The importance of the foot in life of the people with visual impairment

(overview essay)

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Abstract: *The importance of the foot in the life of the visually impaired is unimaginable. People with visual impairment are a potentially weakened target group regarding the genesis of various orthopedic problems as well as morphological and structural foot deformities. The foot has an important functional relation within the lower limb and body. The paper shows importance of the health state of the foot in their life and describes the foot as an important potential therapeutic tool for maintaining or improving the quality of life. Maintaining a healthy foot in this population should be a significant need. A lot of studies are solving the foot on foot-based interfaces that stimulate the surface of the foot with vibrations. It could be used in several fields such as sensory substitution virtual reality, rehabilitation and among others.*

Keywords: *foot, visual impairment, foot stimulation, postural balance, sensory feedback*

1 Introduction

The foot has an important functional relation within the lower limb and body. It constitutes an important supposition for maintaining the balance while standing, walking and in other derived movements (Votava, 2002). The function of the foot is static (bearing) and dynamic. The foot is illustrated as a "tripped model", when the healthy foot with well-developed arches is supported only in 3 points (calcaneal protuberance, 1st metatarsal head and 5th metatarsal head). A healthy foot has a metatarsal head when laid on the mat and contributes roughly equally to transfer body weight. Plantar scrolling (unwinding) in healthy feet is the transfer of the pressure (center of pressure) through the lateral beam, from the 5th metatarsal head toward the 1st metatarsal head (Riegerová, Přidalová, & Ulbrichová, 2006).

The function of the foot is to create a solid base and an equal distribution of excessive burdens of the lower limb while walking, and to reduce the energy intensity of walking while moving the body forward (Gross, 2002). The function of the foot is conditioned by its anatomical structure, which is contingent on the organization of the bones into two-foot arches (longitudinal and transverse). Longitudinal vault is contingent on the higher medial arch, which is created by three medial beams connecting talus, ossa cuneiformia, the 1st to 3rd metatarsus and phalanges of the first to third toes; it is employed during dynamic loading. Transverse vault is conditioned by the shape and organization of osa cuneiformia (cuneiform bones) and proximal metatarsals. Its role is to provide protection to soft structures in the sole of the foot and partially absorb forces created when body weight is transferred. From the phylogenetic point of view, similarly to vertical pater, the vault is a young structure, and therefore labile and relatively easily vulnerable. Its disorders belong to the most common orthopedic defects in general. Static defects of the forefoot (hallux valgus, digitus quintus varus, hallux varus, hallux rigidus, digiti malei, digiti hamate, digiti Hippocratici) occur most frequently. Pain occurs frequently in the heel and in metatarsals. The typical defects of the foot vault are flat longitudinal vault (pes planovalgus), transverse flat foot (pes transversoplanus), and hollow foot (pes cavus; pes excavatus) (Riegerová, Přidalová, & Ulbrichová, 2006). The structure and function of the foot are adjusted to an appropriate distribution of body weight while standing and when moving in a gravitational field, the flexibility and shock absorption during movement, as well as a huge source of receptors necessary for the proper management of posture and motor on the principle of cybernetics (the principle of biological "locomotive computer") (Müller, 2011).

Results of studies of foot stimulation show that people understand easier directional information with patterns providing reference points rather than motion. Familiar patterns and emotions can also be easily recognized by the foot if information displayed is simple and encoded as short, structured messages. New patterns abstractly representing information can also be understood, quickly learned, and retained in memory (Velázquez, Bazan, Alonso, & Delgado-Mata, 2011). It was describing the development of vibrating insoles, which providing a subsensory mechanical noise signal to the plantar side of the feet. It may improve balance in healthy young and older people and in patients with stroke or diabetic neuropathy. This study describes the requirements for the tactors, (tactile actuators) insole material and noise generator. A search for the components of vibrating insoles providing mechanical noise to the plantar side of the feet was performed. The mechanical noise signal should be provided by tactors built in an insole or shoe and should obtain an input signal from a noise generator and an amplifier. Possible tactors are electromechanical tactors, a piezo actuator or the VBW32 skin transducer (Hijmans, Geertzen, Schokker, & Postema, 2007). For example, the study of Hijmans, Geertzen, Zijlstra, Hof, & Postema (2008) investigated the effects on standing balance of random vibrations applied to the plantar side of the feet by vibrating insoles in subjects with neuropathy and nondisabled subjects. In subjects with neuropathy, an interaction effect between vibration and an ADT was found for balance. No effects of vibration on balance were found in nondisabled subjects. Vibrating insoles improved standing balance in subjects with neuropathy only when attention was distracted. Improvement of the insoles and their activation is needed to make their implementation in daily living possible and effective.

Multiple sensory information arising from one or various sensory sources might be co-processed following a common vectorial addition mode for postural regulation purposes. Such an integrative mechanism does not imply that the relative contributions of all sensory modalities must be equivalent, however. Rather, this study suggests that proprioceptive and tactile feedback might be differentially involved in human postural control according to body or environmental constraints (Kavounoudias, Roll, & Roll, 2001).

2 Overview of research findings in the topic related to foot stimulation

Velázquez, Pissaloux, & Lay-Ekuakille (2015) stated that tactile interfaces that stimulate the plantar surface with vibrations could represent a step forward toward the development of wearable, inconspicuous, unobtrusive, and inexpensive assistive devices for people with visual impairments. They studied how people understand information through their feet and to maximize the capabilities of tactile-foot perception for assisting human navigation. Based on the physiology of the plantar surface, three prototypes of electronic tactile interfaces for the foot have been developed. With important technological improvements between them, all three prototypes essentially consist of a set of vibrating actuators embedded in a foam shoe-insole. Perceptual experiments involving direction recognition and real-time navigation in space were conducted with a total of 60 voluntary subjects. The developed prototypes demonstrated that they could transmit tactile information that is easy and fast to understand. Average direction recognition rates were 76%, 88.3%, and 94.2% for subjects wearing the first, second, and third prototype, respectively. Exhibiting significant advances in tactile-foot stimulation, the third prototype was evaluated in navigation tasks. Results show that subjects could follow directional instructions useful for navigating spaces. Footwear providing tactile stimulation can be considered for assisting the navigation of people with visual impairments. The study of the Velázquez & Bazan (2013) presents work on foot-based interfaces that stimulate the plantar surface with vibrations. These vibrations convey spatial and temporal information that could be exploited in several domains. One of the most challenging applications is perhaps the assistance of the visually impaired: vibrations can be perceived by users as cardinal directions that assist their navigation. Three prototypes of foot-based interfaces have been developed seeking to optimize user perception. Designs, prototypes, and perceptual results are presented and discussed. Results show the potentials of podotactile stimulation in assistive devices. Another paper wrote by Velázquez, Bazan, Alonso, & Delgado-Mata (2011) presents further development of a wearable electronic tactile display that stimulates the mechanoreceptors in the foot sole with vibrations and proposes a technologically improved second device and new optimized tactile patterns that lead to significant advances in tactile-foot perception. Following the lessons learned from a previous prototype, they propose a technologically improved second device and new optimized tactile patterns that lead to significant advances in tactile-foot perception. A series of experiments involving directional information, pattern and emotion recognition, and language learning were conducted with 20 healthy sighted voluntary subjects. Results obtained confirm the pertinence of these advances and show the potentials of podotactile stimulation and the proposed device. Velázquez et al. (2019) mentioned that haptic technology allows producing computer-generated signals that a perceiver experiences through touch. In general, haptic devices can be classified as active and passive. In this paper, they present a performance evaluation of a group of 10 voluntary subjects in a task of shape perception when both active and passive kinesthetic haptic feedback are provided. The results of a series of psychophysical experiments show that active haptics is superior for shape recognition: active haptics enhances the perception of surfaces while passive haptics conveys the sensation of being guided along pathways. In addition, the guidance nature of passive haptics makes the pathway direction easy to recognize. This last observation can be effectively exploited in more challenging tasks such as navigation/mobility assistance. It is unknown to what extent automatic postural responses are triggered by lower leg proprioception.

Bloem, Allum, Carpenter, & Honegger (2000) was studying postural control in five carefully selected patients with subtle diabetic polyneuropathy (restricted to the lower legs) and 15 healthy subjects. All patients had bilaterally absent Achilles tendon reflexes and weak or absent patella tendon reflexes, but muscle strength was fully preserved. Subjects were tested while standing on a supporting, movable force-plate. The contribution of lower leg proprioception to automatic postural responses was investigated by randomly exposing the subjects to either 4 degrees 'toe-up' rotational perturbation ('normal ankle input'), a simultaneous 4-cm rearward translation and 4 degrees toe-up rotation ('enhanced ankle input'), or a simultaneous 4-cm rearward translation and 4 degrees 'toe-down' rotation ('nulled ankle input'). A few automatic postural responses appeared to be triggered or modulated by lower leg proprioception. The absent stretch reflex and weaker balance-correcting responses in patients produced changed trunk velocity profiles (mainly a reduced initial backward motion of the trunk), but lower-body segment movements showed no consistent differences between the two groups. Velázquez, Bazán, Varona, Delgado-Mata, & Gutiérrez (2012) presents a novel wearable interface for the foot: a shoe-integrated tactile display that enables users to obtain information through the sense of touch via their feet. A 16-point array of actuators stimulates the sole of the foot by inducing different vibration frequencies. A series of experiments were conducted with 20 sighted and 5 blind voluntary subjects to evaluate the role of tactile perception by the human foot and the tactile sensitivity of the plantar surface. Tests evaluated the perception of simple shapes, patterns, and directional instructions. The results showed that some information is discriminable, and that tactile-foot stimulation could be used for a wide number of applications in human-machine interaction. Furthermore, the results also suggested that the blind perform better in some key tasks and support the feasibility of footwear providing tactile feedback for situational awareness, mobility, and the navigation assistance of the blind.

Deficits in motor control can be observed with a decrease in plantar sensation. There is evidence that changing the plantar feedback leads to kinematic, kinetic, and neuromuscular adaptations in static as well as dynamic conditions. The effect of changes in plantar feedback on the modulation of gait has not been clarified conclusively. Changes in plantar feedback led to stimulation-specific adaptations of gait characteristics. Further prospective studies should be performed to investigate interventions for enhancing plantar receptor feedback for the prevention of falls and the treatment of injuries and movement disorders (Alfuth & Rosenbaum, 2012).

Lipsitz et al. (2015) tested whether subsensory vibratory noise applied to the sole of the foot using a novel piezoelectric vibratory insole can significantly improve sensation, enhance balance, and reduce gait variability in elderly people, as well as to determine the optimal level of vibratory noise and whether the therapeutic effect would endure, and the user's sensory threshold would remain constant during a day. The vibratory insoles significantly improved performance on the Time Up and Go test, reduced the area of postural sway, and reduced the temporal variability of walking at both 70% and 85% of the sensory threshold and during a day. Vibratory sensation thresholds remained relatively stable within and across study days. This study provides proof of concept that the application of the principle of stochastic resonance to the foot sole sensory system using a new low-voltage piezoelectric technology can improve measures of balance and gait that are associated with falls. Effective vibratory noise amplitudes range from 70% to 85% of the sensory threshold and can be set once daily.

Rocha, Bonfim, Assis, Oliveira, & Almeida (2020) have collected the research data from the scientific databases (Science Direct, MEDLINE/PubMed, Web of Science and Scielo). The study is a literature review aimed at synthesizing information regarding the relationship between body posture, gait biomechanics, and the use of sensory insoles, as well as contributing to the investigations on this topic. They have selected the articles that contained literature reviews, treatment, or on-site surveys, published up to 2020. This review has identified the existence of several commercially available pressure sensors, with technologies such as capacitive, resistive, piezoelectric, and piezoresistive sensors. This study has also identified several advantages in the use of the insole technology: improvements in balance and speed rates in the anteroposterior region; redistribution of plantar pressure during walking for diabetic patients; alteration of the pressure over time relationship throughout the entire plantar region. The progress obtained using these sensors over the past few years has been motivating researchers to aim for improvements in its performance and practicality, allowing for its use in diagnosing balance disorders, which can be related to body posture and gait biomechanics.

Giri & Borkar (2021) reviewed the effects of sensory stimulation interventions on balance and postural control in diabetic peripheral neuropathy. Here was strong evidence of effects of sensory stimulation on postural control and balance with noticeable difference in diabetic peripheral neuropathy. Based on our analysis results, most of the study stated that vibration, plantar massages, kinesiotaping, rocker shoe, vibromedical insole, conventional exercises with proprioception stimulation, mechanical noise have shown significant difference on balance and postural control.

Subsensory mechanical noise applied to the feet of quietly standing individuals with vibrating insoles leads to enhanced feedback and reduced postural sway. Differential effects noted between young, and elderly indicate that elderly people gain more in motor control performance than do young people with the application of noise to the feet. Young participants might have almost optimum sensory feedback and balance control compared with elderly patients, who often have lateral postural instability and raised sensory feedback thresholds. Noise-based devices, such as randomly vibrating shoe insoles, might be effective in enhancement of performance of dynamic balance activities (e.g., walking), and could enable older adults to overcome postural instability caused by age-related sensory loss (Priplata, Niemi, Harry, Lipsitz, & Collins, 2003).

3 Conclusion

Several studies are solving the foot on foot-based interfaces that stimulate the surface of the foot with vibrations. It could be used in several fields such as sensory substitution virtual reality, rehabilitation and among others. Some study was describing the development of vibrating insoles which providing a subsensory mechanical noise signal to the plantar side of the feet. These may improve balance in persons with visual impairment, also. Vibrations can be perceived by users with visual impairment as main directions that assist their navigation. Studies show the potentials of podotactile stimulation in assistive devices. Noise-based devices, vibrating shoe insoles, might be helpful in overcoming postural instability caused by age related sensory loss. Some automatic postural responses seem to be started or impacted lower leg proprioception. The observed improvement with these sensors over the past few years has motivated researchers to focus on improving their performance and practicality. This is used in the diagnosis of balance disorders. Next studies should be realized to investigate interventions for enhancing plantar receptor feedback for the wider spectrum of diseases and movement disorders, also.

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