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Foot Structure and Muscle Reaction Time to a Simulated Ankle Sprain

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Context: Foot structure has been shown to affect aspects of neuromuscular control, including postural stability and proprioception. However, despite an association between pronated and supinated foot structures and the incidence of lateral ankle sprains, no one to our knowledge has measured muscle reaction time to a simulated ankle-sprain mechanism in participants with different foot structures.

Objective: To determine whether pronated or supinated foot structures contribute to neuromuscular deficits as measured by muscle reaction time to a simulated ankle-sprain mechanism.

Design: Cross-sectional study.

Setting: University biomechanics laboratory.

Patients or Other Participants: Thirty volunteers were categorized into 3 groups according to navicular-drop–height measures. Ten participants (4 men, 6 women) had neutral feet (navicular-drop height = 5–9 mm), 10 participants (4 men, 6 women) had pronated feet (navicular-drop height $\geq$ 10 mm), and 10 participants (4 men, 6 women) had supinated feet (navicular-drop height $\leq$ 4 mm).

Intervention(s): Three perturbations on a standing tilt platform simulating the mechanics of an inversion and plantarflexion ankle sprain.

Main Outcome Measure(s): Muscle reaction time in milliseconds of the peroneus longus, tibialis anterior, and gluteus medius to the tilt-platform perturbation.

Results: Participants with pronated or supinated foot structures had slower peroneus longus reaction times than participants with neutral feet ($P = .01$ and $P = .04$, respectively). We found no differences for the tibialis anterior or gluteus medius.

Conclusions: Foot structure influenced peroneus longus reaction time. Further research is required to establish the consequences of slower peroneal reaction times in pronated and supinated foot structures. Researchers investigating lower limb muscle reaction time should control for foot structure because it may influence results.

Key Words: tilt platform, arch height, injuries, neuromuscular control

Key Points

- Reaction time of the peroneus longus muscle was slower in participants with pronated and supinated feet than in participants with neutral feet.
- Reaction times of the tibialis anterior and gluteus medius muscles were not different among groups.
- Further research is required to investigate if the risk of sustaining a lateral ankle sprain is greater in people with pronated or supinated feet than in people with neutral feet.

Medial longitudinal arch abnormalities frequently are associated with lower limb injuries.[1–3] The most prevalent injuries are lateral ankle sprains, and both low arches[2] and high arches[3] have been shown to be risk factors. In the United States, ankle sprains have an estimated incidence rate of 2.15 per 1000 person-years[4] and an estimated annual health care cost of $2 billion.[5] The United Kingdom also has a high incidence rate, with as many as 302 000 patients attending emergency departments with ankle sprains each year.[6] Further research clearly is needed in this area in terms of both treatment and suggestions to reduce the rate of ankle sprains.

Arch height is related to foot function. A high arch is typically rigid and characteristic of oversupination, whereas a low arch is usually hypermobile and is related to overpronation.[7] Researchers[8,9] have associated excessively pronated or supinated foot structures with deficits in some aspects of neuromuscular control compared with neutral foot structure. Components of neuromuscular control include proprioception, muscle strength, postural control, and muscle reaction time.[10] Both Cote et al[8] and Tsai et al[9] found evidence to suggest that foot structure affects postural control; however, no one has assessed the effects of pronated or supinated foot structures on muscle reaction time.

The measurement of muscle reaction time to a tilt-platform perturbation is a well-established method of analyzing neuromuscular control in the lower limb.[11–15] Using a static (standing) platform[11–15] or a dynamic (walking) platform,[16,17] it is designed to simulate the mechanics of an inversion ankle sprain, therefore stressing the dynamic defense mechanism.[11] Typically, electromyographic (EMG) measurements include the peroneus longus[11–14] and the tibialis anterior[11] because these muscles have direct roles in the dynamic defense mechanism.[11] The gluteus medius also has been included to identify the hip strategy during perturbation.[14]

Therefore, the purpose of our study was to determine whether pronated or supinated foot structures contribute to neuromuscular deficits as measured by muscle reaction time to a simulated ankle-sprain mechanism. We hypothesized that participants with pronated or supinated foot

Table 1. Participant Characteristics (Mean ± SD)

Group	Sex		Age, y	Height, cm	Mass, kg	Navicular-Drop Height, mm
	Men	Women				
Neutral	4	6	20.2 ± 2.1	169.3 ± 8.8	70 ± 11.2	7.0 ± 1.0
Pronated	4	6	21.4 ± 1.5	169.8 ± 10.5	70.4 ± 14.6	11.0 ± 2.0
Supinated	4	6	20.8 ± 1.6	169.3 ± 6.2	69.5 ± 10.7	3.0 ± 1.0

structures would have slower muscle reaction times than participants with neutral foot structures.

METHODS

Participants

Thirty volunteers participated in this study and were categorized into 3 groups according to navicular-drop–height measures. Participants within each group were matched for height, mass, and sex (Table 1). We included people who were 18 to 30 years of age and participated in at least 2 hours of exercise each week. Volunteers were excluded if they had had a lower limb injury within 6 months before the study; had a history of lower limb surgery, myositis ossificans, poor circulation, general illness, acute trauma to the lower limb, soft tissue inflammation, skin infection, or allergy to alcohol wipes; were under the influence of alcohol or another psychoactive substance; or regularly used orthotic devices, taping, or bracing. Following the recommendations of Tsai et al[9] to improve internal validity, volunteers also were excluded if they had participated in any activity involving regular balance training (eg, ballet, gymnastics, tai chi) during the 1 year before testing or for a total period of more than 1 year during the 10 years before testing. All participants provided written informed consent, and the study was approved by the University of Hertfordshire School of Life Sciences Ethics Committee.

Procedures

We categorized participants according to navicular-drop–height measures following the procedure described by Brody[18] and using the same height gauge (model HG-1; Axminster Power Tool Centre, Ltd, Devon, United Kingdom) for all measures. All measurements were taken by the same researcher (J.R.D.), who had established high day-to-day reliability during pilot testing (intraclass correlation coefficient = 0.97, standard error of measurement = 0.5 mm). First, the participant stood in a relaxed position with his or her feet placed shoulder-width apart, and we marked the most prominent point of the navicular tuberosity with a pen. Second, we found the subtalar neutral position by gently pinching with the thumb and index finger on either side of the talus and instructing the participant to slowly invert and evert the ankle until the examiner felt equal pressure on both fingers. At this point, we measured the height of the marked navicular tuberosity from the ground. Next, the participant was instructed to return to a relaxed stance, and the height of the navicular tuberosity to the ground was measured again. The navicular-drop height was calculated by subtracting the relaxed-stance measure from the subtalar-neutral measure. The average of 3 measurements was used to categorize participants following the guidelines of Cote et al[8]: equal to or greater than 10 mm indicated a pronated foot, 5 to 9 mm indicated a neutral arch, and equal to or less than 4 mm indicated a supinated foot.

The tilt platform, as used by Mitchell et al,[11] comprised 2 independently movable platforms, each moving from a neutral position to 30° of inversion and 20° of plantar flexion when released. We instructed participants to stand on the tilt platform in a relaxed stance and to look directly ahead. Participants were informed that 6 to 8 tilts would occur and either ankle might be tested at any one time. Participants were not told when the perturbations would occur, and perturbations were initiated at variable intervals to reduce anticipatory effects. An average of 3 tilts on the dominant side was used for analysis. In accordance with Hoffman et al,[19] the *dominant side* was defined as the foot used to kick a ball. If participants were unsure or stated that either foot could be used to kick a ball, the *dominant side* was defined further as the leg on which the participant would prefer to recover balance if pushed.[19]

All testing was conducted using the same 8-channel DataLINK EMG system (model DLK900; Biometrics Ltd, Newport, UK). Before applying the electrodes, we prepared the skin by shaving the area, cleaning it with an alcohol wipe to reduce skin impedance, and letting it dry. A passive reference electrode was placed on the radial styloid process, and preamplified surface bipolar electrodes (model SX230; Biometrics Ltd) with a gain of 1000, bandwidth of 20 to 460 Hz, noise of less than 5 μV, input impedance greater than 100 MΩ, and common mode rejection ratio greater than 96 dB were positioned on the peroneus longus, tibialis anterior, and gluteus medius according to "Surface Electromyography for the Non-Invasive Assessment of Muscles guidelines"[20] in the direction of the muscle fibers. The EMG signals were sampled at 1000 Hz. Electrodes were not moved throughout the testing period.

Data Reduction and Statistical Analysis

Raw EMG data were processed with a root mean square filter using a 10-millisecond moving window. Data were reduced using a custom-made Excel template (Microsoft Corporation, Redmond, WA). *Muscle reaction time* was defined as the time between the onset of the tilt mechanism and the onset of the EMG signal when it reached a level of 3 SDs[17] above the baseline for 25 consecutive milliseconds. The baseline value was the average value recorded over 150 milliseconds immediately before the onset of the tilt mechanism.

Given that data were distributed normally (Shapiro-Wilk $P > .05$), a separate 1-way analysis of variance was performed for each dependent variable (peroneus longus, tibialis anterior, gluteus medius), with foot structure (neutral, pronated, supinated) as the independent variable. When a main effect was observed, a Dunnett post hoc test

Table 2. Reaction Time Measurements, ms (Mean ± SD)

	Group		
Muscle	Neutral	Pronated	Supinated
Peroneus longus	39.6 ± 5.1	49.7 ± 9.5[a]	47.2 ± 5.8[a]
Gluteus medius	52.0 ± 10.2	54.0 ± 10.9	47.8 ± 7.2
Tibialis anterior	43.6 ± 8.3	45.7 ± 6.4	49.2 ± 4.3

[a] Indicates slower reaction time compared with the neutral group ($P < .05$).

was used to compare pronated and supinated foot structures against the neutral foot group. The α level was set a priori at .05. Effect size (η_p^2 values) and observed power also were calculated. All statistical analyses were performed using IBM SPSS (version 19.0; IBM Corporation, Armonk, NY).

RESULTS

The average reaction times across the different groups are shown in Table 2. Across the 3 groups, the reaction time of the peroneus longus ranged from 39.6 to 49.7 milliseconds, that of the tibialis anterior ranged from 43.6 to 49.2 milliseconds, and that of the gluteus medius ranged from 47.8 to 54.0 milliseconds. Analysis of the peroneus longus indicated a main effect of foot structure ($F_{2,27} = 5.5$, $P = .01$, $\eta_p^2 = 0.29$, observed power $= 0.82$). Post hoc testing revealed differences between the neutral and the pronated ($P = .01$) and supinated ($P = .04$) groups, with both groups showing slower peroneal reaction times than the neutral group. No differences were identified within the tibialis anterior ($F_{2,27} = 1.9$, $P = .17$, $\eta_p^2 = 0.12$, observed power $=$ 0.35) or the gluteus medius ($F_{2,27} = 1.1$, $P = .35$, $\eta_p^2 = 0.07$, observed power $= 0.22$).

DISCUSSION

We are the first to measure muscle reaction time to a tilt-platform perturbation in participants with pronated, supinated, or neutral foot structures. The mean peroneal reaction time of participants with neutral feet was 39.6 ± 5.1 milliseconds, which was faster than the reaction times of participants with pronated (49.7 ± 9.5 milliseconds) or supinated (47.2 ± 5.8 milliseconds) feet ($P < .05$). Therefore, we accepted the hypothesis that participants with pronated or supinated feet have slower muscle reaction times of the peroneus longus than participants with neutral feet. Compared with the neutral group, these values represent a 25% decrease in reaction time for the pronated group and a 19% decrease for the supinated group. Researchers[10] have shown that delayed peroneal reaction times may mean that the muscles are incapable of protecting the ankle joint from sudden inversion. Although we did not measure the incidence of lateral ankle sprains, our results could indicate that the risk of lateral ankle sprain may be greater in people with pronated or supinated foot structures than in people with neutral foot structures. This is a notable finding that has not been observed in the literature and has important implications considering that ankle sprains are among the most common sporting injuries, with around 23 000 each day in the United States alone.[21] Clearly, a thorough epidemiologic study is required in which researchers observe foot structure and the incidence of lateral ankle sprains.

The theoretical basis for why pronated and supinated foot structures had slower peroneal reaction times in our study is unclear. As Johnson and Christensen[22] described, the peroneus longus originates from the head and lateral shaft of the fibula and becomes tendinous in the middle third of the lateral compartment of the lower leg. The tendon inserts onto the plantar lateral surface of the base of the first metatarsal via a system of pulleys: the lateral malleolus, the peroneal tubercle, and the cuboid.[22] With such a complex anatomic path in relation to other musculature, it is unsurprising that slight biomechanical alterations in the foot may lead to changes in muscle activity. In addition to biomechanical differences in the foot, pronated and supinated foot structures may have repercussive effects in the lower leg; increased pronation results in excessive internal tibial rotation, whereas increased supination leads to excessive external tibial rotation.[23]

Tiberio[24] stated that a pronated foot reduces the mechanical advantage of the peroneus longus, perhaps because of slight shortening of the muscle in the pronated position.[7,25] In addition to the mechanical differences caused by different foot structures, researchers have indicated that EMG amplitude differs between neutral and pronated foot structures during the stance phase of gait. Hunt and Smith[26] found that people with pronated feet had lower EMG amplitude of the peroneus longus than people with neutral feet. They admitted that the differences were only small[26]; however, this result still may provide an insight into why the reaction times of the pronated group were different from the neutral group.

Investigators analyzing other aspects of neuromuscular control have suggested that differences among foot structures are caused by altered sensory feedback due to structural differences among the groups.[8,9,27] For example, a supinated foot has less ground contact than a pronated or neutral foot, so theoretically it receives less afferent input from the cutaneous receptors on the plantar surface, which may affect how perturbations to stance are addressed.[27] This explanation for the slower reaction time of the supinated group seems feasible, but given that we did not measure plantar sensory input, it remains speculative.

Researchers[28] have shown that patients with chronic ankle instability rely more on hip strategy than ankle strategy because of increased hypermobility in the ankle. Ankle strategy involves shifting the center of body mass by rotating the body about the ankle joint,[29] whereas hip strategy involves using the gluteus medius to correct posture.[30]

A viable assumption is that people with pronated or supinated feet also may rely more on hip strategy than people with neutral feet because of decreased efficiency of the ankle strategy in maintaining balance. We did not identify differences in gluteus medius reaction time, possibly because the perturbation caused by the static (standing) tilt platform could be corrected by ankle strategy alone in all groups. It would be interesting to observe the reaction times of the gluteus medius in people with different foot structures during a more demanding task, such as using a dynamic (walking) tilt platform as described by Hopkins et al[16,17] or during a perturbed dynamic landing task as described by Gutierrez and Kaminski.[31]

We did not identify differences among foot structures for the tibialis anterior, indicating that foot structure does not affect the function of this muscle during an inversion and plantar-flexion simulation. Researchers have implied that foot structure may affect tibialis anterior function. For example, Hunt and Smith[26] identified a small increase in tibialis anterior EMG amplitude in pronated feet compared with neutral feet. In some epidemiologic studies, investigators[3] have noted that differences in foot structure may predispose athletes to tibialis anterior strains, implying that more stress is placed on the tibialis anterior muscle because of altered foot biomechanics. We could argue again that the static (standing) platform used in this study did not place sufficient stress on the tibialis anterior muscle to elicit differences among foot structures.

In general, the reaction times in our study appeared to be faster than those reported in previous studies.[11–13] Several reasons could explain this, but given that no one has investigated the effects of foot structure on muscle reaction time in this way, making direct comparisons is difficult. One major factor is that in some previous studies, participants have worn footwear,[12] which has been shown to reduce the speed of inversion[32] and therefore slow the reaction time of the peroneus longus muscle. In contrast, our participants were barefoot. Further explanations for differing reaction times among studies are differences in tilt platform designs. For example, authors[12,13,33–35] of many studies in this area have used tilt platforms that tilt in only 1 plane, whereas the tilt platform that we used combines inversion and plantar flexion, which is more applicable to the ankle-sprain mechanism.

In addition, variances in data-analysis techniques may account for differences in reaction times among studies. No consensus exists in the literature on the best data-analysis technique in studies using tilt platforms. Variables include the method used for exporting data, the length of the baseline measure, the number of standard deviations above the baseline measure, and the duration for which the burst is maintained. In some studies,[13,34] these variables are not reported, making comparisons difficult; however, the most widely reported value is the number of standard deviations above the baseline measure. This number has varied enormously, ranging from 2 SDs[33,35] to 3,[17] 5,[36] and 10 SDs[37] above the baseline measure. Few authors have justified the variables chosen; however, Hodges and Bui[38] advised that the standard deviation must be high enough to avoid a type I error, where the muscle is identified as active when it is not, yet low enough to avoid a type II error, where the researcher does not identify the EMG onset when it occurs. Definitive variables clearly need to be identified and used throughout this research area to enable accurate comparison of results to make valid conclusions.

CONCLUSIONS

Our results suggest that people with pronated or supinated foot structures have slower muscle reaction time than people with neutral feet. In light of our results, researchers should address whether people with pronated or supinated foot structures are at greater risk of lateral ankle sprain than people with neutral foot structures. Researchers investigating other aspects of muscle reaction time should control for foot type because differences among participants may affect results.

REFERENCES

1. Kaufman KR, Brodine SK, Shaffer RA, Johnson CW, Cullison TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *Am J Sports Med*. 1999;27(5):585–593.
2. Mei-Dan O, Kahn G, Zeev A, et al. The medial longitudinal arch as a possible risk factor for ankle sprains: a prospective study in 83 female infantry recruits. *Foot Ankle Int*. 2005;26(2):180–183.
3. Williams DS III, McClay IS, Hamill J. Arch structure and injury patterns in runners. *Clin Biomech (Bristol, Avon)*. 2001;16(4):341–347.
4. Waterman BR, Owens BD, Davey S, Zacchilli MA, Belmont PJ Jr. The epidemiology of ankle sprains in the United States. *J Bone Joint Surg Am*. 2010;92(13):2279–2284.
5. Soboroff SH, Pappius EM, Komaroff AL. Benefits, risks, and costs of alternative approaches to the evaluation and treatment of severe ankle sprain. *Clin Orthop Relat Res*. 1984;183:160–168.
6. Bridgman SA, Clement D, Downing A, Walley G, Phair I, Maffulli N. Population based epidemiology of ankle sprains attending accident and emergency units in the West Midlands of England, and a survey of UK practice for severe ankle sprains. *Emerg Med J*. 2003;20(6):508–510.
7. Franco AH. Pes cavus and pes planus: analyses and treatment. *Phys Ther*. 1987;67(5):688–694.
8. Cote KP, Brunet ME II, Gansneder BM, Shultz SJ. Effects of pronated and supinated foot postures on static and dynamic postural stability. *J Athl Train*. 2005;40(1):41–46.
9. Tsai LC, Yu B, Mercer VS, Gross MT. Comparison of different structural foot types for measures of standing postural control. *J Orthop Sports Phys Ther*. 2006;36(12):942–953.
10. Richie DH Jr. Functional instability of the ankle and the role of neuromuscular control: a comprehensive review. *J Foot Ankle Surg*. 2001;40(4):240–251.
11. Mitchell A, Dyson R, Hale T, Abraham C. Biomechanics of ankle instability, part 1: reaction time to simulated ankle sprain. *Med Sci Sports Exerc*. 2008;40(8):1515–1521.
12. Shima N, Maeda A, Hirohashi K. Delayed latency of peroneal reflex to sudden inversion with ankle taping or bracing. *Int J Sports Med*. 2005;26(6):476–480.
13. Karlsson J, Andreasson GO. The effect of external ankle support in chronic lateral ankle joint instability. *Am J Sports Med*. 1992;20(3):257–261.
14. Beckman SM, Buchanan TS. Ankle inversion injury and hypermobility: effect on hip and ankle muscle electromyography onset latency. *Arch Phys Med Rehabil*. 1995;76(12):1138–1143.
15. Ricard MD, Sherwood SM, Schulthies SS, Knight KL. Effects of tape and exercise on dynamic ankle inversion. *J Athl Train*. 2000;35(1):31–37.
16. Hopkins JT, Hunter I, McLoda T. Effects of ankle joint cooling on peroneal short latency response. *J Sports Sci Med*. 2006;5(2):333–339.
17. Hopkins JT, Brown TN, Christensen L, Palmieri-Smith RM. Deficits in peroneal latency and electromechanical delay in patients with functional ankle instability. *J Orthop Res*. 2009;27(12):1541–1546.
18. Brody DM. Techniques in the evaluation and treatment of the injured runner. *Orthop Clin North Am*. 1982;13(3):541–558.
19. Hoffman M, Schrader J, Applegate T, Koceja D. Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. *J Athl Train*. 1998;33(4):319–322.
20. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol*. 2000;10(5):361–374.
21. Kannus P, Renstrom P. Treatment for acute tears of the lateral ligaments of the ankle: operation, cast, or early controlled mobilization. *J Bone Joint Surg Am*. 1991;73(2):305–312.
22. Johnson CH, Christensen JC. Biomechanics of the first ray, part 1: the effects of peroneus longus function. A three-dimensional

kinematic study on a cadaver model. *J Foot Ankle Surg*. 1999;38(5):313–321.
23. Dawe EJC, Davis J. Anatomy and biomechanics of the foot and ankle. *J Orthop Trauma*. 2011;25(4):279–286.
24. Tiberio D. Pathomechanics of structural foot deformities. *Phys Ther*. 1988;68(12):1840–1849.
25. Karatsolis K, Nikolopoulos CS, Papadopoulos ES, Vagenas G, Terzis E, Athanasopoulos S. Eversion and inversion muscle group peak torque in hyperpronated and normal individuals. *Foot (Edinb)*. 2009;19(1):29–35.
26. Hunt AE, Smith RM. Mechanics and control of the flat versus normal foot during the stance phase of walking. *Clin Biomech (Bristol, Avon)*. 2004;19(4):391–397.
27. Hertel J, Gay MR, Denegar CR. Differences in postural control during single-leg stance among healthy individuals with difference foot types. *J Athl Train*. 2002;37(2):129–132.
28. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train*. 2002;37(4):364–375.
29. Horak FB. Clinical measurement of postural control in adults. *Phys Ther*. 1987;67(12):1881–1885.
30. Leavey VJ, Sandrey MA, Dahmer G. Comparative effects of 6-week balance, gluteus medius strength, and combined programs on dynamic postural control. *J Sport Rehabil*. 2010;19(3):268–287.
31. Gutierrez GM, Kaminski TW. A novel dynamic ankle supinating device. *J Appl Biomech*. 2012;26(1):114–121.
32. Ricard MD, Schulties SS, Saret JJ. Effects of high-top and low-top shoes on ankle inversion. *J Athl Train*. 2000;35(1):38–43.
33. Berg CL, Hart JM, Palmieri-Smith R, Cross KM, Ingersoll CD. Cryotherapy does not affect peroneal reaction following sudden inversion. *J Sport Rehabil*. 2007;16(4):285–294.
34. Konradsen L, Ravn JB. Prolonged peroneal reaction time in ankle instability. *Int J Sports Med*. 1991;12(3):290–292.
35. Konradsen L, Ravn JB, Srensen AI. Proprioception at the ankle: the effect of anaesthetic blockade of ligament receptors. *J Bone Joint Surg*. 1993;75(3):433–436.
36. Cordova ML, Bernard LW, Au KK, Demchak TJ, Stone MB, Sefton JM. Cryotherapy and ankle bracing effects on peroneus longus response during sudden inversion. *J Electromyogr Kinesiol*. 2010;20(2):348–353.
37. Lynch SA, Eklund U, Gottlieb D, Renstrom PA, Beynnon B. Electromyographic latency changes in the ankle musculature during inversion moments. *Am J Sports Med*. 1996;24(3):362–369.
38. Hodges PW, Bui BH. A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography. *Electroencephalogr Clin Neurophysiol*. 1996;101(6):511–519.

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