The Effect of Three Different Insoles on Ankle Movement Variability during Walking in Athletes with Functional Ankle Instability

Abstract

Background: Increased ankle movement variability has been reported in people with functional ankle instability (FAI). The purpose of this study was to investigate the effect of textured insole, lateral wedge, and textured lateral wedge insole on ankle movement variability during walking in athletes with FAI. **Materials and Methods:** Twenty-one athletes diagnosed with FAI participated in this before-after study. Kinematic data were collected during four conditions (5 repeated trials per condition): (1) flat ethylene-vinyl acetate (EVA) insole, (2) textured flat EVA insole, (3) prefabricated lateral heel and sole wedge insole, and (4) textured lateral heel and sole wedge. The analysis of ankle movement variability was conducted during stance phase and 200 ms before initial contact to 200 ms after initial contact. The coefficient of multiple correlations (CMC) was calculated to investigate pattern variability and intraclass correlation (ICC) was used to investigate variability at the points of interest. **Results:** In terms of pattern variability, wearing textured lateral wedge increased CMC compared to other insoles. However, statistically significant differences were observed only in the frontal plane during stance phase ($P < 0.05$). In terms of variability at the points of interest, in the frontal plane and in all points of interest, wearing textured lateral wedge increased ICC compared to other insoles. The effects of other insoles on ankle movement variability were inconsistent. **Conclusions:** The results of this study showed that textured insole has the potential to decrease variability and the use of texture with lateral wedge may more improve variability in athletes with FAI.

Keywords: *Ankle, gait, movement, orthotic device*

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Introduction

Lateral ankle sprains are very common in athletic population[1] and occur due to ankle inversion injury,[2] and often, both ligament structures and mechanoreceptors are damaged.[3] Longer term some individuals are left with intact ligaments and mechanical constraints but impaired neuromotor control of the foot and ankle, and this has been termed functional ankle instability (FAI).[4] FAI is a serious condition affecting the quality of life and the performance of professional and amateur athletes.[5] Since the mechanical constraints are intact, it is assumed that recurrent sprains in these cases are due to sensorimotor deficits,[3,6] and there is good evidence of loss of normal sensory function in FAI. This includes deficits in passive inversion/eversion movement detection,[7] diminished joint position sense,[8] and deficits in inversion during gait.[9-12]

Researchers have previously reported biomechanical changes in people with chronic ankle sprains during transition time periods between swing and stance phase. Delahunt *et al*. found a more inverted position of foot during 200 ms before and after initial contact in FAI.[9] Brown *et al*. found that FAI patients had greater maximum plantar flexion in the 250 ms before initial contact than people with mechanical instability and participants without lateral ankle sprains (LAS) instability.[13]

There are also reports of increased movement variability in cases of chronic ankle sprain (CAI) during variety of tasks.[14-17] Brown *et al*.[14] reported that individuals with FAI demonstrated greater ankle frontal plane displacement compared with ankle sprain copers. In another study, Brown *et al*.[15] showed that individuals with FAI exhibited greater variability in ankle frontal plane motion compared with

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mechanical ankle instability and ankle sprain coper groups. Kipp and Palmieri-Smith[16] showed increased variability in the frontal plane from 100 ms before touchdown to 200 ms after touchdown during single-leg landing in individuals with chronic ankle instability.

Increases in variability have been associated with gait instability,[18,19] risk of falling in older people,[19] and lower extremity overuse injuries.[20] The assumption is that greater movement variability places a joint at greater risk of unconstrained loading and thus leads to tissue damage and injury. Greater movement variability may also make control of movements more difficult, since the range of strategies required is likely far greater and the need for a specific strategy less predictable. The increased foot and ankle movement variability in FAI[14,15,17] may explain the risk of recurrent ankle sprains even in the absence of mechanical ligament damage. This also suggests that reducing movement variability could be one target of preventative strategies.

The reason for the greater movement variability in FAI is likely multifactorial such as impaired feedback, feedforward, and local sensorimotor deficits. Reduced plantar sensitivity has been reported in cases of FAI,[21,22] and loss of plantar sensitivity has already been associated with increased movement variability in multiple sclerosis[23] and Parkinson's disease.[24] It follows that any intervention that might alter plantar sensation could reduce ankle movement variability. The use of textured surfaces to change plantar sensory information and performance of motor tasks has received considerable attention, and thus far, evidence is generally positive, while not related to FAI.[25,26]

While a textured surface alone might offer some potential to reduce movement variability and risk of recurrent sprain, there are already mechanical strategies to achieve this. The use of a wedge placed under the lateral side of the heel and midfoot has been shown to reduce the external inversion moments responsible for the inversion movement that causes the ankle sprain.[27] This intervention could perhaps be further enhanced through the use of a textured surface, thus combining mechanical and sensory components to preventative strategies.

We hypothesized that both a textured surface and a laterally wedged insole would reduce ankle movement variability in people with FAI and that their effects would be accumulative when used together. The purpose of this study was, therefore, to investigate the effect of a textured insole, a laterally wedged insole, and a textured laterally wedged insole on ankle movement variability during walking in athletes with FAI.

Materials and Methods

Participants

Ethical approval was obtained from the Institutional Ethics Committee. Initially, 65 athletes with self-reported ankle instability (>6 months) were recruited from local sports centers. All reported a history of at least 1 significant unilateral inversion ankle sprain within the previous 5 years. All reported that previous sprains required limited weight-bearing or full immobilization for a minimum of 3 days, complained of failure to return to preinjury function, and experienced repeated episodes of ankle sprain. All reported at least 2 episodes of the ankle "giving way" in the past 12 months and a subjective feeling of ankle instability or weakness.[15,28]

From the 65 athletes, those with FAI were identified using physical examination, Foot and Ankle Ability Measure (FAAM),[29] and a self-reported questionnaire that assessed the presence of experiences associated with FAI. An experienced physical therapist performed the anterior drawer and talar tilt test to assess mechanical instability of ankle (1–5 scale), and potential participants who demonstrated score 1 (very hypomobile) or score 4 and 5 (loose and very loose, respectively) were excluded.[30] Individuals were also excluded if participants scored >90% in the FAAM activities of daily living score and >80% in the FAAM sports score.[29,31]

Participants were also excluded if they had taken medication in the past 48 h that could affect cognition and balance or if they had known vestibular, visual, auditory, cognitive, neurological, and any other musculoskeletal disorders, diabetes, and history of fracture or surgery of lower extremities. Exclusion criteria also included receiving ankle rehabilitation and presence of any acute signs and symptoms in the lower extremities (other than giving way or turning over and sprain of affected ankle) within the 3 months before data collection.

After this screening, 21 athletes (11 males) with clinically diagnosed FAI participated in the study. All participants provided written consent to participate, and Table 1 shows pathology and function-related information.

Insoles

Four different insoles were compared: (1) a flat 3 mm ethylene-vinyl acetate (EVA) insole with smooth top surface, (2) prefabricated laterally wedged insole (Salfordinsole, England) with smooth top surface, (3) a 3 mm flat EVA insole with a 1 mm thick textured surface on top, texture comprising a pattern of 10 hemisphere projections per cm^2, and (4) prefabricated laterally wedged insole (Salfordinsole, England) with a 1 mm textured layer added to the top surface (same texture as insole number 3) [Figure 1]. All were used in individual shoe sizes. Condition 1 was considered the control condition.

Data collection

A seven-camera motion capture system (Qualysis Proreflex, Sweden) was used to obtain three-dimensional kinematic

Table 1: Mean and standard deviation of participants' demographics and function-related information

Age (years)	Mass (kg)	Height (m)	FAAM sports score (%)	FAAM ADL score (%)	Sports activity (hours/week)	Giving way (numbers/year)
25.6±4.8	67.3±15.3	1.7±0.1	63.4±16.9	80.9±7.7	9.2±0.5	6.4±3.7

FAAM: Functional Ankle Ability Measure, ADL: Activities of daily living

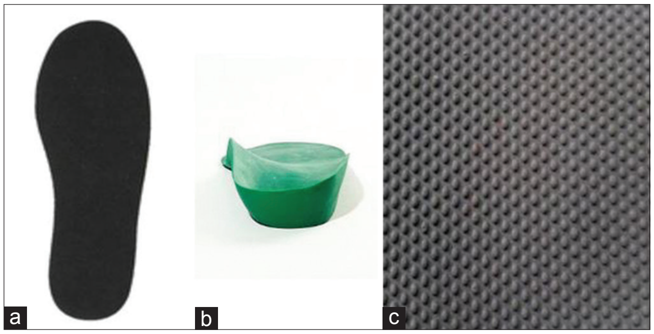

Figure 1: A flat 3 mm ethylene-vinyl acetate insole with smooth top surface (a), prefabricated laterally wedged insole (Salfordinsole, England) with smooth top surface (b), 1 mm thick textured layer added to the top surfaces (c)

data for the foot and leg (100 Hz). Ground reaction force (GRF) data were collected using a Kistler force plate (1000 Hz) (Kistler Instrument Corp., Amherst, New York, USA). Reflective markers were attached to the head of the first, second, and fifth metatarsals and the posterior calcaneus. Markers were attached to medial and lateral femur epicondyles and medial and lateral malleoli. A rigid cluster of four 14 mm markers was positioned over the lateral aspect of shank.

Familiarization with the insole conditions is fundamental. All participants were allowed to become familiar to laboratory environment, procedure, and different insoles before testing. One relaxed standing trial was performed to define the reference position (0º) of the foot. Several practice walks were conducted to determine a starting position, after which participants completed four test conditions while walking on a 10 m walkway. Five successful walking trials were collected for each of the four insole conditions. Participants were advised to walk at their own normal walking speed during all conditions. The same type of shoes was used for all participants. Elastic lace bands were used and adjusted for the first test condition of each participant and then remained unchanged for all other test conditions. The order of conditions was randomized (5 repeated trials per condition).

Data processing and analysis

Kinematic and force data were exported to Visual3D (C-motion, USA) and a fourth-order Butterworth low-pass filter (cutoff 6 Hz and 15 Hz, respectively) applied to both. Movement was motion of the foot relative to the shank. The calibrated anatomical system technique was adopted to establish a suitably anatomical model of the foot and shank.[32] The origin of the shank coordinate system was midway between medial and lateral femoral epicondyles (knee joint center [KJC]). The vertical axis, z-axis, was the line joining the KJC with the point midway between the medial and lateral malleolus (MMAL and LMAL). The x-axis was orthogonal to z-axis and in the frontal plane defined by MMAL, LMAL, and the z-axis. The y-axis was perpendicular to x- and z-axes. The origin of the foot system was located at the midpoint between MMAL and LMAL. The foot longitudinal axis, y-axis, was the line joining the origin and metatarsal 2 (D2MT). The x-axis was orthogonal to y-axis and laid in a plane defined using the MMAL, LMAL, and D2MT. The z-axis was mutually perpendicular to x and y. Foot-shank angles were calculated using Cardan sequence of sagittal, frontal, and transverse planes. The relaxed standing position was used as 0º.

GRF data were used to determine stance and swing phase since the transition between the two is central to LAS. Windows of 200 ms before and after initial contact and initial contact to toe off were identified for all trials.

Between-trial variability of foot-shank (ankle) movement was evaluated using the coefficient of multiple correlations (CMC) and intraclass correlation (ICC). These evaluate variability of ankle rotations time curves and ankle angles at specific gait events, respectively, and are commonly reported measures of kinematic variability.[33] CMC was used to evaluate the variability of ankle movement pattern. Similarity of the ankle movement pattern in five dynamic trials for each intervention was compared by CMC. This was reported in two time windows: (1) initial contact (IC) to toe off (TO) and (2) 200 ms before initial contact to 200 ms after initial contact. In additional, ICC was used to report the movement variability at distinct time points. These time points included 200 ms before initial contact, initial contact, and 200 ms after initial contact.

SPSS version 21.0 (SPSS Inc., Chicago, Ill., USA) was used for statistical analysis. Shapiro–Wilk test was used to check whether CMC data were normally distributed. Nonparametric test (Friedman) was performed to investigate differences between conditions. All findings were considered statistically significant at $P \leq 0.05$.

Results

There was a trend toward increased CMC values (in other word, less movement variability) when wearing both textured insoles compared to insoles without texture but only for movement in the frontal plane [Table 2]. There were statistically significant differences for the frontal plane motion when wearing textured laterally wedged insoles and for IC-TO in comparison with nontextured flat EVA (*P* = 0.015) and nontextured laterally wedged insole (*P* = 0.004). The other significant difference was for the sagittal plane motion when wearing textured laterally wedged insoles and for IC-TO in comparison with nontextured laterally wedged insole (*P* = 0.012).

There was a trend toward increased ICC values (in other word, less movement variability) when wearing both textured insoles compared to insoles without texture but only for angles 200 ms before initial contact [Table 3]. There were no observable trends at for initial contact angles nor angles at 200 ms post initial contact.

Discussion

We investigated the effect of a textured insole, a laterally wedged insole, and a textured laterally wedged insole on ankle movement variability in athletes with FAI. Movement variability is normal and necessary for individual adaptation with personal, task, or environmental constraints during different activities.[34,35] However, excessive movement variability is associated with an increased risk of injury and pathology.[20,36] Furthermore, individuals with FAI have increased frontal plane ankle movement variability compared with healthy controls, and this has suggested at one explanation for the recurrent instability, episodes of "giving way," and reoccurring sprains.[14-17] The results of this study provide some evidence for texture as a method to reduce frontal plane

Table 2: Mean (and standard deviation) and 95% confidence interval of coefficient of multiple correlations of ankle movement during walking in four insole conditions

Time windows/ Planes	Mean±SD (95% CI)				*P*						
	Flat EVA (A)	Lateral wedge (B)	Textured flat EVA (C)	Textured lateral wedge (D)	Friedman	A versus B	A versus C	A versus D	B versus C	B versus D	C versus D
200 ms before and after IC											
Frontal plane	0.913±0.077 (0.872-0.947)	0.903±0.094 (0.853-0.946)	0.922±0.058 (0.894-0.952)	0.933±0.048 (0.909-0.958)	0.981	0.765	0.823	0.263	0.411	0.374	0.526
Sagittal plane	0.950±0.035 (0.933-0.967)	0.935±0.058 (0.906-0.963)	0.954±0.035 (0.937-0.971)	0.967±0.018 (0.958-0.976)*	0.254	0.478	0.629	0.028	0.546	0.179	0.136
Transverse plane	0.880±0.083 (0.835-0.915)	0.880±0.148 (0.803-0.949)	0.847±0.114 (0.786-0.896)	0.879±0.105 (0.823-0.925)	0.061	0.391	0.232	0.601	0.062	0.526	0.126
HS-TO											
Frontal plane	0.886±0.13 (0.825-0.947)	0.882±0.108 (0.831-0.933)	0.908±0.073 (0.873-0.942)	0.924±0.072 (0.890-0.958)*	0.011	0.526	0.681	0.015	0.101	0.004	0.86
Sagittal plane	0.986±0.012 (0.980-0.992)	0.976±0.038 (0.959-0.994)	0.987±0.012 (0.981-0.992)	0.987±0.018 (0.978-0.996)*	0.018	0.204	0.881	0.103	0.247	0.012	0.057
Transverse plane	0.907±0.061 (0.878-0.936)	0.906±0.089 (0.864-0.948)	0.909±0.07 (0.876-0.941)	0.924±0.053 (0.899-0.949)	0.705	0.654	0.852	0.794	0.526	0.526	0.243

**P*<0.05. SD: Standard deviation, CI: Confidence interval, EVA: Ethylene-vinyl acetate, IC: Initial contact, TO: Toe off

Table 3: Intraclass correlation and 95% confidence interval of intraclass correlations of ankle movement at 200 ms before initial contact, initial contact, and 200 ms after initial contact in four insole conditions

Time windows/ Planes	ICC values 95% CI			
	Flat EVA	Lateral wedge	Textured flat EVA	Textured lateral wedge
200 ms before IC				
Frontal plane	0.956 (0.896-0.981)	0.932 (0.852-0.972)	0.959 (0.912-0.984)	0.961 (0.916-0.989)
Sagittal plane	0.809 (0.648-0.923)	0.372 (0.142-0.663)	0.904 (0.813-0.963)	0.946 (0.878-0.983)
Transverse plane	0.810 (0.650-0.923)	0.851 (0.711-0.944)	0.912 (0.824-0.966)	0.948 (0.883-0.984)
IC				
Frontal plane	0.964 (0.927-0.986)	0.962 (0.925-0.984)	0.933 (0.871-0.973)	0.965 (0.924-0.985)
Sagittal plane	0.848 (0.717-0.937)	0.850 (0.730-0.934)	0.881 (0.778-0.95)	0.887 (0.783-0.954)
Transverse plane	0.931 (0.862-0.973)	0.964 (0.929-0.985)	0.931 (0.866-0.972)	0.936 (0.872-0.975)
200 ms after IC				
Frontal plane	0.944 (0.887-0.978)	0.935 (0.875-0.972)	0.897 (0.805-0.957)	0.954 (0.902-0.984)
Sagittal plane	0.945 (0.889-0.978)	0.926 (0.857-0.97)	0.841 (0.712-0.932)	0.940 (0.874-0.978)
Transverse plane	0.972 (0.943-0.989)	0.915 (0.836-0.965)	0.948 (0.897-0.979)	0.944 (0.882-0.982)

IC: Initial contact, EVA: Ethylene-vinyl acetate, ICC: Intraclass correlation, CI: Confidence interval movement variability when used with a laterally wedged insole but not when used on a flat insole. The fact that this occurred mainly in the frontal plane seems significant because this is the plane in which the recurrent ankle injury occurs. While the results were not unequivocal, the general trend was for reductions of variability in the textured insoles compared to the smooth flat EVA insole and the laterally wedged insole alone.

The only statistically significant result, complemented by the general trend, was for less movement variability when the texture was combined with the laterally wedged insole. Compared to the textured flat insole, the laterally wedged insole likely has an increased contact area in both the medial arch and heel areas of the foot and causes greater rearfoot eversion after initial contact. Neither of these was measured in this study, but these effects are consistency reported for insoles with contours and materials similar to the laterally wedged insole used.[37,38] This might arguably increase the "dose" of sensory input from the textured surface. The lack of change in movement variability with the laterally wedged insole alone suggests that it is the texture not contact area alone that is important.

According to the sensory reweighting theory, as soon as one sensory input is impaired, the system adapts by adjusting the relative contributions and it allows from other sensory sources.[39] For example, sensory reweighting has been demonstrated in patients with low back pain occurring from paraspinal muscles to ankle-muscle receptors.[40] Impairment in mechanoreceptors and neuromuscular control post ankle sprains has been proposed as one of the main reasons for increased movement variability in FAI.[16] Plantar cutaneous mechanoreceptors are an important source of foot proprioception information,[41] and according to the sensory reweighting theory, enhancements in this could compensate for other deficits. It has been demonstrated that stimulation of the plantar surface of feet by insoles can contribute to sensory reweighting.[25] In this context, we propose that the use of texture and greater contact area from the laterally wedged insoles are the primary modes by which the insoles reduced movement variability.

There are several important limitations to this study. The participants were only exposure to the insoles during the testing session, and neurological responses to the texture may take time to develop. The participants typically took 10 steps in each insole before data were collected. The texture chosen was relatively subtle in that it comprised a compliant material and was low in height. Alternative textures may have different effects. We characterized movement variability over five walking trials. While there is a ceiling effect at some point, arguably more trials would allow a more robust characterization of variability, and thus, increased likelihood of observing any effect should there be one. Likewise, our use of walking poses a relatively low-risk challenge to ankle function, and the capacity for improving variability might be limited. It is also the case that most ankle sprains occur during running or other dynamic activities, where underlying movement variability could be greater.[14-17] Finally, the use of a single-segment model of the foot is a potential limitation since it does not isolate ankle nor rearfoot kinematics specifically. However, making ground contact is a functional task for the whole foot, and in the first instance, this model was felt to be appropriate. Assuming the results are not an entirely random outcome, that differences in the reported movement variability reflect the ability of the foot model to detect kinematic differences. However, the use of a multisegment foot model would certainly enhance the characterization of any effect of the texture.

Conclusions

The results of this study show that when combined with a laterally wedged insole, texture has the potential to decrease foot movement variability in athletes with FAI.

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Conflicts of interest

Professor Christopher Nester is a Director and owns equity in a company (Salfordinsole Healthcare Ltd.) that manufacturers the laterally wedged foot orthoses used in this study. There have been no financial or other arrangements between the company and the authors.

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