Effect of textured foot orthoses on walking plantar pressure variables in children with autism spectrum disorders

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Abstract

The aim of this study was to evaluate the effect of textured foot orthoses on plantar pressure variables in children with autism spectrum disorders (ASDs). Thirty boys were divided into two groups based on their health status, namely: autism spectrum disorder and healthy matched controls. Plantar pressure data were captured during stance phases of shod walking with and without textured foot orthoses. Remarkably larger peak force under the toe1 and metatarsal1 and peak pressure under the toe1 and toe2-5 regions were observed in the autism group comparing with the healthy group, while lower peak force under the toe1, metatarsal1 and metatarsal2 were seen during walking with textured foot orthoses comparing with the cases of walking without them. The results showed higher values of peak pressure under metatarsal3, metatarsal4 and metatarsal5 for the textured foot orthoses walking against the cases without them. Also, analysis depicted huge reductions from pre-to-posttest for the peak pressure under toe2-5 only cases within the autism group. The reason of observing higher peak values of forces and pressures within their forefoot can potentially be their tendency to walk on their toes comparing against the healthy control children. This causes lower pressure values within all toes and the first metatarsal regions during normal walking with textured foot orthoses than walking without them. The findings revealed that the use of textured foot orthoses reduced peak pressure under toe2-5 only in the autism group. This suggests that the use of such interventions can help boys with ASDs move more safely.

Keywords: Plantar pressure, Insole, Walking, Autism
Introduction

Autism has been described as a disorder that can affect the brain’s normal function and appears in the first 3 years of life (Association, 2010). It has been shown that about 1 in 59 children has an autism spectrum disorders (ASDs) (Speaks, 2019). ASDs appears in boys three to four times more than in girls (Association & DSM-V, 2015). ASDs are associated with a constant deficit in social communication and the presence of restricted behaviors (Christensen et al., 2018). The existence of motor deficits, which includes abnormal walking, is considered one of the possible signs that could be used to identify ASDs (Association, 2013).

Abnormal walking could cause deterioration in most of the daily activities of individuals with ASDs (Kanner, 1968). A wide range of abnormal walking patterns in spacio-temporal variables, joint angles, and joint kinetics during walking in individuals with ASDs have been mentioned in previous studies (Calhoun, Longworth, & Chester, 2011; Kindregan, Gallagher, & Gormley, 2015). Earlier studies introduced differences in step rate and peak hip and ankle flexion angles (Calhoun et al., 2011; Hallett et al., 1993) in individuals with ASDs compared with healthy control subjects. In a recent review, Fournier et al. reported that children diagnosed with an ASDs may be less coordinated and demonstrate weak motor abilities (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010). Furthermore, it has been mentioned that ASDs children are more prone to walking on their toes than matched healthy control children (Barrow, Jaworski, & Accardo, 2011; Marcus, Sinnott, Bradley, & Grey, 2010). Therefore, plantar pressure variables can possibly highlight the differences between the active pressure areas, especially in the hindfoot of ASDs children (Lim, O’Sullivan, Choi, & Kim, 2016).

Plantar pressure variables refer to the magnitude of force that is applied to the plantar portion of the foot during walking (Kwon et al., 2001). This technique is important as changes in
Pressure are associated with alterations to forces acting on proximal joints, such as the knee (Kwon et al., 2001). It has been reported that ASDs children have a lower second peak of vertical ground reaction forces (GRFs) in the late stance (Hasan, Jailani, Tahir, & Ilias, 2017). These findings suggest that ASDs children experience difficulties in supporting their body mass and endure walking instability during the stance phase (Hasan et al., 2017).

One study showed that ASDs children rely extensively on proprioceptive than visual information during the normal learning process of movements (Morris et al., 2015). Since the foot plantar is the first contact point of the body with the ground, its position is highly relied on how the central nervous system works. Therefore, passive stimulation of the mechanoreceptors in the foot can potentially help the ASDs children for better sensing the foot stretcher with an enhanced performance. With regards to the orthoses, ASDs children can potentially do treatments with proprioceptive sensory based designs, helping them in aligning the lower extremities and a smoother postural control. This also helps them in learning essential skills in gross motor control. Some changes within the shoe sole or its surface can influence the sensory feedback system from the feet, as reported by Nurse et al. (2005). They have shown some texture alterations of a shoe insert, without any change of its geometry, can affect the muscle activities during locomotion, helping in better sensing of the local pressure differences by the foot mechanoreceptors (Watanabe & Okubo, 1981). The main beneficial impacts of such textured insoles have been examined extensively in literature (Aruin & Kanekar, 2013; Hatton et al., 2012; Ma, et al., 2016; Ritchie, et al., 2011; Waddington & Adams, 2000). For instance, Watanabe and Okubo (Watanabe & Okubo, 1981) provided some evidence indicating that standing on different surfaces can change the transmission of afferent signals from the plantar surface. Increased activity of the tibial nerve was observed in individuals standing on textured surfaces with varied stiffness (de Lima Gomes et al., 2017). Improvements in postural control during quiet standing have been
reported using textured FOs in individuals with Parkinson’s disease (Kenny, Eaves, Martin, Hatton, & Dixon, 2019), and in healthy young and older participants (Palluel, Nougier, & Olivier, 2008; Palluel, Olivier, & Nougier, 2009). However, to the authors’ knowledge, no study has examined the effect of textured FOs on plantar pressure variables in boys with an ASD during walking. Therefore, the aim of this study was to evaluate the effect of textured FOs on walking GRF and plantar pressure variables in children with ASDs.

Material and Methods

Participants

Thirty boys were divided into two groups based on their health status, namely: ASD (15 boys) and healthy matched controls (15 boys). A priori power analysis software (G*Power) revealed that for a statistical power of 0.80 at an effect size of 0.80 and with an alpha level of 0.05, a sample size of at least 30 participants is required (Faul, Erdfelder, Lang, & Buchner, 2007). ASD participants were recruited from an autism centre in Ardabil, Iran. Date of birth, medical conditions, date and severity of autism were recorded in a questionnaire. Participants who demonstrated any neuro-motor dysfunctionalities, orthopaedic disorders or any other medication which can potentially influence the the central nervous system were excluded. None of the participants reported any secondary neurological or orthopaedic conditions, including lower limb injury, in the 12 months prior to data collection. Autism disorder status and the presence or absences of learning disabilities were ascertained via parents or their teacher report. Participants’ parents were fully informed about the aim and protocol of the study and signed an informed consent form. Ethics approval was obtained from the ethical committee of the Ardabil University of Medical Sciences.
**Instruments and examination**

Before the measurements were taken, all participants performed training trials (6 trials) to become familiarized with the test situation. After familiarization, plantar pressure data were assessed during stance phases of shod walking with (5 trials) and without (5 trials) textured FOs. The orders of the different conditions were selected randomly. During testing, subjects walked at a constant speed of \(~1.1\) m/s. The Rs-Scan device was located in the middle of the 18-metre walking path. A foot scan pressure plate (RsScan International, Belgium, 0.5m × 0.5× 0.02m, 4363 sensors, 300 Hz) was clearly marked along the 18-metre walkway. The foot was automatically divided into the following ten anatomical zones by the software (Footscan1 software 9 Gait 2nd Generation, RsScan International): medial heel (MH), lateral heel (LH), midfoot (MF), the first to fifth metatarsals separately: (M1), (M2), (M3), (M4), (M5), the hallux (T1) and the lesser toes collectively (T2–5).

An attempt to walk correctly included perfect foot contact on the middle portion of the foot scan. If the participant was not able to target the foot scan, or lost his balance during walking trials, the trials were repeated. The mean of five trials during each condition was used for statistical analysis.

Dependent variables in this study included peak vertical GRF, their time to peak, vertical loading rate, peak pressure (N/cm²) of the 10 regions of the foot, and peak forces of the 10 regions of the foot. Vertical GRF has a bimodal curve during walking and also contains two peaks: the first peak on heel contact (Fz_HC) and the second peak on the push-off phase (Fz_PO). There is also a downfall in between the two peaks (Fz_DF) during mid-stance (Liikavainio et al., 2007). To calculate the vertical loading rate during walking, the slope of the connecting line was calculated from the moment of the heel contact to the initial peak of the curve of the vertical GRF (Farahpour, Jafarnezhad, Damavandi, Bakhtiari, & Allard, 2016). A 20 Hz cut off frequency was used for filtering of GRF data during walking (Damavandi, Dixon, &
Pearsall, 2012). To normalize the values of vertical GRF data, these values were divided by body mass and then multiplied by 100 (Damavandi et al., 2012).

**Textured FOs**

All participants used the same shoes (Chabok, Tantak, Iran) in this study. Textured FOs (Lp Support Insoles Silicone 321, USA) were used in the present study (Figure 1).

Figure 1 here

**Statistical analysis**

After normal distribution was examined and confirmed using the Shapiro-Wilk Test, a separate 2 (groups: healthy, autism) x 2 (foot orthoses: walking with and without FOs) ANOVA with repeated measures was used for statistical analysis. Post-hoc analyses were calculated using Bonferroni adjusted paired sample t-tests. Additionally, effect sizes were determined by converting partial eta-squared ($\eta^2_p$) to Cohen’s d (Cohen, 2013). The significance level was set at $p<0.05$. All analyses were performed using the Statistical Package for Social Sciences version 20.0.

**Results**

Demographic characteristics were similar in both groups ($p>0.05$) (Table 1).

Table 1 here
Results revealed significantly greater FZMS (p=0.027) and TTP of FZPO (p=0.032) during walking with textured FOs than walking without them (Table 2). Statistical analysis revealed significantly lower FZPO (p=0.020) during walking with textured FOs than walking without them (Table 2).

Table 2 here

Findings demonstrated significantly larger Ftoe1 (p=0.020) and Fmeta1 (p=0.025) in the autism group than in the healthy group (Table 3). Results showed significantly greater Fmeta3 (p=0.001), Fmeta4 (p=0.009), Fmeta5 (p=0.020), and Fmidfoot (p=0.001) during walking with textured FOs than walking without them (Table 3). Moreover, findings revealed significantly lower Ftoe1 (p=0.004), Fmeta1 (p=0.002) and Fmeta2 (p=0.046) during walking with textured FOs than walking without them (Table 3). Post hoc analysis demonstrated significant reductions from pre- to post-test for Ftoe2-5 (p=0.015, d=1.14) and Fmeta1 (p=0.009, d=1.87), only in the autism group (Table 3).

Table 3 here

Findings demonstrated significantly greater Ptoe1 (p=0.047) and Ptoe2-5 (p=0.012) in the autism group than in the healthy group (Table 4). Results revealed significantly greater Pmeta3 (p=0.035), Pmeta4 (p=0.029) and Pmeta5 (p=0.004) during walking with textured FOs than walking without them (Table 4). Findings showed significantly lower Ptoe1 (p=0.023), Ptoe2-5 (p=0.002) and Pmeta1 (p=0.024) during walking with textured FOs than walking without them (Table 4). Post hoc analysis demonstrated significant reductions from pre- to post-test for Ptoe2-5, only in the autism group (p<0.001, d=1.89) (Table 4).
Discussion

The aim of this study was to evaluate the effect of textured FOs on walking GRF and plantar pressure variables in children with ASD. Lower values of $F_{zPO}$ were observed within the autism group than the healthy ones, with higher values of $F_{toe1}$, $F_{meta1}$, $P_{toe1}$, and $P_{toe2-5}$ for the ASDs children. While lower $F_{toe1}$, $F_{meta1}$ and $F_{meta2}$ were seen during walking with textured FOs, pressure values beneath the third, fourth and fifth metatarsals were more than walking without them. In addition, our results depict lower $P_{toe1}$, $P_{toe2-5}$ and $P_{meta1}$ during walking with textured than walking without them with significant reductions from pre-to post-test for $P_{toe2-5}$, only observed in the autism group.

The lower values of $F_{zPO}$ in the autism group were in line with the findings of a similar study by Hasan et al., (2017). Within ASDs children, lower second peak values of vertical ground reaction forces were observed mainly in the late stance, which can be related to some difficulties to have a stable walking mainly because they cannot support their body mass (Hasan et al., 2017). The reason of observing higher peak values of forces and pressures within their forefoot can potentially be their tendency to walk on their toes comparing against the healthy control children (Barrow et al., 2011; Marcus et al., 2010). This causes lower pressure values within all toes and the first metatarsal regions during normal walking with textured foot orthoses than walking without them as a mechanism of defense while having problematic forefoot gait (Emborg et al., 2009). Kwon and Mueller (2001) showed that by distributing the weight across the whole plantar surface during gait, the plantar pressure can be decreased and as a result, the plantar pressure at critical points (i.e. forefoot) can also reduce down, which this by itself causing a small increase within the midfoot pressure.
Relatively higher values of $F_{meta3}$, $F_{meta4}$, $F_{meta5}$, $F_{midfoot}$, $P_{meta3}$, $P_{meta4}$ and $P_{meta5}$ were reported during walking with textured FOs compared to walking without them, in this study. One reason for this difference could be that subjects, to avoid overuse of the forefoot and the risk of incurring forefoot pain, adapt their walking pattern in such a way that the force and pressure under the forefoot is decreased through a relative increase in other areas. The fat pad at the other areas of the foot has excellent shockabsorbing and weight-bearing qualities and is less prone to blisters (De Clercq, Aerts, & Kunnen, 1994; Wearing, Smeathers, Yates, Urry, & Dubois, 2009). Hence, shifting the load to the other areas of the foot might be a defense mechanism when forefoot loading becomes problematic (Wearing et al., 2009). Such an interpretation has been supported by Emborg et al. (Wearing et al., 2009) who studied the effects of repetitive painful stimulation at different sites of the foot during different phases of the step cycle. They found that after stimulations near toe off, withdrawal was primarily accomplished by ankle dorsiflexion, thereby avoiding forefoot pressure. This response to painful stimulation probably differs from that to stimulation by textured FOs, however. Therefore, further study is warranted to better establish this issue.

Significant reductions from pre- to post-test for $F_{toe2-5}$ and $F_{meta1}$ were observed only in the autism group. This finding may be caused by sensory feedback provided by textured FOs from the feet (Nurse, Hulliger, Wakeling, Nigg, & Stefanyshyn, 2005; Watanabe & Okubo, 1981). Kwon and Mueller (Kwon & Mueller, 2001) showed that the highest pressure values were exerted in the forefoot in the pre-swing phase, because in this phase the heel leaves the ground and the body weight is transferred to the forefoot and toes. Therefore, this is an important variable when we study the plantar pressure distribution or the efficiency of certain FO materials during walking. Textured insoles have been used in different fields with the twofold aim of improving performance and preventing injuries (Hatton, Dixon, Rome, Newton, & Martin, 2012; Kalron, Pasitselsky, Greenberg-Abrahami, & Achiron, 2015).
Amadio and Sacco (Amadio & Sacco, 1999) also showed a predominance of pressure peaks in the anterior region of the foot and consequently more pain in this location. Improvements in such performance variables may in turn reduce the risk of injuries (Vieira et al., 2017). FO-related reduction in $F_{toe2-5}$ and $F_{meta1}$ in the autism group may be associated with improving performance and preventing injuries. However, further study is warranted to better investigate this issue.

There are limitations to the current study as we only evaluated the immediate effects of textured FOs on plantar pressure variables and the long-term effect of such interventions remains to be investigated. This study sample came from groups of boys divided into healthy and ASD, so the results cannot be generalized to other populations.

**Conclusion**

Within ASDs children, lower second peak values of vertical ground reaction forces were observed mainly in the late stance, which can be related to some difficulties to have a stable walking mainly because they cannot support their body mass. The reason of observing higher peak values of forces and pressures within their forefoot can potentially be their tendency to walk on their toes comparing against the healthy control children. This causes lower pressure values within all toes and the first metatarsal regions during normal walking with textured foot orthoses than walking without them as a mechanism of defense while having problematic forefoot gait. The findings revealed that the use of textured FOs reduced $P_{toe2-5}$ only in the autism group. This may indicate that the use of such interventions can make boys with ASD move more safely. Such FOs can provide sensory information and persuade boys with ASD to move within a safe range. This may reduce the risk of falling and imbalance in boys with ASD. Therefore, clinicians are advised to apply textured FOs to improve functions in boys with ASD.
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Conflict of interest statement

None.

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