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Effects of textured socks on balance control during single-leg standing in healthy adults

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Abstract

Balance is important in many activities of daily living and sports movements. Texture, added to shoe insole material, has been shown to improve balance in young, older and pathological populations. The aim of this study was to develop and test textured socks, which might have several potential benefits over insole use including: they can be worn without, or transferred between, shoes, and texture can be applied to areas of the foot other than the plantar surface. Prototypes socks were made with nodules (5 mm diameter) sewn onto socks on: 1) the plantar surface, 2) the dorsal surface, 3) sides of the foot and 4) covering the entire surface. Participants ($n=13$) performed three single-legged stance trials, standing on a force platform. with eyes open and eyes closed, whilst wearing each of the prototype socks and a control sock. Balance was quantified using the postural time-to-boundary measure. Results revealed a trend towards improved balance in the *Sides sock* condition (eyes open $d = 0.62$, eyes closed $d = 0.51$) conditions. This finding supported previous data from studies showing benefits of wearing insoles with plastic tubing around the perimeter of the foot, suggesting that textured socks might be useful as an intervention to improve balance.

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1. Introduction

Maintaining balance requires refined postural control which can be enhanced by perception of information from the environment and exploiting adaptive compensation tendencies in relevant muscle groups to constantly adjust

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for changes in body motion and position (Maki et al., 2008). Augmenting somatosensory information has been shown to enhance balance and postural control (Maki et al. 1999; Qiu et al., 2012). Populations that could benefit from improved balance include older adults, those with medical conditions, and athletes. In essence, performing standing goal-directed behaviors as simple as reaching for an object or as complex as an athletic performance requires proper balance control (Riccio, 1993).

Multiple exercise-based interventions, including balance-board training (Verhagen et al., 2005), Tai Chi (Tsang & Hui-Chan, 2004) and computer games-based training (Betker et al., 2006), have been investigated to improve balance. However, these programs can be difficult to administer and are heavily dependent on participant compliance (Campbell et al., 2005). Alternative approaches have involved the development of ankle and foot appliances (AFAs) - physical devices which interact with the foot or ankle to enhance somatosensory system feedback. AFAs have been used to apply sub-sensory mechanical vibrations to the feet, benefitting balance in older and pathological populations (Priplata et al., 2006; Priplata et al., 2003). However, vibrating insoles require a power source, are bulky and costly to produce and maintain. An alternative type of AFA, which improved proprioception in a sample of athletes, involves the addition of texture to the plantar surface of the foot (Waddington & Adams, 2003). Waddington and Adams (2003) demonstrated that male soccer players exhibited better discrimination between different extents of subtalar inversion when a textured insole was placed in their shoe. In a recent systematic review, Orth et al (2013) concluded that there is clear support for using textured materials to improve perceptual-motor performance. For example, textured insoles have been shown to decrease postural sway, and enhance balance, in older people (Qiu et al., 2012).

Previous investigations have added texture to shoe insoles or required participants to stand on a textured surface. However, only approximately 62% of the foot outline is in contact with the ground during stance (Low et al., 1993), suggesting that texture added to insoles might not be applied to a significant proportion of the plantar foot surface. We sought to investigate the role of socks in providing a more functional application of texture to a greater area of the foot plantar surface. Indeed, textured socks might offer additional benefits. First, they would be easily transferred between different shoes. Furthermore, socks could be worn without footwear in dwellings, or in slippers and gym shoes. Second, socks offer the potential to apply texture to areas of the foot other than the plantar surface. For example, texture could be added to the sides of the feet, which might be beneficial according to data reported by Maki and colleagues in the development of an AFA. A raised ridge was placed on an insole around the perimeter of the foot which was shown to improve balance by providing increased stimulation of sensory receptors when loss of balance was imminent (Maki et al., 1999; Perry et al., 2008).

Therefore, the aim of this exploratory study was to design and test textured socks to determine their effects on balance in young healthy adults performing a single-leg standing task. We hypothesised that wearing textured socks would improve balance. We also expected that enhanced somatosensory feedback would be more beneficial when visual information was not available to regulate postural control (i.e. eyes closed condition).

2. Methods

2.1. Sock Development

Four preliminary prototype textured socks were designed and developed. Craft pom-poms served as nodules and were sewn to commercially-available athletic socks. Three different socks had nodules sewn on the bottom, sized 5mm, 10mm and 12mm, respectively. The fourth sock had 12mm nodules around the circumference of the foot, to simulate the balance-facilitating insole of Maki et al. (1999). Seven adults – with no neuromuscular pathologies that could affect balance - participated in a focus group to evaluate the socks for comfort and fit. Results from the focus group guided the development and construction of five prototype textured sock models for testing. Socks, for which 5 mm nodules were added to the: 1) plantar surface, 2) sides, 3) dorsal surface and 4), entire surface of the foot (Fig. 1) were developed. In addition a sock designed to be most comfortable - based on focus-group feedback – was also developed with 10 mm nodules on the dorsal surface and sides of the feet, together with 5 mm nodules on the plantar surface. In all socks, the inter-nodule distance was approximately 200 mm.

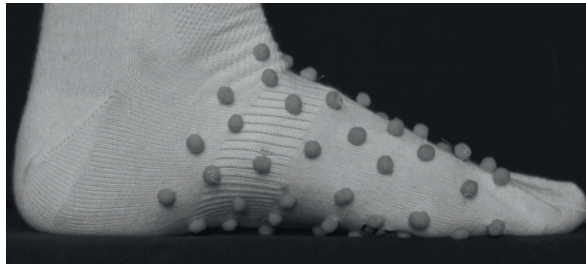


Fig. 1. A textured sock with texture applied over all of the foot surface (the 'All' model)

2.2. Participants

Thirteen healthy adults (7 females and 6 males, (mean \pm SD) age 27.2 ± 3.7 years, height 1.67 ± 0.09 m, and mass 71.4 ± 13.0 kg) were recruited by emails and word-of-mouth. Participants were excluded if they were younger than 18 years, older than 35 years, had extensive sport experience, or had a pre-existing injury or pathology that might affect balance. All procedures were approved by the Faculty of Health and Wellbeing Research Ethics Committee (Sheffield Hallam University) and all participants provided written informed consent before data collection.

2.3. Experimental setup and procedures

Participants were tested during single-leg standing - chosen because it is a challenging task that better simulates the relatively intensive demands of postural control in everyday activities and sport tasks. This paradigm was a departure from the more typical bipedal stance task used in previous studies of textured insoles/surfaces (e.g., Hatton et al., 2009; Palluel et al., 2008; Wilson et al., 2008). After an explanation and demonstration of the test procedure, the participant chose a preferred leg on which to stand (Spry et al., 1993). All tests were completed on the same leg. Before the start of testing, an outline of the foot was traced onto paper taped to a force platform which the participants used to position their feet for each trial. The long axis of the foot was aligned with the x axis of the force platform.

Each participant randomly chose one of the six socks (five prototype models and one unmodified control sock) from a black bag. The socks were balled inside-out to render them similar to immediate touch. To ensure hygiene, textured socks were worn over a tight, thin sock with no texture. The participant's own shoe was then worn over the two socks. Instructions were given to focus on a visual target located 1.5m away at eye level. During the eyes closed trials, participants were asked to focus on the target before closing their eyes, maintaining the head in the same orientation throughout the trial. Participants stood on one leg, raised the foot of the contralateral leg, and attempted to maintain stance for 10 seconds. Data collection began after an initial stabilisation period of approximately 3s. The trial ended if the foot of the contralateral leg touched the ground. Data from three acceptable trials were collected with each sock in both the eyes open and eyes closed conditions. Thirty seconds of rest were allowed between trials (Jakobsen, Sundstrup, Krstrup, & Aagaard, 2011). In all trials, anterior-posterior (AP) and medio-lateral (ML) centre of pressure (COP) data were obtained using a Kistler 9281CA (Winterthur, Switzerland) force platform, sampling at 100 Hz.

2.4. Data Analysis

Raw COP data were filtered using a low-pass finite impulse response filter with a 5Hz cutoff frequency - similar to previous studies of single-legged balance (Hertel et al., 2006; Hertel & Olmsted-Kramer, 2007). Balance performance was quantified using the postural time-to-boundary (TtB) which indicates the spatio-temporal proximity of the COP to the boundary of support at any point during the trial. TtB was calculated using an

approach adopted in previous investigations of single-leg quiet standing (Hertel et al., 2006; Hertel & Olmsted-Kramer, 2007). Boundary of support was defined as a rectangle fitted to the foot outline. The anterior and posterior sides of the rectangle were parallel to the force platform y axis, with their position defined by the most anterior and posterior point on the foot, respectively. Medial and lateral sides were defined in a similar manner. TtB in the ML and AP directions were calculated as the time it would take the COP to contact the BOS given its instantaneous position and velocity by dividing the instantaneous position by instantaneous velocity. To prevent mean TtB estimates being biased by values that tend to infinity - as can happen when the velocity of the COP is close to zero - the resulting TtB time series were quantified using an approach adopted by Haddad and colleagues (Haddad, et al., 2006). An average estimate of TtB was calculated by taking the mean of the 10 smallest TtB minima in the time series.

Each TtB dependent variable was analysed using a 2x5 (Vision x Sock Type) repeated measures Analysis of Variance (ANOVA). Results for the sock designed to be most comfortable were not included in the analysis since, during testing, participants actually rated this sock as least comfortable. To follow up any interaction or Sock Type main effects, planned contrasts were assessed between the control sock and the four textured socks in both the eyes open and eyes closed conditions. Furthermore, as this was an initial, exploratory study, with a relatively small sample size, Cohen's *d* effect size statistics were also calculated for the differences between the control and four textured socks to reduce the chance of overlooking a meaningful effect by considering only *p*-values.

3. Results

There was no interaction between sock type and vision condition in the ML ($F(4,48) = 1.494, p = 0.219$) and AP directions ($F(4,48) = 0.364, p = 0.833$). The main effect for vision indicated that TtB was lower in the eyes closed than the eyes open condition in the ML ($F(1,12) = 138.812, p = 0.00$) and AP ($F(1,12) = 223.266, p = 0.000$) directions. Although the main effect for sock type was not significant in either the ML ($F(4,48) = 2.021, p = 0.106$) or AP ($F(2,0,23.7) = 0.377, p = 0.687$) directions, effect sizes (relative to the Control sock) indicated a trend towards greater TtB in the Sides sock condition (Table 1), mainly in the ML direction (moderate effects sizes: eyes open $d = 0.62$, eyes closed $d = 0.51$).

Table 1. TtB in the four sock conditions with eyes open and eyes closed. Effect sizes are relative to the control sock condition

Sock	Vision	AP		ML	
		TtB (s)	Effect Size (<i>d</i>)	TtB (s)	Effect Size (<i>d</i>)
Control	Open	3.97 ± 1.30	-	0.96 ± 0.34	-
	Closed	1.46 ± 0.58	-	0.33 ± 0.11	-
Plantar	Open	4.01 ± 1.06	0.03	0.97 ± 0.27	0.02
	Closed	1.47 ± 0.42	0.02	0.34 ± 0.09	0.09
Dorsal	Open	4.16 ± 0.95	0.17	0.99 ± 0.33	0.06
	Closed	1.45 ± 0.35	0.03	0.33 ± 0.10	0.03
Sides	Open	4.31 ± 0.93	0.30	1.16 ± 0.29	0.62
	Closed	1.55 ± 0.34	0.19	0.38 ± 0.10	0.51
All	Open	4.12 ± 0.95	0.13	1.01 ± 0.25	0.15
	Closed	1.55 ± 0.38	0.19	0.34 ± 0.05	0.16

4. Discussion

The aim of this study was to design and test textured socks to determine their effects on balance in young healthy adults performing a single-leg standing task. Although no interaction between sock type and vision or main

effect for sock type were observed, there was a trend towards improved balance in the Sides sock condition in the ML direction with eyes open ($d = 0.62$) and eyes closed ($d = 0.51$). All other sock models exhibited only small differences relative to the Control sock condition with weak effect sizes.

The design for the Sides sock is similar to the facilitatory shoe insole used by Maki and colleagues (Maki et al., 1999), which incorporates a raised ridge at the perimeter of the foot (3mm wide/high and 10 mm from the edge of the insole). That addition caused indentations to the skin – with associated stimulation of the cutaneous mechanoreceptors – when the centre of mass/COP approached the boundary of support and loss of balance was imminent. Those authors reported fewer multiple-step responses to unexpected perturbations and a reduction in the backward excursion of the COP during standing on a moving platform (Maki et al., 1999). The trend towards greater ML TtB in the Sides sock than control sock condition suggests that adding texture to the sides of the feet resulted in similar improvements in balance control. A similar mechanism to that described by Maki and colleagues (Maki et al., 1999) could explain performance improvements. Nodules sewn into the sock indent the skin, stimulating the cutaneous mechanoreceptors when the COP approaches the boundary of support – when TtB is low. These results highlighted that information about the interface between the performer and the environment is crucial in balance regulation, as proposed by an ecological dynamics approach to motor control (Riccio, 1993). Sock texture potentially enhances this important information, especially when loss of balance is imminent at points when the COP is in close spatio-temporal proximity to the stability boundary. The trend toward improvements in balance with the sides sock were most evident in the ML direction. As the foot is longer than it is wide, the COP is in greater spatio-temporal proximity to the stability boundary in the medio-lateral direction during single-legged stance, increasing the importance of augmented somatosensory information to reduce the threat of balance loss.

In a recent review, Orth et al. (2013) concluded that adding texture to the plantar surface of the feet via textured insoles or surfaces improves perceptual-motor performance (see also Palluel et al., 2008). For example, improvements in the postural sway of older adults when standing on textured insoles were reported by Qui et al. (2012). However, adding texture to the plantar surface of the sock had no effect on balance in the current study. The disagreement between the literature and our findings could be related to the morphology of the texture added to the Plantar prototype sock. The nodules sewn into the sock were 5 mm in diameter, which is similar to the nodules on the insoles used by Qui et al. (2012) (5 mm) and Palluel et al. (2008) (3-5 mm). However, both of these studies included insoles on which the nodules were separated by 5 mm whereas our prototype socks had inter-nodule distances of approximately 20 mm. It is possible that the greater separation of the nodules produced a texture pattern that was not sufficient to elicit an improvement in balance. Future work will investigate the effects of texture morphology and material characteristics – in insoles, surfaces or socks – on balance and other perceptual motor tasks. Such work will investigate parameters including nodule separation, height, width and hardness.

TtB was lower in the eyes closed than the eyes open condition across all socks in both the ML and AP directions indicating decreased stability when visual information was removed, in agreement with data from many previous studies highlighting the importance of visual information in the control of balance (e.g. Maurer et al., 2000). A trend was evident towards improvements in balance with the Sides sock in both the eyes open and closed conditions. However, there was no evidence for the enhanced somatosensory feedback from texture providing greater benefits with eyes closed when visual information was not available.

This was an exploratory study to develop prototype textured socks and investigate their effects on balance in young, healthy participants, with a relatively small sample size ($n=13$). Differences between the Sides and Control sock approached statistical significance in the ML direction for eyes open ($p = 0.07$) and eyes closed ($p = 0.18$) conditions, with moderate effect sizes. Future studies should include a larger sample size and investigate effects of textured socks on balance in older or pathological populations as, for example, older participants have been shown to demonstrate greater improvements in balance when standing on textured insoles (Qui et al., 2012) and textured socks could potentially be used as a cheap, readily accessible intervention in falls prevention. Work with athletic samples is also needed.

In summary, there was no statistically significant effect of adding texture to socks at any location on balance during single-legged standing in young, healthy adults. However, there was a trend towards improved balance when texture was added to the sides of the feet. More work is required to further explore this tentative finding.

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