Review

Use of Insoles to Enhance Postural Control

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Abstract:
Postural control is a complex process involving sensory inputs from visual, vestibular, proprioceptive and tactile receptors, processed by the central nervous system (CNS). Sensory information provided by muscle and cutaneous afferents in the foot optimize the ability to stand upright and control the postural sway. The foot, as a direct and often only interface between the body and the ground, constitutes an essential functional whole participating in mechanisms of postural control and regulation, allowing the body to sense and interact with the surrounding environment. Among many somatosensory stimulations designed to improve balance, wearing shoe insoles presents one of the easiest and most cost-effective ways. This method can be used both amongst elderly population for fall prevention and amongst athletes to reach better performance and furthermore prevent injuries. With the growing interest in insole use, several prototypes have been developed to monitor movement during day to day use. For therapeutic purposes, the type of insoles used in the studies was often not clarified, and the term insole was used as a general term.The proposed theme of the discussion is to review already existing data on insole use for treatment of postural balance.

Keywords: Postural control; Postural sway balance; Insoles; Foot stimulation

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1. Postural control

Postural control is a complex process involving sensory inputs from visual, vestibular, proprioceptive and tactile receptors, processed by the central nervous system (CNS). Afferent information received from these sources allows for an internal representation of the body's position and location in space. Postural control may be defined as the act of achieving, maintaining or restoring a state of balance during posture or activity (Pollock et al., 2000). It comprises of a combination of active mechanical control,characterized by a neural regulation of skeletal muscles responsible for sway detection and postural correction; and passive mechanical control, which refers to the stiffness and kinematic properties of the joints, as well as the effect exerted on them by gravity (Bauby and Kuo, 2000). When balance is threatened by either an external or internal perturbation, CNS initiates appropriate muscular response (Samuel et al., 2015). This is accomplished by comparing the collated afferent information to the internal model (expected state), thus eliciting a motor response, which maintains the center of mass within the limits of stability (Mancini and Horak, 2010). Due to a high center of mass over a relatively small base of support, maintaining an upright balance can be difficult for humans. Even while standing statically (often termed quiet standing), the body produces small amounts of sway (Peterka, 2002). These postural movements are an indicator of displacement and motor corrections to maintain the body segments in equilibrium. Consequently postural control requires constant conscious and subconscious regulation of postural sway to manage balance and achieve postural stability (Pruszynski and Johansson, 2014). These movements of regulation can be performed particularly by cutaneous plantar informations arising from the feet. (Inglis et al.,2002).

2. Cutaneous plantar feedback

The foot constitutes a functional whole that participates in the mechanisms of postural control and regulation. As a direct and often only interface between the body and the ground it allows the body to sense and interact with the surrounding environment (Kavounoudias et al.,1999). Sensory information provided by muscle and cutaneous afferents in the foot contribute to optimize the ability to stand upright and control the postural sway to detect both position and motion of the body in space. This ability results from coordination between the somatosensory afferent system and the motor system, which controls muscular activity and pressure exerted by the feet. Somatosensory feedback arises from a variety of sources, most notably the cutaneous mechanoreceptors in the skin and muscle spindle endings found within most of the skeletal muscles,together providing tactile and proprioceptive feedback. Plantar cutaneous afferents transmit spatial and temporal feedback concerning the pressure variations and skin stretch exerted on the soles of the feet (Vallbo and Johansson, 1984). This cutaneous feedback is provided by four classes of low threshold mechanoreceptors (Abraira and Ginty, 2013). They are highly sensitive toforces applied to the sole of the foot and demonstrate adaptive and receptive ground properties (Priplata et al., 2003). They are activated by moderate mechanical stimuli and encode reversible deformations of the skin induced by pressure, vibration or stretch (Zehr et al., 2001). Fast adapting type I (Meissner) and type II (Pacinian) afferent fibers are sensitive to dynamic stimuli; their activation evokes perception of fluttering and vibration. In contrast, slowly-adapting type I (Merkel discs) and type II (Ruffini endings) afferents respond to stretching of the skin. Their activation allows perception of pressure and movement of the skin (Macefield et al., 2009). The distribution, density and variety of cutaneous receptors indicates that the role of the feet is not only important for supporting the body, distributing plantar pressure and absorbing impacts from the ground but it also plays a vital role in controlling postural adjustments for maintaining an erect standing posture (Kavounoudias et al.,1999). It has in fact been shown that reducing information from receptors located in the skin through cooling foot sole, anesthesia, ischemia conditions and/or eliminating sensory information is associated with an increase in postural sway under perturbed postural responses (Palazzo et al., 2021). Controversially, stimulation of the foot sole, through the modulation of load of lower limbs and the positioning of feet, could lead to an improvement of balance (Zehr et al., 2014).

3. Somatosensory stimulations to improve postural control

Among various available interventions, one of the easiest and most cost-effective ways to solve problems foot disorders is wearing insoles (Iglesias et al., 2012). Insoles are commonly used to treat foot disorders. The use offoot orthotics is very old and insoles have (historically) been usedeither for comfort or correction of deformities due to the feet characteristics of each individual, or to relieve pain caused by daily or sports activities (Laperiere et al.,2006; Sobel et al., 2001). Presently, prescription of these orthotics is no longer limited to correction of flat feet as it has been in the beginning. available literature describes the use of insoles in the elderly for fall prevention, the use of functional and proprioceptive insoles in patients with neurological disorders, and postural insoles for postural correction. In addition, insoles are often prescribed for patients with diabetic neuropathies or to athletes to either achive better performances or prevent injuries (Elraiyah et al.,2016). With the growing interest in daily activity monitoring, several insole designs have been developed to identify postures, detect activities and count steps. However, the validity of these devices is not clearly established (Ngueleu et al., 2019). In recent years, studies have demonstrated that by using various stimulation methods, additional somatosensory input has positive effects on postural control. These findings confirm that mechanical stimulation of the plantar sole has an impact on the mechanoreceptors of the feet, which helps in upright standing. Nevertheless, the effect of mechanical stimulation on postural control by using insoles still remains unclear (Viseux et al.,2019). with a rapidly growing body of evidence in research literature defining the most effective insole type intervention is becoming more and more challenging. Insole types can be categorized as electrical and non electrical devices or also as (a) orthopedic, (b) vibrating, and (c) textured (Viseux et al.,2019).

3.1 *Non electrical stimulation*

Sensory feedback from the foot can be facilitated by non-electrical stimulation of plantar mechanoreceptors by using orthopedic devices, skin indentation, textured or different thickness material surfaces and by focal activation with additional thickness. Orthopedic insoles with arch supports, lateral wedge, metatarsal pads, and heel cups are conventionally prescribed to correct/compensate foot deformity and relieve pain (Watanabe and Okubo, 1981). They change the contact area between the foot and support surfaces and redistribute plantar loading. Such designs may provide supplemental information to users about the relative position of the foot on the ground during walking (Perry et al., 2008). In population with significant foot deformation, it may be difficult to wear a conventional shoe and customized insoles may be required. The skin stimulation by indentation produces delicate pressure changes under the feet, inducing a sensation of changing pressure under the feet with no sensation of body position change. an observed barely present postural response represents a protection responsereducing pressure to the foot when the skin indentation increases. consequently, information deriving from cutaneous receptors of the foot could provide information about properties of the support surface and its contact with the foot (Takata et al., 2016). Textured insoles are another type of insole that often vary in shape and structure. they can be small and flexible or semirigid with different density shaped pyramids or spheric knots. The stiffness and textures of insoles influence mechanical stimulation of the plantar foot and affect postural stability. thus, adding various textures to insoles has been demonstrated to increase sensory afferent feedback via enhanced tactile stimulation of plantar cutaneous mechanoreceptors (Hatton et al., 2012). Specific focal sole stimulation, for example, showed that adding additional thickness (3 mm) coin-shaped piece of aluminum placed under the sole induced an increase in activation of the plantar flexor musculature and consequentely confirmed predictable postural reactions (Kavonoundias et al., 2009; Hijamans et al., 2007).

3.2 *Electrical stimulation*

Stimulation of the plantar surface of the foot can be achieved by incorporating vibration devices. Stimulation of cutaneous receptors increases afferent feedback and may, therefore, decreas reaction time. Ideally, the CoP moves trough plantar surface stimulating high sensitivity cutaneous receptors without excessive pressure, causing postural corrections to occur faster when balance is lost. (Wei et al., 2012). Application of vibration insoles is commonly used to activate low-threshold cutaneous afferents receptors. The subsensory noise signal amplifies tactile input, such as change in pressure distribution under the sole of the foot, resulting in earlier detection of pressure changes (Wang and Yang, 2001). In this field researchers have used different types of vibration inputs, at0%, 85% and 90% of plantar sensory threshold values and have tested both static and dynamic balance (Wang and Yang, 2001). Collins et al., (1996) postulate that delivering subsensory noise (white noise) through vibratory tactors (piezo-electric actuators) placed underneath the forefoot and heel regions, lead to earlier detection of changes in foot pressure and, therefore, earlier corrective postural responses. It is not known yet, whether less precise noise levels between 70 and 90% of the sensory threshold would yield similar results, or whether the threshold changes throughout the day require repeated modifications of different noise setting amplitudes to remain effective during prolonged use (Wang and Yang, 2001).The phenomenon of Stochastic Resonance (SR) has been observed in a variety of physiological systems. It is also present in our body's somatosensory system where the presence of a sub-sensory threshold noise could enhance the system's response to weaker signals (Santhiranayagam et al., 2015). Imperceptible (subsensory) vibratory noise applied to the feet can improve balance especially in elderly subjects and patients with neuropathic diseases rather then in healthy young people. Mostly it depends of different foot sensory perception conditions. Another technological advancement is the ongoing development of digital gait analysis, which focuses on using body mounted inertial measurement units (IMU). These sensors mounted in the insole are able to measure angular velocity, linear acceleration, foot pressure etc. using Bluetooth, this data can be transmitted to any Android device, creating the potential for online data management, including mass data storage and automatic recording of personal gait data. Due to complex noise filtering, one of the most prominent difficulties in utilizing IMUs for gait monitoring remains deriving position-time data (Santhiranayagam et al., 2015).

4. Conclusions

The relationship between improvements of balance and facilitation of sensory feedback related to the activation of plantar cutaneous mechanoreceptors using insoles, due to a variety of therapeutic benefits, provides an interesting perspective for clinical application. In the studies reviewed, the type of insoles used as a therapeutic resource is often not clarified and a general term "insole" is used to describe insoles that can vary in type of material, form of evaluation or the form of customization used. The most commonly cited terms include "customized insoles", "prefabricated insoles" or "sham insoles.", resulting in magnetic insoles, vibrating insoles and all other forms of insoles all receiving the same interpretation, causing great confusion and doubts amongst clinicians and researchers (Mendes et al., 2020). Nevertheless, the future research goals are to investigate the effects of insole use step by step. The goal is to find and standardize the approach to propper evaluation of the insoles effects on specific tested populations. The importance of this lies in foot orthoses having both positive and negative effects on the detection of tactile input from the bottom of the foot. Soft soles can distribute pressure over the soles of the foot, which has a positive effect on pain, but it may also result in a deterioration of the detection of pressure changes, which can negatively affect balance. In contrast, firm inlays and inlays with tubing at the plantar surface boundaries may improve balance. Therefore an optimal insole design, texture geometry, material composition, new generation sensors and proper stimulation implemented can lead to the optimal effects of mechanoreceptors in isolated foot regions. All previous mentioned factors have to be considered for future footwear intervention designs.

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