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Orthotic interventions to improve standing balance in somatosensory loss

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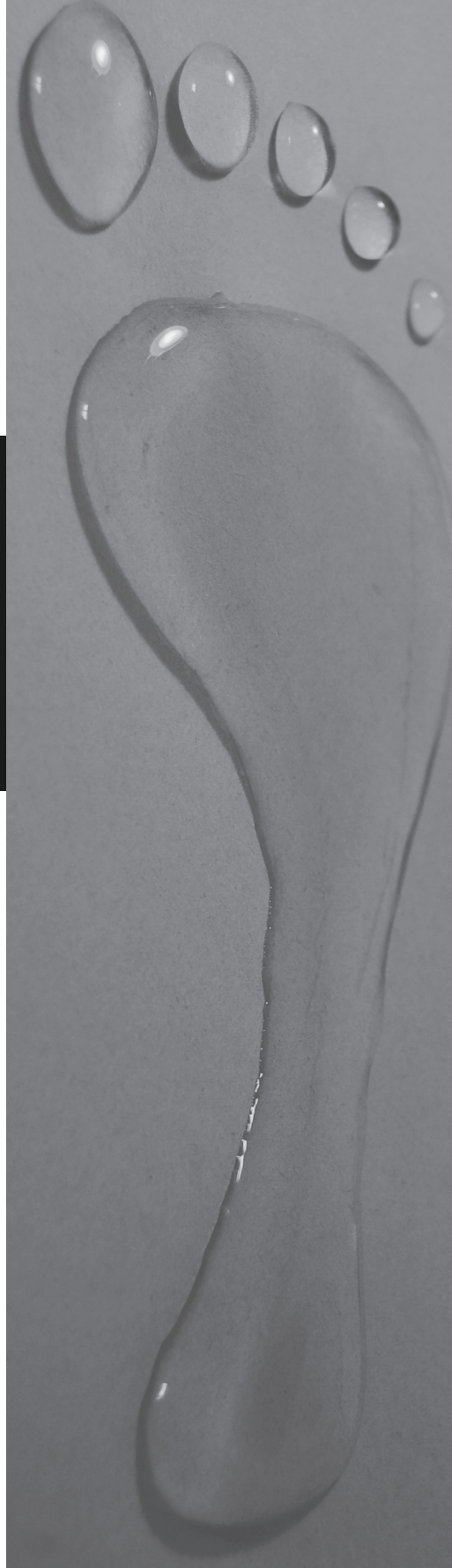
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Development of vibrating insoles

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ABSTRACT

The objective of this study was to describe the development of vibrating insoles. Insoles, providing a subsensory mechanical noise signal to the plantar side of the feet, 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. The Minirator MR1 of NTI, a portable MP3 player or a custom-made noise generator can provide these tactors with input. The tactors can be built in foam, silicone or cork insoles. In conclusion, a C2 electromechanical tactor, a piezo actuator or the VBW32 skin transducer, activated by a custom-made noise generator, built in a cork insole covered with a leather layer seems the ideal solution.

INTRODUCTION

Stochastic resonance (SR) can be described as a counter-intuitive mechanism whereby the addition of noise to a nonlinear system can enhance the detection of weak stimuli or enhance the information content of a signal [1]. SR is associated with biological systems and even with human somatosensation [2]. The somatosensory system provides the central nervous system with information concerning joint position sense and the sense of touch. Mechanoreceptors, muscle spindles, Golgi tendon organs and joint afferents are responsible for somatosensation. Mechanoreceptors situated in the soles of the feet provide the central nervous system with information concerning pressure distribution under the feet. Muscle spindles, Golgi tendon organs and joint afferents situated in the lower leg are responsible for the detection of changes in the ankle joint angle. During standing, changes in pressure and changes in ankle joint angle are often related to changes in upright position. In older people and people with peripheral sensory deficits the detection of changes in upright position is often impaired, resulting in impaired balance and an increased risk for falling.

Application of mechanical noise to the feet may improve somatosensation due to SR. Vibrating insoles may be used for the application of a subsensory mechanical noise signal to the soles of the feet [3;4]. The subsensory noise signal may amplify tactile input like change in pressure distribution under the sole of the foot, resulting in earlier detection of the pressure change. It has been shown that the sway amplitude, measured by motion capture of a shoulder marker, decreased when vibrating insoles were applied to healthy adolescents, elderly, stroke patients, and patients with diabetic neuropathy [3;4]. Our research group is engaged in studies concerning the effects of ankle and foot appliances on balance. To be able to compare the effects of vibrating insoles with the effects of other appliances we developed vibrating insoles. In this study we will describe the development and the requirements for vibrating insoles.

METHODS

The main reason for developing vibrating insoles is to improve balance in people with a deterioration of the somatosensory feedback from mechanoreceptors that play a role in balance control. Most crucial mechanoreceptors are located at the metatarsal phalangeal joint (MTP) region, the heel and the plantar side of the first toe [5]. Therefore, it seems reasonable to position vibrating tactile actuators, called tactors, at these positions (Fig. 1). To apply a vibration to the soles of the feet, these tactors should be built in an inlay or in the shoe. As the mechanical noise should be applied with a certain adaptable amplitude, some requirements for the actuator should be taken into account.

Requirements for tactors

To make it possible to build in tactors in an insole or shoe without increasing the thickness of

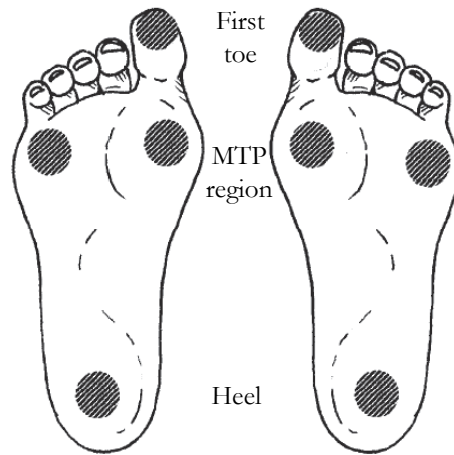


Figure 1. Tactor locations; one at the first toe, two at the metatarsal phalangeal joint (MTP) region and one at the heel.

the sole too much, the tactors should be as thin as possible. A large sole thickness (between 16 and 27 mm) is associated with deterioration of balance [6]. Therefore, the thickness of the tactor should not exceed 15 mm. As two actuators should be positioned next to each other at the MTP region (as seen in Fig. 1), the width of the tactor should not exceed half of the width of the foot at this location. Moreover, one of the tactors should fit under the first toe. Consequently, the width or diameter of the tactors should not exceed 35 mm. The vibration frequency should be adjustable within limits of about 1–1000 Hz (noise signal with varying frequency) and the tactors should instantly react to the input frequency changes. In the only studies concerning the effects of vibrating insoles on balance, the amplitude of the vibration was set at 90% of the sensory threshold [3;4]. Therefore, the amplitude of the vibration applied by the tactor should be adjustable, to make tuning of the amplitude towards individual differences in tactile perception threshold possible. As the appliance may benefit people with impairment of the somatosensory system, the maximum amplitude when loaded should reach the tactile perception threshold in these people. The average threshold amplitude (vibration perception threshold) in a neuropathic population is about 400 mm, in a healthy population this threshold is about 20 mm, both at a vibration frequency of 60 Hz [7].

Requirements for noise generator/amplifier

The tactors should be activated by a noise generator and possibly by an amplifier. To make utilization in daily living (e.g. during walking) possible, both the noise generator and the amplifier should be portable. It is not known what the ideal frequency range of the noise signal should be and whether white noise or coloured noise has the best effects on

balance. Therefore, the noise generator should be able to produce different types of noise within a wide range of frequencies. Moreover, it would be best to set the amplitude of all tactors individually, because of differences in tactile perception thresholds at the different locations.

Requirements for material

It would be best to replace a standard insole by a vibrating insole without making any modifications to the shoe, instead of building in tactors in a shoe. The material of which this insole is made plays an important role. The material should be comfortable, should not absorb the vibration and should be adaptable to make fitting of the actuators possible. Moreover, the material should be relatively hard (Shore A50), because soft insoles (Shore A15 or A33) are associated with negative effects on balance [6]. In a diabetic population, however, too hard material will increase the risk for wounds owing to incorrect pressure distribution.

RESULTS

A profound search resulted in a wide range of brands and types of actuators that can produce a vibration. In Table 1 the actuators found and their properties are shown. All actuators described in Table 1 should be provided with an input signal. Noise generators may be responsible for the input signal.

A lot of different noise generators exist. Most of them are, however, not portable, or have to be built in a personal computer. Only one suitable portable noise generator was found. The Minirator MR1 of NTI is an analogue noise generator that can produce a noise signal with a frequency range of 20 Hz–20 kHz. This noise generator has only one output channel. Another possibility is to use a portable audio player, such as a MP3 player; these have only one output channel as well.

Materials most used for insoles are synthetic foam (as polyurethane and ethylene vinyl acetate; Shore A10A80), rubber (Shore A10-A95), silicone (rubber) (Shore A5-A90) and cork, combined with thermoplastic material to make adaptations possible when the material is heated (Shore A55-A65). All these materials are often covered with a thin leather or fabric layer, to make the insole more comfortable.

DISCUSSION

A combination of a tactor, a noise generator and sole material should make the ideal product to apply a random vibration to the soles of the feet. For prototyping and individually moulded insoles, cork covered with a thin leather layer seems an ideal product. The hardness of the cork material ranges between Shore A55 and A65. In our opinion, Shore A55 is soft enough,

Table 1. Tactile actuators and their properties.

| Actuator | Dimensions | Suitable | Frequency | Suitable | Amplitude | Suitable |
|-------------------------------|---|----------|--|----------|----------------------------------|----------|
| C2 Tactor | D = 30.5 mm H = 7.9 mm | Yes | Not known | Possibly | 0.635 mm | Yes |
| C1026B200F Vibration motor | D = 10 mm H = 5 mm | Yes | Max. 55 Hz | No | Not known | Possibly |
| B5A-11W Vibration motor | L = 11 mm W = 11 mm H = 2 mm | Yes | 10 – 150 Hz | No | Not known | Possibly |
| P-289 Piezo actuator | D = 50 mm H = 12 mm | No | 1 st resonance freq. = 1.1 kHz | Yes | 0.2 mm | Possibly |
| APA400M Actuator | L = 48.4 mm W = 11.5 mm H = 13.0 mm | Yes | 1 st resonance freq. = 4.6 kHz | Yes | 0.4 mm | Yes |
| VBW32 Skin Transducer | L = 25.4 mm W = 18.5 mm H = 10.7 mm | Yes | 100 – 800 Hz | Possibly | Till 50 dB above threshold | Possibly |

D= Diameter (of round actuators); H= Height (in actuation direction); L= Length; W= Width

especially when a leather layer on top of the cork is used.

Different tactors can be used in vibrating insoles. Vibration motors are not usable because only a small frequency range can be applied and the amplitude of the vibration depends on the design of the vibration motor only, and is therefore not individually adaptable. Possible tactors are the C2 electromechanical tactor, used by Priplata *et al.* (2003, 2006) in vibrating insoles [3;4]; piezo actuators, for example the APA400M actuator; or the VBW32 skin transducer. The dimensions, frequency range and amplitude of the vibration applied by these tactors seem to be suitable for vibrating insoles.

The different tactors should be provided with different input. Piezo actuators require a high voltage and low amperage, whereas the C2 tactor and the VBW32 skin transducer require a lower voltage and a higher amperage. Moreover, the tactors applying a subthreshold vibration to the soles of the feet should be individually controlled, to be set on 90% of the tactile threshold on a specific portion of the foot sole. For both reasons, portable noise generators on the market and standard portable audio players are not usable in vibrating insoles. The power supply for vibrating insoles should be custom-made. A custom-made noise generator can be constructed in a small and light version, and can be constructed in such a way that the amplitude of the vibration can be set for every insole individually.

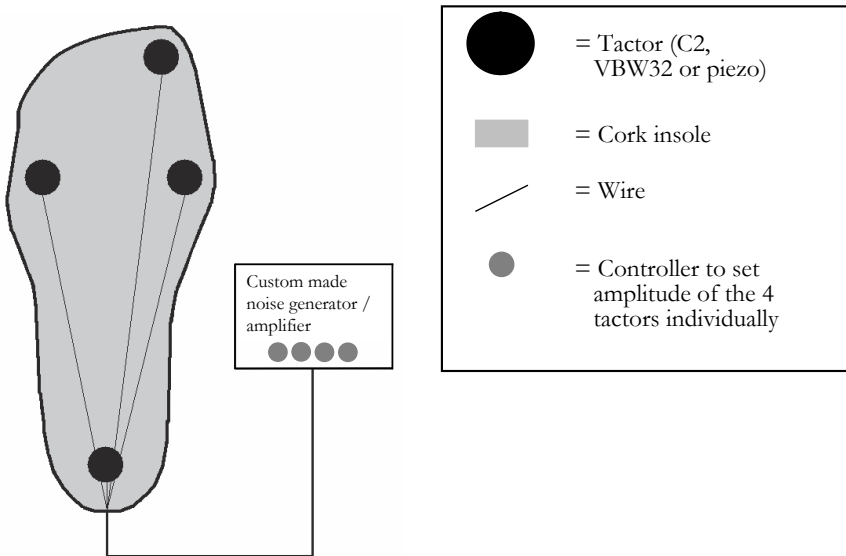


Figure 2. The design of vibrating insoles. The cork insole and the tactors will be covered with a leather layer.

CONCLUSION

Figure 2 shows the final design of the vibrating insoles.

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