Effects of five-toed socks with multiple rubber bits on the foot sole on static postural control in healthy young adults

Junji Shinohara and Philip Gribble

Abstract The purpose of this study was to assess the effectiveness of five-toed socks with multiple rubber bits on the foot sole in influencing static postural control among healthy young adults. Twenty six healthy young adults were asked to complete three testing sessions to measure static postural control under three sock conditions: wearing five-toed socks with multiple rubber bits on the foot sole (FS), wearing regular socks (RS), and wearing no socks (NS). For each sock condition, static postural control was assessed on a force plate with the subject in a single-limb stance with eyes open (EO) and eyes closed (EC). The subjects were instructed to stand on the dominant limb as still as possible for 15 seconds. Center of Pressure Velocity (COPV) was calculated in anteroposterior (AP) and mediolateral (ML) directions. The dependent COPV variables were calculated in AP and ML separately for EO and EC trials. The independent variable was sock condition (FS, RS and NS). For each dependent variable, a one-way repeated measures ANOVA was performed, with Sidak post hoc analyses. During EO trials in AP direction, the FS condition (0.53±0.15 cm/second) had a significantly slower COPV value than the RS condition (0.59±0.21 cm/second). During EO trials in ML direction, there was a trend that the FS condition (0.60±0.16 cm/second) had a slower COPV value than the RS (0.67±0.21 cm/second) condition. No significant relationship was observed during EC trials in either AP or ML directions. These results indicate that, during EO trials, the FS condition was associated with increased static postural stability when compared to the RS condition.

Keywords: footwear, balance, sensory feedback

Introduction

Socks are standard equipment in most forms of physical activity. Today, footwear scientists have contributed to the development of various kinds of footwear, such as shoes, orthotic insoles, and ankle braces, to support individuals within a wide range of age groups and pathological conditions during physical activities. However, limited attention has been paid to the influence of socks on physical performance. One particular style of sock of interest that may provide useful insight is referred to as the five-toed sock. In the United States, five-toed socks with multiple rubber bits on the foot sole have been marketed for individuals who do yoga and/or pilates exercise, and are gaining popularity because of their foot gripping capability (traction) that provides better postural stability and balance during exercise. Five-toed socks have been popular in Japan, especially among athletes and physical laborers, for these same reasons. Five-toed socks mimic a glove with five pockets, one for each individual toe. Some versions of the socks have multiple rubber bits made of non-slip material on the sole of the foot (Fig. 1). In Japan, the individual toe pockets and multiple rubber bits on the foot sole are believed to provide better balance by improving sensitivity and perception of the ground, while also allowing more stable foot grip; but there has been little controlled investigation to confirm these potential benefits.

Somatosensory input from the foot sole has been known to contribute to balance during standing and walking. Subsequently, reducing sensation from the foot sole,
as a result of age-related degeneration with the elderly population or diabetic peripheral neuropathy, is known to produce significant postural control instability with an associated higher risk of falling\(^8\). An initial investigation was conducted to examine the effect of using plain five-toed socks, with no multiple rubber bits on the foot sole, on static postural control among healthy young adults\(^9\). While the authors hypothesized that static postural control, measured by center of pressure excursion velocity, would be improved because of facilitated tactile sensation around the toes, the five-toed socks did not provide a significant improvement in postural control compared to wearing regular socks and a no sock condition\(^9\). The possible mechanism of wearing plain five-toed socks has been theorized to be that the five toe pockets provide constant novel sensory stimulation between the toes, which could enhance sensory inputs to the central nervous system (CNS) through the somatosensory system, producing more efficient efferent output for better motor control\(^10\).

Constant neuromuscular adjustments to maintain equilibrium and proper posture were provided by afferent inputs coming from the mechanoreceptors of skin, joint, tendon, and muscles\(^10\). Therefore, offering more sensory information around the toes, by wearing plain five-toed socks for cutaneous stimulation, could influence the somatosensory system to improve postural control\(^1\). A possible explanation for not finding postural control improvement, from wearing the plain five-toed socks, was that the toe pockets of the socks did not enhance tactile sensation enough to influence the CNS to improve postural control. Perhaps a larger area of skin needs to be stimulated in order to change the postural control effects. In addition to tactile feedback provided from the toes, the multiple rubber bits of five-toed socks may potentially increase plantar tactile feedback to the CNS, and provide the toes with better grip, which may possibly influence postural control.

While decreasing sensitivity of the foot sole has been reported to negatively influence postural stability, several researchers have attempted to improve cutaneous sensation of the foot sole by using electric stimulation and insoles to improve postural control. Maki et al.\(^1\) reported that electrical stimulation applied to the foot sole significantly improved postural control in both healthy young adults and older subjects. Similar to the study reported by Maki et al.\(^1\), Priplata et al. suggested that subsensory mechanical noise applied to the foot sole via a vibrating insole was effective in improving postural control in healthy and elderly individuals\(^12\), as well as in diabetes and stroke patients\(^13\). They stated that a possible explanation for these findings was that subsensory noise, provided by the insole, may enhance the detection of pressure changes on the sole of the feet, leading to better postural control. Corbin et al.\(^14\) reported improved static postural control during bilateral stance by using textured insoles among healthy subjects. They stated that this improvement was observed because of hyperesthesia of the plantar surfaces of the feet, resulting in enhanced cutaneous afferent inputs when standing on the textured insoles\(^14\). Efficacy of sandals equipped with spike insoles on postural control was investigated by Palluel et al.\(^15\). They reported that the application of spike insoles improved static postural control in both elderly and young adults during double-leg stance testing. They claimed this was possibly due to the indented surface of the insoles having direct contact with the foot soles and affecting the pressure distribution on the feet, which positively influenced postural control\(^15\).

Similar to these devices that are applied to the foot sole and toe area, potentially increasing cutaneous receptor activation, five-toed socks with multiple rubber bits on the foot sole may be beneficial in improving balance by increasing tactile sensation of the toes and foot sole, and also enhancing grip on the ground. There is a multitude of anecdotal evidence and speculative explanation to support the use of these socks\(^1,14,16\). However, there is very limited scientific evidence of the efficacy of the socks to improve measures of performance, specifically postural control. Therefore, the purpose of this study was to assess the effect of five-toed socks with multiple rubber bits on the foot sole on static postural control during single-limb stance with eyes open and closed. It was hypothesized that, using the five-toed socks with multiple rubber bits on the foot sole, static postural control could be improved by enhancing sensory feedback from the mechanoreceptors of the toes and foot into the CNS and providing more stable grip.

**Materials and methods**

**Subjects.** Twenty-six healthy young adults (9 males, 17 females; 22.8 ± 3.1 yrs, 169.8 ± 9.2 cm, 68.2 ± 12.0 kg) were recruited from a university community. All subjects were between 18 to 30 years old, physically active (at least 30 minutes of sustained exercise 3 times/week), and had no history of knee or hip musculoskeletal injury or surgery, fracture or dislocation of the testing ankle or leg, neurological problems, vestibular disorders, concussions within the last 6 months, or any other conditions that may influence postural control.

**Instrumentation.** A force plate (Bertec FP4060-NC; Bertec Corp., Columbus, OH) integrated with MotionMonitor\(^\text{TM}\) software (Innovative Sports Training, Inc, Chicago, IL) was utilized to collect center of pressure (COP) during the single limb (leg) balance test. A custom program using MATLAB software (The Mathworks Inc., Natick, MA) was utilized to calculate the COP excursion velocity (COPV) in both the anteroposterior (AP) and mediolateral (ML) directions. Regular socks (Tabio Corporation, Osaka, Japan) and five-toed socks (Tabio Corporation, Osaka, Japan) were used for testing. The fabric type of the regular socks was 100% cotton. The fabric type of the five-toed socks was a combination of cotton and ny-
Both regular and five-toed socks manufactured with the same fabric were not available. Therefore, the closest fabric types were chosen based on a subjective evaluation of the texture, elasticity, and thickness. Multiple rubber bits were attached to the plantar surface of the five-toed socks by Tabio Corporation.

Procedures. Prior to testing, details of the study were provided to each subject orally as well as in written form. At the beginning of the testing, each subject read and signed an informed consent form approved by the university’s Biomedical Institutional Review Board. During the testing session, the subjects’ age, height, mass and gender were recorded. The subjects reported to the laboratory on three separate testing days, one week apart, with each day involving one of the three sock conditions: wearing five-toed socks with multiple bits on the foot sole (FS), wearing regular socks (RS), and wearing no socks (NS) in a randomized order (Fig. 2). The subjects were asked to wear clothing items (shorts, etc) that did not cover the lower extremities, other than the applied testing socks, to minimize cutaneous sensation in the lower limbs.

Static postural control was assessed on the force plate with subjects assuming a single-limb stance in eyes-open (EO) and eyes-closed (EC) conditions, and with the hands on the iliac crests. The subjects were instructed to stand as still as possible for 15 seconds while COP data was collected. During the EO condition, subjects were asked to focus their vision on a large “X” on the wall 3.5 m in front of them and 1.5 m from the floor. At the beginning of each testing session, the sock condition was revealed. After affirming the designated sock condition on the testing limb, subjects performed three trials of EO and three trials of EC single limb stance trials for a total of six trials in the AP direction during EO trials (F2,24 = 3.75; p = 0.03) (Table 1). Sidak post hoc analyses revealed that the FS condition (0.60 ± 0.16 cm/second) had a slower COPV value than the RS condition (0.53 ± 0.15 cm/second) (p = 0.03), indicating that FS is associated with improved static postural control during EO. While it was not a significant relationship, with the sock conditions in the ML direction during EO trials (F2,24 = 3.27; p = 0.05) (Table 1), there was a trend that the FS condition (0.60 ± 0.16 cm/second) had a slower COPV value than the RS (0.67 ± 0.21 cm/second) condition. No significant relationship was observed among the sock conditions in either AP or ML directions during EC trials.

Discussion

The primary purpose of this study was to examine the influence of FS in static postural control among healthy young adults during EO and EC trials. The results indicate that the FS condition during EO trials was associated
with increased static postural stability when compared to the RS condition. This finding suggests that these socks could be considered as a clinical or performance intervention tool to improve postural stability.

The importance of tactile sensation of the foot sole during physical activities has been recognized by many studies. Some of these studies have shown that diminished somatosensory feedback from the foot sole due to diabetic peripheral neuropathy, anesthetizing nerve receptors and joint mechanoreceptors, by athletic tape or ankle brace application, might result in earlier and improved muscular contractions during joint position sense testing. Another possible mechanism of postural control improvement was the enhanced ground surface grip (traction) provided by FS, which helped to maintain balance. Several researchers have suggested that functions of the toes, during standing, play an important role in postural control. Ihara has suggested that toe grasp training is effective for improving postural stability by enhancing sensitivity of muscle reaction in the lower limbs and mechanoreceptors located at the bottom of the feet. In our current study, it was observed that, during single-limb balance testing, subjects were constantly moving their toes. These constant movements of the toes likely assist continual adjustments of postural equilibrium. The multiple rubber bits located on the foot sole were possibly beneficial for these toe movements by providing a stable base of support and enhanced toe grip (traction) on the floor.

It was not clear why postural control improvement was observed in the AP direction, but not in ML direction, during EO trials with the FS condition. However, multiple

Table 1. Group means (± SD) of COPV measures of postural control (N = 26)

<table>
<thead>
<tr>
<th></th>
<th>RS</th>
<th>FS</th>
<th>NS</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>COPV in AP with EO</td>
<td>0.59 ± 0.21</td>
<td>0.53 ± 0.15</td>
<td>0.56 ± 0.20</td>
<td>3.75</td>
<td>*0.03</td>
</tr>
<tr>
<td>COPV in ML with EO</td>
<td>0.67 ± 0.21</td>
<td>0.60 ± 0.16</td>
<td>0.64 ± 0.21</td>
<td>3.27</td>
<td>0.05</td>
</tr>
<tr>
<td>COPV in AP with EC</td>
<td>1.22 ± 0.45</td>
<td>1.17 ± 0.39</td>
<td>1.21 ± 0.40</td>
<td>0.92</td>
<td>0.41</td>
</tr>
<tr>
<td>COPV in ML with EC</td>
<td>1.26 ± 0.42</td>
<td>1.21 ± 0.41</td>
<td>1.23 ± 0.39</td>
<td>1.58</td>
<td>0.22</td>
</tr>
</tbody>
</table>

(*) P<0.05
rubber bits on the foot sole may help increase plantarflexor muscle activities, especially for the toe flexor muscles (flexor hallucis longus muscle and flexor digitorum longus). As we already discussed, toe strength provides an essential role in postural control \(^{35,34,36,37}\), and FS possibly provides enhanced toe grip of the floor surface to help improve balance. Plantarflexor muscle fatigue has been known to cause impairment to postural control mainly in the sagittal plane \(^ {38}\). Plantarflexor muscle activities are strongly related to ankle strategy while maintaining balance \(^ {39}\). Winter suggested that COP changes during standing have been reported to be directly reflected by the plantarflexor, including toe flexor muscle, and dorsiflexor motor responses \(^{39}\). They also reported that plantarflexor muscle activities are increased when correcting forward sway using an ankle strategy during standing \(^ {39}\). With these reported evidences \(^ {33,34,36,37,39}\), FS may have provided some positive benefits for plantarflexor muscle activation. Therefore, wearing FS could provide more assistance to maintaining stable balance in the AP direction compared to ML direction.

Human balance is maintained by sensory feedback from the vestibular and visual and the somatosensory system \(^ {40}\). Removal of vision significantly limits the sensorimotor system’s ability to maintain postural control \(^ {41}\). It was reported that, without vision, spontaneous postural oscillations increased by up to 50% \(^ {42}\). In the results of the current study, during EC trials, the standard deviations of the mean values, in both AP and ML directions, were significantly increased compared to when visual feedback was available. These higher standard deviations may indicate the constrained subject ability to find effective movement strategies \(^ {41}\). With this challenging task, peripheral tactile feedback and foot grip, enhanced by FS, may not be effective enough to provide adequate mechanisms to compensate for the removal of vision in the postural control system. However, the mechanisms of how these unique socks, with and without vision, influence postural control are unclear.

To our knowledge, this is the first study to investigate the influence of FS on postural control with and without the concomitant removal of vision. Further studies are needed to reveal the mechanisms of the postural control improvement that was observed in the current study. The effect of the tactile sensation coming from the five individual toe pockets was not clearly understood. Our previous study \(^ {35}\) showed that the five-toed socks without rubber bits did not improve postural control in young individuals; however, it was still unclear that how the five-toed characteristics would influence the elderly population or individuals with pathological conditions such as diabetes. It was reported that toes and metatarsal heads had higher tactile sensitivity than the heels among the elderly \(^ {41}\). Wells et al. \(^ {43}\) have suggested that vibration sensation thresholds on the foot sole increase as individuals become older, which is associated with a decrease in postural control seen in the elderly population. The study also reported that the greatest age difference in the vibration sensation threshold was observed in the toes compared to other foot sole areas, indicating that elderly individuals are much less sensitive in the toes compared to the younger population.

Future studies are required to reveal the possible mechanisms of postural control improvement with FS in individuals who have postural control deficits. The following three possible mechanisms are suggested: 1) the multiple rubber bits of the socks may provide better sensory feedback to the CNS because of increased tactile sensation from the foot sole, 2) the multiple rubber bits may provide increased ground surface grip (traction), 3) individually-wrapped toes may enhance cutaneous input to the CNS from the skin around the toes.

**Potential clinical applications.** The findings of our study contribute to the efficacy of the use of FS to provide an immediate improvement in postural control in healthy young adults. Furthermore, this information may prove useful in determining appropriate interventions for individuals with postural control deficits, such as the elderly population and diabetic peripheral neuropathy patients. Regular socks with grippers on the foot sole have been marketed as an elderly or diabetic foot care product, and these socks are often utilized in hospitals, nursing homes, and other health care clinics. Wearing this type of sock could provide better friction against the shoe insole or floor surface. Therefore, individuals wearing this kind of sock can “feel” a better grip in each step they make. The shape of grippers with these regular socks, however, is usually flat; not designed to provide enhanced plantar cutaneous sensation. And, little scientific research has focused on if this has an effect on postural control. While further investigation is needed, we believe our findings may stimulate continued research on these five-toed socks with multiple rubber bits on the foot sole to determine what potential benefits they have for elderly and diabetic peripheral neuropathy patients to improve their postural control, which may reduce the risk of falling and improve self-reported function.

**Conclusion**

Single-limb balance testing using COPV revealed that the five-toed socks with multiple rubber bits on the foot sole improved static postural control among healthy young adults. However, the mechanism of this observed postural control improvement remains unclear. Further study on populations with compromised postural control is needed to determine if the socks are effective for overcoming deficits in postural control.
References


18) Okubo J, Watanabe I, Kotaka S, Murase H and Numanov F. 1980. The mechanism for equilibration and sway of the center of gravity in neurological diseases. Effect of the plantar pressure receptor on body sway in spino-cerebellar degenera-


41) McKeon P and Hertel J. 2008. Spatiotemporal postural control deficits are present in those with chronic ankle instability. BMC Musculoskeletal Disorders 2: 76.