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Original



## The effect of hyper-pronated foot on postural control and ankle muscle activity during running and cutting movement

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### ABSTRACT

**Objective:** The aim of this study was to examine the effect of hyper pronated foot on postural control and ankle muscle activity during running and cutting movement (v-cut).

**Methods:** In this Cross-Sectional study, 42 young physically active (exercising three times per week regularly) males participated in this study, including 21 with hyper-pronated feet and 21 with normal feet. Each participant completed a running and cutting task. Body postural control was measured using a force platform (1000Hz) which was synchronized with surface electromyography of selected ankle muscles. MATLAB software was used to process and analyze the data. One-away ANOVA was used to identify any differences between groups.

**Results:** Differing muscle activation patterns in the surrounding ankle musculature (tibialis anterior, peroneus longus) through to reduced postural stability in the medial-lateral direction and increased vertical ground reaction forces were observed between groups.

**Conclusion:** According to the obtained results it seems that subtalar hyper-pronation can be regarded as a factor affecting the biomechanics of cutting by changing activation patterns of the muscles surrounding the ankle, and reducing postural control of the body in medial-lateral direction, but not in anterior-posterior direction.

**Keywords:** Biomechanics; Kinesiology; Foot; Athlete; Injury prevention.

## El efecto del pie hiperpronado sobre el control postural y la actividad de los músculos del tobillo durante el movimiento de carrera y cambio de dirección

### RESUMEN

**Objetivo:** El objetivo de este estudio fue examinar el efecto del pie hiperpronado sobre el control postural y la actividad de los músculos del tobillo durante el movimiento de carrera y cambio de dirección.

**Métodos:** En este estudio transversal, participaron 42 hombres jóvenes físicamente activos (ejercitándose tres veces por semana con regularidad), incluidos 21 con pies hiperpronados y 21 con pies normales. Cada participante completó una tarea de correr y cambiar de dirección. El control de la postura corporal se midió utilizando una plataforma de fuerza (1000 Hz) que se sincronizó con la electromiografía de superficie de los músculos seleccionados del tobillo. Se utilizó el software MATLAB para procesar y analizar los datos. Se utilizó un ANOVA de una distancia para identificar las diferencias entre los grupos.

**Resultados:** Se observaron diferentes patrones de activación muscular en la musculatura del tobillo (tibial anterior, peroneo largo) con estabilidad postural reducida en la dirección medial-lateral y un aumento de las fuerzas de reacción vertical del suelo entre los grupos.

**Conclusión:** De acuerdo con los resultados obtenidos, parece que la hiperpronación puede ser considerada como un factor que afecta la biomecánica del cambio de dirección al modificar los patrones de activación de los músculos que del tobillo y reducir el control postural del cuerpo en dirección medial-lateral, pero no en dirección anteroposterior.

**Palabras clave:** Biomecánica; Cinesiolgia; Pie; Atletas; Prevención lesiones.

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## O efeito do pé hiper-pronado no controlo postural e actividade muscular no tornozelo durante a corrida e movimentos cortantes

### RESUMO

**Objetivo:** O objetivo deste estudo é examinar o efeito do pé hiper-pronado no controlo postural e actividade muscular no tornozelo durante a corrida e movimentos cortantes.

**Métodos:** Neste estudo seccionado, 42 rapazes fisicamente ativos (exercitam regularmente 3 vezes por semana) participaram neste estudo, incluindo 21 com pé hyper-pronated. Cada participante completou um desafio de corrida e corte. A postural corporal foi medida usando uma plataforma com potência de 1000Hz, cujo fora sincronizada com uma eletromiografia superficial do músculos do tornozelo seleccionados. O software MATLAB foi utilizado para processar e analisar os dados. ANOVA foi utilizado para identificar quaisquer diferenciações entre grupos.

**Resultados:** Padrões divergentes de ativação por volta do músculo do tornozelo (tibialis anterior peroneus longus) pela redução de estabilidade postural na direção medial-lateral e foi observado um aumento de reacções verticais téreas entre grupos.

**Conclusão:** De acordo com os resultados obtidos, parece que a hyper-pronation pode ser observada como um factor que afecta os biomecânica de corte através da mudança e ativação dos padrões dos músculos à volta do tornozelo, reduzindo assim o controlo do corpo na direção médio-lateral mas não na direção anterior-posterior.

**Palavras chave:** Biomecânica; Kinesiología; Pie; Deportista; Prevención lesiones

### Introduction

The foot-ankle complex of the lower extremities provides the base of support for the generation and execution of movement; an essential foundation for many sports skills such as running, jumping, and throwing.<sup>1</sup> Biomechanical alterations in this most distal segment in the multi-segment chain of the human body has implications on postural control,<sup>2</sup> especially in activities involving single-leg stance.<sup>3</sup> The consequences of a hyper- or hypo-mobile foot has received extensive attention in human movement studies of static balance, walking, running, and its association with injury.<sup>4-5</sup>

The medial longitudinal arch of the foot plays an important role in shock attenuation and in generating sufficient power for propulsion.<sup>6</sup> Findings from two recent population-based studies indicate that pronated dynamic foot function is associated with hallux valgus and overlapping toes.<sup>7-8</sup> Similarly, planus foot posture and pronated foot function are associated with generalised pain in the foot as well as with heel and arch pain in men.<sup>9</sup> Cadaver studies have shown that simulating a pronated foot results in increased plantar fascia strain, talo-navicular joint motion and dorsal compressive forces in the midfoot, factors that could potentially lead to tissue damage and subsequent foot symptoms.<sup>2</sup>

In sport, there is an increased likelihood of injury such as a non-contact anterior cruciate ligament (ACL) tear, if dysfunction such as hyper-pronation is combined with movements involving deceleration.<sup>10</sup> This is due to the greater challenge on the neuromuscular system.<sup>11</sup> One common action involving deceleration in sport is cutting. Cutting whilst running is a prevalent action in sports such as basketball, football (e.g. Gridiron, Australian Rules, soccer), and handball. Cutting can be preplanned such as during offensive play or unanticipated such as during defensive play. In handball, cutting movement was the primary mechanism for the majority (60%) of non-contact ACL injury incidences.<sup>12</sup>

To the author's knowledge, the effects of subtalar joint hyper-pronation on cutting during running has not been examined. Increased knowledge on the effects of ankle hyper-pronation on cutting whilst running may provide further insight on biomechanical factors that are potentially associated with injury. As changes in the foot structure can change in the postural control of the body and muscle activity during V-cut action, and since these changes can affect lower extremity joints, knowing these variables can help therapists and coaches choose the right

therapeutic and training approach. So, the purpose of the current study was to examine the effect of hyper-pronation foot on ankle muscle activity and postural control during sharp cutting.

### Method

#### Participants

Sample size was calculated using the G\*power 3.1.9.2 (Franz Faul, Kiel, Germany) based on our pilot experiment data. A required sample size was determined by achieving an estimated effect size of 0.80, alpha level of 0.05, and power of 0.80. Consequently, 42 individuals (21 in each of the two groups) were recruited. This study was approved by the Kharazmi University Institutional Review Board.

The subjects were selected based on the inclusion criteria, including general health, male gender, voluntary participation, and the completion of the consent form. Individuals were excluded from participation if they: (1) had continuous pain or underwent surgery on a lower extremity within the past 6 months, (2) had a diagnosed psychological illness that might interfere with the study protocol, (3) had experienced overt neurological signs, and (4) had active medical, surgical, or neurologic illness, painful conditions, history of peripheral neuropathies, or any disorders affecting the central nervous system.

#### Procedures

Participants were asked to wear sport clothes including shorts and athletic shoes to the testing sessions. The height and body mass of the participant was measured using a stadiometer (Seca 217, Hamburg, Germany) and electronic scales (Seca 813, Hamburg, Germany). In addition, information regarding the participant's age, foot preference, and previous history of lower extremity or foot injury was obtained. Foot preference was identified as their preferred limb for hopping. The participant then completed the Foot Posture Index<sup>13</sup> to identify if they had normal or increased (hyper-pronation) sub-talar joint motion.

Foot Posture Index (FPI) method was used for dividing the subjects into hyper pronated and normal groups.<sup>14</sup> Each participant was asked to stand, take a few steps forward and march on the spot for six-eight steps and then to stand still, with arms by their side and looking forward. During the assessment, it is important to ensure that the patient does not swivel to try to see what is happening for themselves, as this will significantly affect the

foot posture (consultation with a medical practitioner). The observers performed foot assessment of each participant using the six criteria of the FPI: 1-talar head palpation 2-curvature at the lateral malleoli 3-inversion/eversion of the calcaneus 4-talonavicular bulging 5-congruence of the medial longitudinal arch 6-abduction/adduction of the forefoot on the rearfoot, where each item is scored between -2 and +2 to give a sum total between -12 (highly supinated) and +12 (highly pronated).<sup>13</sup>

The participant was asked to sit in a chair. The length and width of the sole of the participant's right foot was measured to the nearest millimeter using a ruler. A self-selected warm-up including tasks such as jogging, running, jumping, lateral cutting, and stretching (averagely 10 minutes) to minimize the risk of injury during the proceeding movement task was completed. After the warm up, the skin was prepared for electrode placement by shaving, abrading and cleaning the skin surface. Electrodes were placed on the following muscles: medial gastrocnemius, soleus, tibialis anterior, and peroneus longus of the right limb. The SENIAM protocol was followed for electrode placement (Dual electrodes, Versa-Trode Solid Gel Foam, USA).<sup>15</sup> When the electrode placement process was completed, the participant was asked to run a few steps in order to identify and resolve any possible movement restrictions that may have been caused by the electrodes. Once electrodes were placed and checked, the participant completed the running and cutting task which involved running a 7 m path at 4.5-7.0 m/s, placing the preferred foot on the force platform which was embedded in the laboratory floor (508 x 464 mm), and cutting at an angle of  $45 \pm 10^\circ$  whilst still running.<sup>14</sup> Each participant was given enough practice trials until they were familiar and comfortable with the running and cutting task. The participant then completed three trials of the running and cutting task, with 1 minute rest between each trial. In total, each participant completed a minimum of 10 trials including the practice and experimental trials.

Following a 10-minute rest, the participant was asked to complete a series of strength tests in order to capture their maximum voluntary isometric contraction (MVIC) for each muscle consistent with the methods of Hagen, Schwiertz, Landorf, Menz, and Murley (2016).<sup>16</sup> Briefly, this included performing maximum voluntary isometric contractions against manual resistance in three movement directions including plantarflexion (medial gastrocnemius, soleus), dorsiflexion (tibialis anterior), and pronation (peroneus longus).<sup>16</sup>

All data was captured at 1000Hz using one triaxial force platform (OR6-6-2000, AMTI, Watertown, MA, U.S.A.), synchronized with a wireless electromyography (EMG) system (TeleMyo DTS, Noraxon, USA).

#### Data Analysis

Custom-written MATLAB software was used to process and analyze the force and EMG data. The vertical, horizontal (anterior-posterior) and medial-lateral force data, as well as center of mass (COM) and center of pressure (COP) data in the anterior-posterior and medial-lateral directions for each cutting trial was exported from the force platform software (BioAnalysis, AMTI, Watertown, MA, U.S.A.). The peak force in each direction (vertical, anterior-posterior, medial-lateral) was identified and normalized using the participant's body weight (BW). The differences in the COP to COM were calculated using Winter inverted pendulum formula as follows:

$$COP-COM = I \times \ddot{C}OM / WH$$

Where I is the inertia torque around the ankle joint,  $\ddot{C}OM$  is acceleration of the center of mass (in two directions: medial-lateral and anterior-posterior), W is the participant's weight and H is their height.<sup>17</sup> The inertia of the torque around the ankle was calculated as follows for each direction:

$$I_{A-P} = 0.0533 \times mH^2$$

$$I_{M-L} = 0.0572 \times mH^2$$

Where H and m is the participant's height and body mass respectively, and A-P is anterior-posterior and M-L is medial-lateral. As the center of pressure and mass are measured independently, the correlation of the equation (COP-COM) with  $\ddot{C}OM$  measure of the validity of the model has been simplified. The average correlation in the A-P and M-L direction has been reported as 0.94.<sup>18</sup> The COP-COM result in each direction (A-P and M-L) was normalized with respect to the length and width of the sole of the participant's right foot.

All EMG data was filtered using a band pass filter with a frequency of 10 to 450 Hz.<sup>5</sup> The peak EMG reading for each muscle was then identified for each trial and normalized as a percentage of the corresponding maximum EMG reading from the MVIC test (MVIC%). Further, the muscle onset time (pre-activation) of each muscle was also identified with reference to the initial contact force on the force platform. Initial contact on the force platform was defined as when the vertical force of 20 Newton (N) was detected.<sup>19</sup>

All statistical tests were completed using SPSS (version 21, IBM, USA) with an alpha level of less than 0.05 set for all analyses. The average result for each participant and measure was collated and then the normality of the resulting dataset was tested using the Shapiro-Wilk test. A Levene's test was also used to test for equality of error variances. An independent samples T test was used to identify any statistically significant differences between the two groups (normal, hyper-pronation) for the descriptive measures (e.g. age, height). A one-way analysis of variance (ANOVA) was used to compare groups for the remaining measures (e.g. peak soleus muscle activity).

#### Results

General characteristics of the participants including the results for the FPI are presented in [Table 1](#). The two groups were homogenous with no statistical differences identified for age, height and body mass. Similarly, the average FPI in the normal group is 2.23 score which is in the normal range (0 to 5 score), and the average FPI in the hyper-pronated foot group is 11.04 score, and as it is more than 9 score, it is considered part of the hyper-pronated foot<sup>20</sup>, and the difference in FPI between the two groups is statistically significant ( $p < 0.001$ ).

**Table 1.** Characteristics of the participants including the FIP results.

Group	Age (years)	Height (cm)	Mass (kg)	FIP (score)
Normal	24.57±2.01	179.42±6.94	77.33±9.10	2.23±1.37
Hyper-Pronation	25.00±1.84	178.04±5.95	76.23±9.41	11.04±0.8
t	0.719	0.692	0.490	25.340
p	0.476	0.493	0.628	<0.001

Significant between group differences are identified as \* $p < 0.05$  and \*\* $p < 0.05$

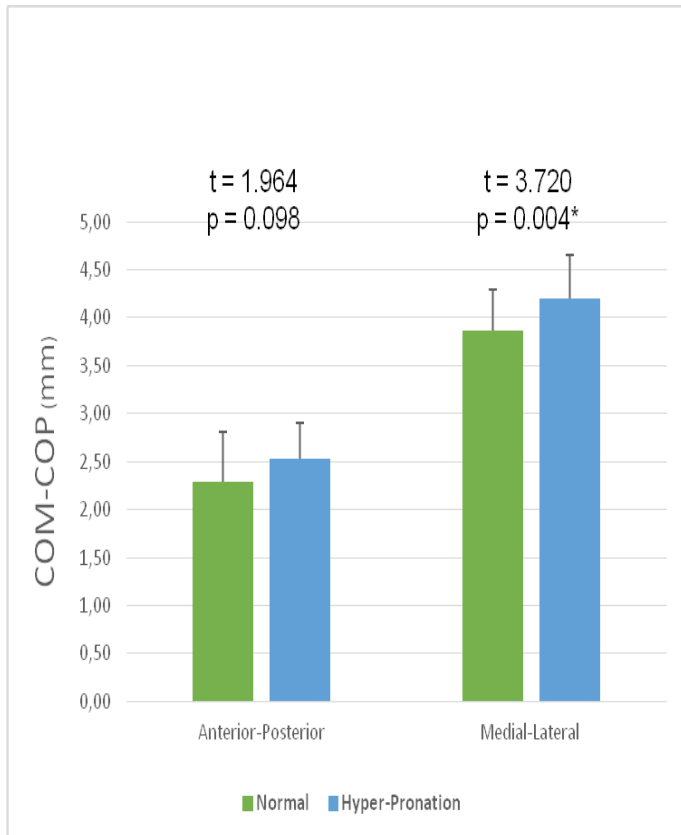
The medial gastrocnemius, soleus and peroneus longus muscles pre-activated approximately 24 to 33% earlier before ground contact in the cutting stance limb of the hyper-pronation group when compared to the normal group ( $p < 0.001$ ; [Table 2](#)). Whereas the tibialis anterior muscle pre-activation was approximately 18% delayed in the hyper-pronation group when compared to the normal group ( $p < 0.001$ ). Despite these timing differences, the peak muscle activity in the medial gastrocnemius and soleus was the same for both groups ([Table 2](#)); however, peak muscle activity was 22% higher in the tibialis anterior ( $p < 0.001$ ) and 14% lower in the peroneus longus ( $p < 0.001$ ) for the hyper-pronation group.

Increased peak medial-lateral ground reaction force ( $p = 0.047$ ) and postural sway (COM-COP;  $p = 0.004$ ) was observed in the hyper-pronation group for the cutting stance limb ([Figure 1](#) & [Figure 2](#)). Further, there was also significantly higher peak vertical ( $p = 0.002$ ) and anterior-posterior ( $p = 0.001$ ) ground reaction forces in the hyper-pronation group.

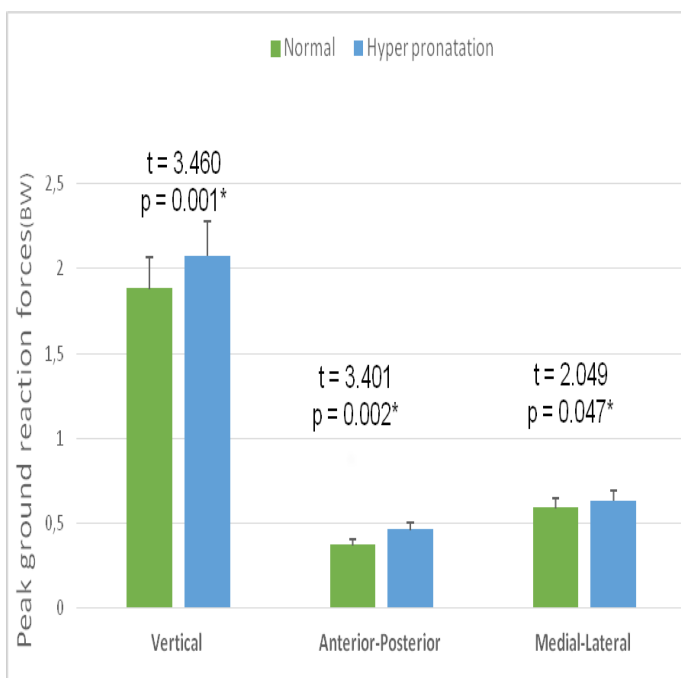
**Table 2.** Ankle muscle pre-activation onset (time) in milliseconds (ms) and peak ankle muscle activity during running and cutting

**Peroneus Longus (ms)	**Tibialis Anterior (ms)	Soleus (ms)**	Gastrocnemius	Group	Variables
±17.48-207.66- 257.26±19.83- 7.26 *0.000	131.06±14.16- 107.00±16.98- 4.21 *0.000	180.86±12.42- 234.80±9.49- 13.35 *0.000	141.86±11.75- 188.06±8.02- 12.57 *0.000	Normal Hyper-Pronation	Muscle pre-activation onset (ms)
58.14±5.64 50.85±5.83 4.114 0.000*	23.61±4.27 30.01±4.82 5.102 0.000*	49.38±3.74 47.71±4.54 1.297 0.202	61.09±5.35 58.33±6.41 1.515 0.138	Normal Hyper-Pronation	Muscle activity (%MVIC)
				t p	

Significant between group differences are identified as \* $p < 0.05$



**Figure 1.** Postural stability (sway) measured from the difference between centre of mass (COM) and centre of pressure (COP).



**Figure 2.** Peak ground reaction forces of the cutting stance limb, normalized with reference to body weight (BW).

## Discussion

Increased ground reaction forces and medial-lateral body sway was observed in participants with ankle hyper-pronation during the running and cutting task. This indicated that hyper-pronation reduces whole body stability and increases the loading forces in this fast deceleration task. This was likely due to the different muscle activation patterns observed for the participants with subtalar hyper-pronation.

Hertel et al.<sup>21</sup> reported that the COP speed of pronated feet was increased when compared to that of normal feet because of the reduced stability of the pronated feet. This indicates that the pronated group has poorer stability than does the normal group. We postulated that this might be due to subtalar joint instability in the pronated group. This may be supported by a greater navicular drop. The subtalar joint controls the stability of the position of the rear foot directly and the distal joints, such as the transverse tarsal joint, indirectly. When weight loaded, excessive flexibility of the subtalar joint increases pronation, and this might lead to an unstable base of support and ultimately decreased stability of the foot.<sup>22</sup>

Subtalar hyper-pronation resulted in earlier pre-activation of the plantarflexors (gastrocnemius, soleus) and peroneus longus muscles, in combination with delayed pre-activation of the dorsiflexor (tibialis anterior) during the cutting task. The tibialis anterior has two functional roles; first it acts to dorsiflex and invert the ankle which occurs near foot strike in cutting.<sup>23</sup> Second, it can act to lock the ankle and midfoot through an isometric contraction.<sup>24</sup> This second function is important for providing a stable base of support from which the body can rapidly pivot during the cutting action. As the pre-activation of this muscle was delayed in the hyper-pronation group this may provide insight on the key mechanical component missing in the cutting movement of these participants. That is, the delayed activation of the tibialis anterior may result in insufficient locking of the sub-talar joint. Further, the peroneus longus was less active in the hyper-pronation group. The peroneus longus acts to evert and plantarflex the ankle and is an antagonist (one of the opposing muscles) to the tibialis anterior. The lower activity of this muscle may therefore also contribute to the insufficient sub-talar joint locking.<sup>25</sup> These findings provide biomechanical insight for the potential reason why cutting movements in sports such as handball is the mechanism for the majority of non-contact ACL injury incidences.<sup>12</sup> Screening athletes for hyper-pronation in combination with tibialis anterior/peroneus longus function and strength testing would enable targeted injury prevention interventions for higher risk athletes.

The results of this study can help therapists and coaches choose the right therapeutic and training approach. In the case of the former, identifying the anomalies and the associated injuries could be leveraged to better gear the therapeutic exercises to cure the individuals. Additionally, coaches may implement balance-related training programs to improve the performance of athletes with foot pronation.

The limitations of the study were that only one (preferred) limb was tested for the cutting movement, the cutting movement was pre-planned, and that the lower limb biomechanical patterns (e.g. knee movement in the sagittal and frontal plane) were not

obtained. Further research should investigate gradual through to sharp cutting movements through an unanticipated protocol where the cutting tasks are randomized (limb, cut angle) in combination with straight line running. That is because ACL injury risk may be greater when the lower limb maneuvers are unanticipated.<sup>9</sup> The next limitation was that in this study, due to using the surface EMG, we could not investigate deep muscles such as Peroneus muscles that are involved in medial-lateral direction.

A hyper-pronated foot can be considered a factor affecting whole-body biomechanics of running and cutting movements. This includes altered muscle activation patterns in the surrounding ankle musculature (tibialis anterior, peroneus longus) through to reduced postural stability in the medial-lateral direction. These altered biomechanical patterns during cutting may expose individuals to a higher associated risk of injury. The results of the research emphasizes the need for accurate and comprehensive study of the effect of abnormal ankle/foot function on the biomechanics of the lower extremities during cutting movements in order to design appropriate training programs to enhance performance and reduce injury risk.

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## References

1. [Chu SK, Jayabalan P, Kibler WB, Press J. The kinetic chain revisited: New concepts on throwing mechanics and injury. Phys Med Rehab. 2016;8\(3\):69-77.](#)
2. [Malik M, Kaur J, Malik A. Correlation between foot overpronation and angle of inclination of hip joint. Indian J Phys Occup Ther. 2017;11\(4\):78-82.](#)
3. [Cote KP, Brunet BMG, Shultz SJ. Effects of pronated and supinated foot postures on static and dynamic postural stability. J Athl Train. 2005;40\(1\):41-6.](#)
4. [Kim J, Lim O, Yi C. Difference in static and dynamic stability between flexible flatfeet and neutral feet. Gait Posture. 2015;41\(2\):546-50.](#)
5. [Khodaveisi H, Sadeghi H, Memar R, Anbarian M. Comparison of selected muscular activity of trunk and lower extremities in young women's walking on supinated, pronated and normal foot. Apunts Med Esport. 2016;51\(189\):13-19.](#)
6. [Menz HB. Biomechanics of the ageing foot and ankle: a mini-review. Gerontol. 2015;61\(4\):381-8.](#)
7. [Hagedorn TJ, Dufour AB, Golightly YM, Riskowski JL, Hillstrom HJ, Casey VA, et al. Factors affecting center of pressure in older adults: the Framingham Foot Study. J Foot Ankle Res. 2013;6\(1\):18.](#)
8. [Golightly Y, Dufour AB, Hillstrom HJ, Jordan JM. Foot disorders associated with overpronated and oversupinated foot function: the Johnston county osteoarthritis project. Foot Ankle Int. 2014;35\(11\):1159-65.](#)
9. [Menz HB, Dufour AB, Riskowski JL, Hillstrom HJ, Hannan MT. Association of planus foot posture and pronated foot function with foot pain: the Framingham foot study. Arthritis Care Res \(Hoboken\). 2013;65\(12\):1991-9.](#)
10. [Besier TF, Lloyd DG, Ackland TR, Cochrane JL. Anticipatory effects on knee joint loading during running and cutting maneuvers. Med Sci Sports Exerc. 2001;33\(7\):1176-81.](#)
11. [Colby SM, Hintermeister RA, Torry M, Steadman JR, Malone TR, Colby SM. Lower limb stability with ACL impairments. J Orthop Sports Phys Ther. 1999;29\(8\):444-54.](#)
12. [Olsen O, Myklebust G, Engebretsen L, Bahr R. Injury mechanisms for anterior cruciate ligament injuries in team handball. A systematic video analysis. Am J Sports Med. 2004;32\(4\):1002-12.](#)
13. [Redmond AC, Crosbie J, Ouvrier RA. Development and validation of a novel rating system for scoring standing foot posture: the Foot Posture Index. Clin Biomech. 2006;21\(1\):89-98.](#)
14. [Sigward SM, Powers CM. The influence of gender on knee kinematics, kinetics and muscle activation patterns during side-step cutting. Clin Biomech. 2006;21\(1\):41-8.](#)
15. [Hermens DH, Feriks B. Surface electromyography for the non-invasive assessment of muscle \(SENIAM\). 2005: <http://www.SENIAM.com/>.](#)
16. [Hagen M, Schwiertz G, Landorf KB, Menz HB, Murley GS. Selective activation of lower leg muscles during maximum voluntary isometric contractions. Hum Mov Sci. 2016;50\(1\):30-7.](#)
17. [Lafond D, Duarte M, Prince F. Comparison of three methods to estimate the center of mass during balance assessment. J Biomech. 2004;37\(9\):1421-6.](#)
18. Winter DA. Biomechanics and Motor Control of Human Movement (4<sup>th</sup> Ed.). New York: John Wiley & Sons. 2009;127-31.
19. [Kristianslund E, Faul O, Bahr R, Myklebust G, Krosshaugh T. Sidestep cutting technique and knee abduction loading: implications for ACL prevention. Br J Sports Med. 2014;48\(9\):779-83.](#)
20. [Evans AM, Copper AW, Scharfbillig RW, Scutter SD, Williams MT. Reliability of the foot posture index and traditional measures of foot position. J Am Podiatr Med Assoc. 2003;93\(3\):203-13.](#)
21. [Hertel J, Gay MR, Denegar CR. Differences in postural control during single-leg stance among healthy individuals with different foot types. J Athl Train. 2002;37\(2\):129-32.](#)
22. [Cobb SC, Tis LL, Johnson BF, Highbie EJ. The effect of forefoot varus on postural stability. J Orthop Sports Phys Ther. 2004;34\(2\):79-85.](#)
23. Floyd RT, Thompson C. Manual of Structural Kinesiology. Boston: WCB. 2014; 320-43.
24. Neumann DA. Kinesiology of the Musculoskeletal System. Foundations for Physical Rehabilitation. St. Louis, Missouri: Mosby. 2010;605-18.
25. [Okamura K, Kanai S, Hasegawa M, Otsuka A, Oki S. The effect of additional activation of the plantar intrinsic foot muscles on foot dynamics during gait. Foot. 2018;34\(1\):1-5.](#)