because DJS 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]. To study DJS, it is necessary to observe the behaviour of joint moments and angle relations [27–29]; analysis of these factors allows the study of the spring-like behaviour of the joint, which is required to calculate DJS and the mechanical energy exchanges [27,29].

Another measure used to assess stiffness in jumping tasks is leg stiffness (KLEG) [26,30]. KLEG results from the quotient of the maximum value of the vertical component of the ground reaction force (GRFy) by the change in vertical leg length, and it takes into consideration the horizontal displacement of the body's centre of mass (CoM) [26,30]. In our study, we assessed KLEG associated with ADJS and KDJS computation because KLEG results from the contribution of the individual joint stiffness of each joint of the lower limb, with a higher contribution of ADJS [26,31–32]. Some important differences appear in the literature regarding the leg length calculation for KLEG computation. Some authors use the CoM vertical displacement to calculate KLEG [25,31–32], whereas others use the kinematic data acquired from a mark located at the greater trochanter landmark [33–34]. However, some authors state that the greater trochanter is not the actual hip joint centre and that the hip joint centre should be used as the correct reference for leg length calculation [26,35].

If SLTJD is considered a commonly used footedness assessment test [19], inter-limb differences in KLEG, ADJS, and KDJS hypothetically exist, and if so, these differences can highlight the foot preference demonstrated by subjects. If this is true, then KLEG, ADJS, and KDJS can be considered indicators of footedness. Thus, the aim of the present study is to verify whether footedness influences KLEG, ADJS and KDJS as demonstrated by inter-limb differences on those biomechanical variables.

2. METHODOLOGY

2.1 Participants and procedures

A total of 164 participants agreed to be part of the initial phase of this study. This first phase consisted of filling out an online version of the Lateral Performance Inventory (LPI) [10]. The LPI was used because it presents good reliability in the assessment of the lateral profile composed by handedness, footedness, eyedness, and eardness [10]. The online version of LPI allows us to reach more participants to answer the questions, and online questionnaires prove to be reliable [36]. A sample of 31 volunteers was selected to be measured in the laboratory according to the following inclusion criteria: 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 the confirmation of footedness as well as the other lateral indexes presented in the inventory. Instead of verbal answers, participants were asked to perform each task as the examiner observed their behaviours. Kinematic data was recorded at 200 Hz by a 3D motion capture system (Vicon®Motion Systems, Oxford, UK), using a Plug-in Gait full body model. Synchronised kinetic data was recorded at 1000 Hz by a force platform (AMTI BP400600-2000, USA). The participants were instructed to perform an SLTJD, starting from a line located at a distance from the force platform corresponding to two times the participant's leg length. This strategy assured that the final jump was carried onto the force platform. The starting limb was selected by the participant without the examiner's influence. A total of six jumps (three valid jumps each side) were collected.

2.2 Data processing

The normal data processing used to compute the ankle and knee DJS in jumping tasks describes the slope value for one regression line that takes into account both eccentric and concentric muscle action [32,34]. In our study, we chose to apply the same criteria for gait stance phase analysis as that proposed by several authors [2,27–29], which divides the moment-angle loop into specific sub-phases related to the type of muscle action performed. Thus, we divided the stance phase of the final jump of the SLTJD into two sub-phases: Controlled dorsiflexion (CDF) and powered plantar flexion (PPF), the first comprising the eccentric muscle action and the second the concentric muscle action. The regression models used the least squares approach—as described in other studies—to address regression lines for each of the sub-phases [2,27,29]. For each sub-phase, the ADJS and KDJS were calculated for the dominant and non-dominant foot, using the formula $DJS = dM/d\theta$ (where M is the ankle moment [normalised to body weight] and θ is the joint angle), as described by several authors [2,23,27,29]. The ADJS and KDJS calculations were performed for each trial of each participant. Mean values per participant were calculated to allow statistical computation.

The KLEG was computed using the equation described by McMahon & Cheng [37–38], $KLEG = Fmax/\Delta L$ (where Fmax corresponds to maximal vertical force; $\Delta L = \Delta y+L(1-\cos\theta)$; $\theta = \sin^{-1}(vTc/2L)$; Δy is the vertical displacement of the centre of mass, v is the forward velocity, L is the initial leg length; and Tc is the contact time).

To assess footedness influences on KLEG, ADJS, and KDJS, a paired samples t-test was carried out. Statistical calculation was assured by the Statistical Package for Social Sciences software (SPSS version 20, IBM, USA).

3. RESULTS AND DISCUSSION

A KLEG mean score of 10.48±2.98 was obtained for the dominant limb and 10.70±2.77 for the non-dominant limb. The regression fit given by the coefficient of determination (R2) for each regression line used for ankle and knee DJS calculation and the score of DJS are grouped according to the sub-phases defined for the present study. On the dominant side, mean values of ankle DJS in each sub-phase were CDF: 1.37±0.48 and PPF: 0.84±0.23. On the non-dominant side, mean DJS values were CDF: 1.29±0.44 and PPF: 0.88±0.22. The knee DJS values presented for the dominant side were 61.67±32.55 in CDF and 56.47±24.58 in PPF. The non-dominant side had mean DJS values of 59.74±31.28 CDF and 53.78±23.40 PPF. R2 values obtained for each of the regression lines used to calculate ADJS and KDJS presented a mean value between 0.95 and 0.98 for ADJS and between 0.59 and 0.89 for KDJS.

The paired samples t-test results are presented in Table 1, which indicates that there are no significant differences between the dominant and non-dominant lower limbs for the biomechanical variables studied.

Often studies report inter-limb differences associated with limb dominance [17]; these are expected to occur. Thus, several studies have reported differences in the functional activities and physiological properties of muscle. For example, functional asymmetries are expected to be related to different patterns of muscle activation and magnitude of activation [39], and different strategies for postural control are present in different footedness demonstrations [40]. The importance of addressing such differences is related to the significance of lower limb dominance in retraining programmes, as this is considered critical for greater effectiveness [41].

Since jumping tasks are among those selected for footedness assessment, where SLTJD is included [19], differences in joint stability control predictably exist because joint stability results from the integrated action of both passive and active joint components [2,23–24]. Because DJS is a joint stability indicator [23], dominant and non-dominant differences should be evident as different subjects are assessed, whatever the footedness demonstration presented. Observing Figs. 1 and 2, the plots and respective regression lines used for ADJS and KDJS computation can be seen. In the present study, a different approach from that of other studies that addressed DJS calculation is proposed. The stance phase of the final jump of the SLTJD was divided into two sub-phases: One essentially eccentric and the other essentially concentric, using the same criteria proposed to assess gait stance phase in other studies [2,27,29]. This procedure was selected because we assume DJS to be different regarding the type of muscle action being developed. This is a major difference; other studies used only one regression line including both behaviours [32,34]. This process should highlight the differences between dominant and non-dominant limbs, as observed in Figs. 1 and 2, in which the moment of force-ankle angle plot and regression lines show differences. Despite the fact that differences can be observed—which indicates the different stability strategies of each limb—such differences are not considered significant by the paired samples t-test as demonstrated in Table 1. The moment-angle relationship was considered to be very close to linear in ADJS, as observed by the R2 values, but less so in KDJS. This linear behaviour can, by hypothesis, be related to the predominant elastic characteristics of the joint's passive and active components and thus support the concept that the moment-angle relationship is representative of the DJS.

The absence of significant differences between the dominant and non-dominant limb can also be observed in KLEG's paired samples t-test shown in Table 1. This result is expected because KLEG results from the contribution of the individual dynamic joint stiffness of each joint of the lower limb, with a greater contribution of ADJS [31]. To the best of our knowledge, no studies have been conducted addressing KLEG inter-limb differences between the dominant and non-dominant limb; however, the KLEG results can be explained in part by accepting that different strategies performed by the body to achieve a selected motor goal may produce the same result, so that the net effect is almost equal. This implies that we need to assume a more generic view of the process and to be aware of the differences that can occur in a more specific part of the body. Another way to view the problem is to search for more sensitive statistical tools that highlight the observed differences.

Table 1. Paired Samples t-Test results

	Paired differences		
DOM vs NDOM	**Mean**	**t**	**P**
KLEG	-0.212±2.66	-0.444	0.660
ADJS_CDF	0.076±0.36	1.181	0.247
ADJS_PPF	-0.039±0.13	-1.644	0.111
KDJS_CDF	-2.083±30.74	-0.371	0.713
KDJS_PPF	-0.519±19.34	-0.147	0.884

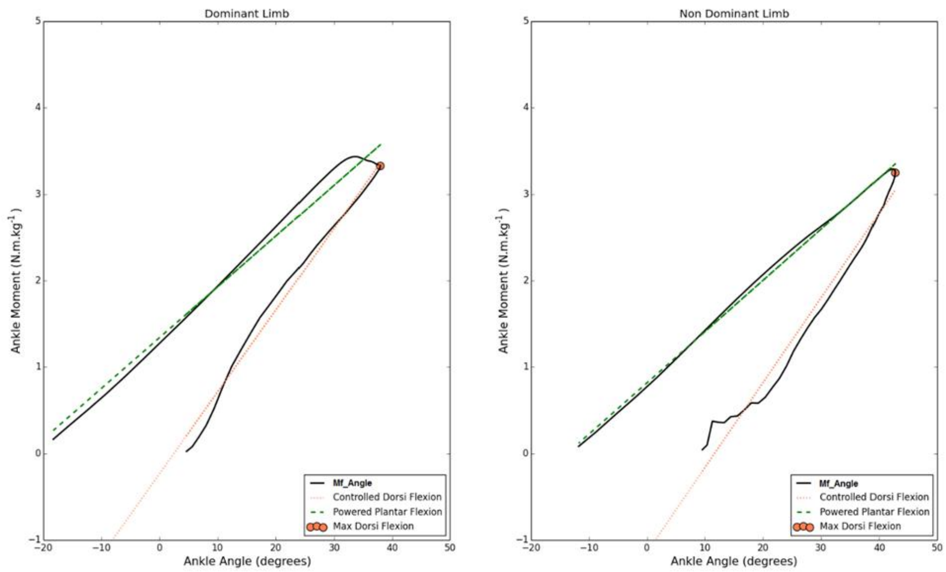

Fig. 1. Ankle joint moment-angle loop for the dominant and non-dominant lower limb with the regression lines for each one of the loop sub-phases

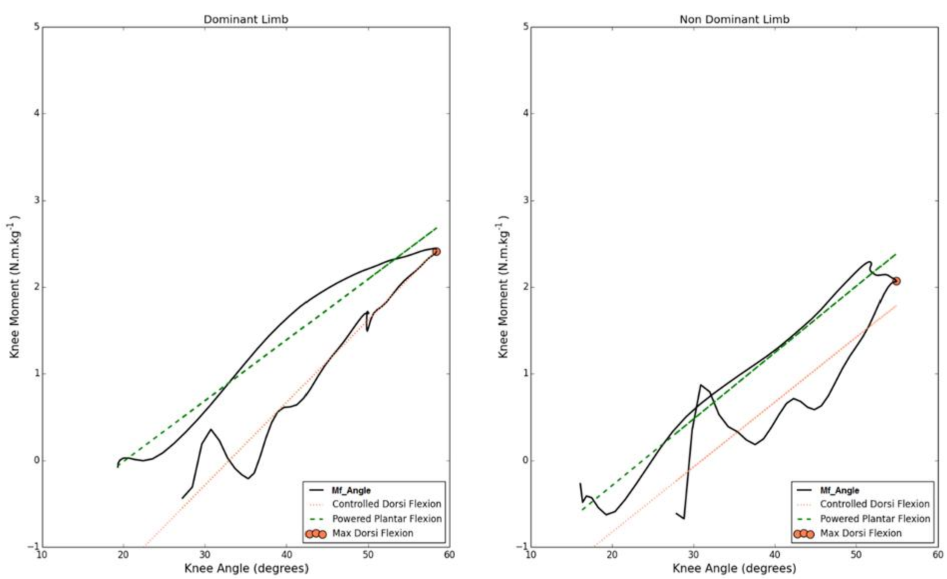

Fig. 2. Knee joint moment-angle loop for the dominant and non-dominant lower limb with the regression lines for each one of the loop sub-phases

4. CONCLUSION

KLEG, ADJS, and KDJS do not appear to be an indicator of footedness. Even if stability changes are expected to occur between the dominant and non-dominant limb, it seems that this tends not to be true. Differences can be observed graphically, but commonly-used statistical tools used to address these variables are unable to highlight differences. Further studies should increase the sample size and search for new statistical procedures to highlight footedness differences. Frontal plane assessments could increase the understanding of DJS and KLEG contributions to joint and body stabilisation strategies.

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.

ACKNOWLEDGEMENTS

The authors wish to thanks to all members of the MovLab /CICANT/ULHT team for their assistance and in particular to Ivo Roupa for the precious help in the data computation and José Maria Dinis in the help on data collection procedures.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Grouios G, Hatzitaki V, Kollias N, Koidou I. Investigating the stabilising and mobilising features of footedness. Laterality. 2009;14(4):362-80.
2. Atalaia A, Abrantes JMCS, Castro-Caldas A. Influence of Footedness on Dynamic Joint Stiffness during the Gait Stance Phase. JSRR. 2015;5(2):175-83.
3. Hart S, Gabbard C. Examining the mobilizing feature of footedness. Percept Mot Skills. 1998;86(3 Pt 2):1339-42.
4. Iteya M, Gabbard C, Hart S. Limb laterality and motor proficiency in children. The International Journal of Neuroscience. 1995;83(3-4):275-9.
5. Iteya M, Gabbard C, Okada M. Lower-limb speed and foot preference in children. Percept Mot Skills. 1995;81(3):1115-8.
6. Peters M. Footedness: Asymmetries in foot preference and skill and neuropsychological assessment of foot movement. Psychol Bull. 1988;103(2):179-92.
7. Wang Z, Newell KM. Footedness exploited as a function of postural task asymmetry. Laterality. 2013;18(3):303-18.
8. Kalaycioglu C, Kara C, Atbasoglu C, Nalcaci E. Aspects of foot preference: Differential relationships of skilled and unskilled foot movements with motor asymmetry. Laterality. 2008;13(2):124-42.
9. Ebben WP, Flanagan E, Jensen RL. Bilateral facilitation and laterality during the countermovement jump. Percept Mot Skills. 2009;108(1):251-8.
10. Coren S. The lateral preference inventory for measurement of handedness, footedness, eyedness and earedness - Norms for young-adults. Bull Psychon Soc. 1993;31(1):1-3.
11. Coren S, Porac C. The validity and reliability of self-report items for the measurement of lateral preference. Br J Psychol. 1978;69(2):207.
12. Lenoir M, Van Overschelde S, De Rycke M, Musch E. Intrinsic and extrinsic factors of turning preferences in humans. Neurosci Lett. 2006;393(2-3):179-83.
13. Schneiders AG, Sullivan SJ, O'Malley KJ, Clarke SV, Knappstein SA, Taylor LJ. A valid and reliable clinical determination of footedness. PM&R. 2010;2(9):835-41.
14. Greenwood JG, Greenwood JJD, McCullagh JF, Beggs J, Murphy CA. A survey of sidedness in Northern Irish schoolchildren: The interaction of sex, age, and task. Laterality. 2007;12(1):1-18.
15. Maupas E, Paysant J, Martinet N, Andre JM. Asymmetric leg activity in healthy subjects during walking, detected by electrogoniometry. Clin Biomech. 1999; 14(6):403-11.
16. Maupas E, Paysant J, Datie AM, Martinet N, Andre JM. Functional asymmetries of the lower limbs. A comparison between clinical assessment of laterality, isokinetic evaluation and electrogoniometric monitoring of knees during walking. Gait Posture. 2002;16(3):304-12.
17. Teixeira MCT, Teixeira LA. Leg Preference and Interlateral Performance Asymmetry in

Soccer Player Children. Dev Psychobiol. 2008;50(8):799-806.
18. Wieczorek M, Hradzki A. Functional and dynamic asymmetry in youth aged 14 and 16 years (comparative research). Acta Universitatis Palackianae Olomucensis Gymnica. 2007;37(1):51-61.
19. Čular D, Miletić Đ, Miletić A. Influence of dominant and non-dominant body side on specific performance in Taekwondo. Kinesiology. 2010;42(2):184-93.
20. Fitzgerald GK, Lephart SM, Hwang JH, Wainner RS. Hop tests as predictors of dynamic knee stability. J Orthop Sports Phys Ther. 2001;31(10):588-97.
21. Kivlan BR, Carcia CR, Clemente FR, Phelps AL, Martin RL. Reliability and validity of functional performance tests in dancers with hip dysfunction. Int J Sports Phys Ther. 2013;8(4):360-9.
22. Brumitt J, Heiderscheit BC, Manske RC, Niemuth PE, Rauh MJ. Lower extremity functional tests and risk of injury in division iii collegiate athletes. Int J Sports Phys Ther. 2013;8(3):216-27.
23. Gabriel RC, Abrantes J, Granata K, Bulas-Cruz J, Melo-Pinto P, Filipe V. Dynamic joint stiffness of the ankle during walking: Gender-related differences. PhysTher Sport. 2008;9(1):16-24.
24. Atalaia T, Abrantes JMCS. Medial-lateral CoP-Rearfoot relation during stance. In: Jorge RN, Tavares JMRS, Pinotti M, Slade A, editors. Proceedings of the 6th International Conference on Technology and Medical Sciences Porto. Taylor & Francis Group - CRC Press. 2011;177- 81.
25. Granata KP, Padua DA, Wilson SE. Gender differences in active musculoskeletal stiffness. Part II. Quantification of leg stiffness during functional hopping tasks. J Electromyogr Kinesiol. 2002;12(2):127-35.
26. Serpell BG, Ball NB, Scarvell JM, Smith PN. A review of models of vertical, leg, and knee stiffness in adults for running, jumping or hopping tasks. Journal of sports sciences. 2012;30(13):1347-63.
27. Crenna P, Frigo C. Dynamics of the ankle joint analyzed through moment-angle loops during human walking: Gender and age effects. Hum MovSci. 2011;30(6): 1185-98.
28. Frigo C, Crenna P, Jensen LM. Moment-angle relationship at lower limb joints during human walking at different velocities. J Electromyogr Kinesiol. 1996;6(3):177-90.
29. Safaeepour Z, Esteki A, Ghomshe FT, Abu Osman NA. Quantitative analysis of human ankle characteristics at different gait phases and speeds for utilizing in ankle-foot prosthetic design. Biomedical engineering online. 2014;13(1):19.
30. Butler RJ, Crowell HP, 3rd, Davis IM. Lower extremity stiffness: Implications for performance and injury. Clin Biomech. 2003;18(6):511-7.
31. Arampatzis A, Schade F, Walsh M, Bruggemann GP. Influence of leg stiffness and its effect on myodynamic jumping performance. J J Electromyogr Kinesiol. 2001;11(5):355-64.
32. Hobara H, Inoue K, Muraoka T, Omuro K, Sakamoto M, Kanosue K. Leg stiffness adjustment for a range of hopping frequencies in humans. J Biomech. 2010;43(3):506-11.
33. Struzik A, Zawadzki J. Leg stiffness during phases of countermovement and take-off in vertical jump. Acta Bioeng Biomech. 2013;15(2):113-8.
34. Wang LI. The kinetics and stiffness characteristics of the lower extremity in older adults during vertical jumping. J Sports Sci Med. 2008;7(3):379-86.
35. Ehrig RM, Taylor WR, Duda GN, Heller MO. A survey of formal methods for determining the centre of rotation of ball joints. J Biomech. 2006;39(15):2798-809.
36. Turner MR, Wicks P, Brownstein CA, Massagli MP, Toronjo M, Talbot K, et al. Concordance between site of onset and limb dominance in amyotrophic lateral sclerosis. J Neurol Neurosurg Psychiatry. 2010(82):853-4.
37. McMahon TA, Cheng GC. The mechanics of running: How does stiffness couple with speed? J Biomech. 1990;23(Suppl 1):65-78.
38. Brughelli M, Cronin J. A review of research on the mechanical stiffness in running and jumping: methodology and implications. Scand J Med Sci Sports. 2008;18(4):417-26.
39. Carpes FP, Diefenthaeler F, Bini RR, Stefanyshyn DJ, Faria IE, Mota CB. Influence of leg preference on bilateral muscle activation during cycling. Journal of Sports Sciences. 2011;29(2):151-9.

40. Golomer E, Mbongo F. Does footedness or hemispheric visual asymmetry influence centre of pressure displacements? Neurosci Lett. 2004;367(2):148-51.
41. Beling J, Wolfe GA, Allen KA, Boyle JM. Lower extremity preference during gross and fine motor skills performed in sitting and standing postures. J Orthop Sports Phys Ther. 1998;28(6):400-4.

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