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Sensory enhancing insoles improve athletic performance during a hexagonal agility task

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ABSTRACT

Athletes incorporate afferent signals from the mechanoreceptors of their plantar feet to provide information about posture, stability, and joint position. Sub-threshold stochastic resonance (SR) sensory enhancing insoles have been shown to improve balance and proprioception in young and elderly participant populations. Balance and proprioception are correlated with improved athletic performance, such as agility. Agility is defined as the ability to quickly change direction. An athlete's agility is commonly evaluated during athletic performance testing to assess their ability to participate in a competitive sporting event. Therefore, the purpose of this study was to examine the effects of SR insoles during a hexagonal agility task routinely used by coaches and sports scientists. Twenty recreational athletes were recruited to participate in this study. Each athlete was asked to perform a set of hexagonal agility trials while SR stimulation was either on or off. Vicon motion capture was used to measure feet position during six successful trials for each stimulation condition. Stimulation condition was randomized in a pairwise fashion. The study outcome measures were the task completion time and the positional accuracy of footfalls. Pairwise comparisons revealed a 0.12 s decrease in task completion time ($p=0.02$) with no change in hopping accuracy ($p=0.99$) when SR stimulation was on. This is the first study to show athletic performance benefits while wearing proprioception and balance improving equipment on healthy participants. With further development, a self-contained sensory enhancing insole device could be used by recreational and professional athletes to improve movements that require rapid changes in direction.

1. Introduction

Professional and recreational athletes require their central nervous system to rapidly recognize and adjust the position of their limbs and joints in order to effectively compete in sporting events (Ducic et al., 2004). Afferent signals from the distal peripheral nervous system send somatosensory information to the central nervous system where they are processed, along with visual and vestibular information, to guide the performance of coordinated and agile actions (Jeka et al., 1998; Peterka, 2002). Sporting events are generally conducted on stable surfaces in well-lit environments where athletes rely on tactile and proprioceptive inputs from their somatosensory system to sense the subtle motions of the lower limbs (Collins and De Luca, 1995; Horak, 2006; Kars et al., 2009). Cutaneous tactile and proprioceptive mechanoreceptors, which are associated with touch, pressure, and kinesthesia, are abundant on the plantar aspect of the foot (Kennedy and Inglis, 2002). These mechanoreceptors are critical for providing an athlete with information about static and dynamic posture, stability, and joint position while performing coordinated and agile motions (Do et al., 1990; Perry et al., 2000).

An estimated 125 million people participate in sporting activities in the United States (Humphreys and Ruseski, 2009). Many of these healthy athletes attempt to enhance their performance by bolstering their somatosensory system with wearable devices (braces, sleeves, and insoles). These devices are suggested to improve, in part, the proprioceptive feedback obtained from cutaneous mechanoreceptors and subcutaneous muscle spindles in order to enhance sensation, proprioception, and ultimately performance. The abundant cutaneous skin receptors on the plantar aspect of the foot provide important control information about tactile sensation, balance, and proprioception (Kennedy and Inglis, 2002). These cutaneous receptors provide an opportunity

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for developing sports equipment as they provide a potential interface for directly applying stimulations to enhance the somatosensory system.

Sensory enhancing insoles, using stochastic resonance technology, are known to improve postural sway and reduce gait variability of healthy individuals, in patients with stroke, and of patients post diabetic neuropathy (Galica et al., 2009; Lipsitz et al., 2015; Priplata et al., 2002, 2003, 2006; Stephen et al., 2012). Stochastic resonance (SR) refers to a phenomenon in non-linear biological systems where sensory signal recognition is enhanced by the introduction of low levels of uncorrelated input noise. The mechanism by which SR improves sensitivity is most likely a partial depolarization of the receptor membrane, biasing the receptor closer to its action potential firing threshold (Cordo et al., 1996; Priplata et al., 2003). When applied to mechanoreceptors, including cutaneous, muscle spindle, and ligamentous receptors, mechanical SR vibration improves touch sensation, joint position sense, and balance when set at a level below the sensation threshold (Priplata et al., 2006).

Training to enhance balance has been shown to improve athletic performance (Hrysomallis, 2011). A link between the positive balance and walking outcomes afforded by sensory enhancing insoles and improved athletic performance appears obvious. In fact, data from Ross et al. (2007) suggests that sub-threshold SR stimulation in combination with coordination training enhances postural stability. Although compelling, the standing balance and steady state walking tasks performed during these studies do not effectively measure athletic performance, and many questions remain regarding the efficacy of sub-threshold SR stimulation on specific athletic performance measures such as agility.

An agility task is a rapid, whole-body changes of direction or speed in response to an activity requiring stimulus (Dawes and Roozen, 2012). For all athletes, the ability to quickly change direction is often the difference between success and failure. Therefore, agility is one of the most common variables measured during athletic performance testing. The hexagonal agility test is a routine test used by coaches and athletic trainers to measure agility (Baechle and Earle, 2008; Dawes and Roozen, 2012; Hoffman, 2006). It is a simple and easy to learn test that can be performed in a confined space, making it ideal for evaluating agility in a laboratory environment.

The purpose of this study was to examine the effects of SR stimulation to the plantar surface of the feet during a task aimed at assessing athletic performance (agility) in healthy recreational athletes. We hypothesized that mechanical SR would decrease the task time and hopping error in healthy active participants during a hexagonal agility task because the proprioceptive and balance improvements gained by SR stimulation to the plantar feet may translate to improvements in agility, a component of athletic performance.

2. Methods

2.1. Research participants

The Harvard Medical School institutional review board approved all experimental procedures and recruitment materials used for this study. Twenty recreational athletes (8 female, 12 male; 24.2 ± 4.7 years old) were enrolled in this study. The self-reported inclusion criteria were: 1) 18–40 years old; 2) no prior medical history of major injuries or pathologies (such as a fracture, ligament tear/sprain, arthritis) to either ankle, knee, or hip that resulted in hospitalization or enrollment in a rehabilitation/therapy program; 3) no chronic disease; 4) no neurological, visual, vestibular, or balance disorders; 5) no systemic infection at the time of the study; 6) not pregnant; 7) no tobacco or recreational drug use; 8), fluent in English (due to language limitations of the research team); 9) exercise at least three hours a week; and 10) a Tegner activity score of four or greater (Tegner and Lysholm, 1985). An additional criteria determined by the research team included a vibratory SR perception threshold within 10 – 100% of the stimulation amplitude of the insole device. This permitted the device to be set to the stimulation range used successfully in previous studies.

Participants were asked to bring their own shoes to the study visit and remove the original insoles. Upon granting their informed consent, each participant donned an athletic shirt, shorts, and socks provided by the research team. Five retro-reflective surface markers were placed on each shoe and ankle in the following locations: first and fifth metatarsal heads, medial and lateral malleolus, and the heel. An additional four markers were rigidly affixed to a contoured plastic plate that was secured to the dorsal aspect of each shoe.

2.2. Insole device

Three-quarter-length vibratory insoles were fitted prior to beginning any study procedures (Fig. 1). Two piezoelectric actuators were placed two centimeters apart in the middle arch region of the insole to deliver SR vibratory stimulation to the plantar foot. These actuators were positioned within urethane foam and double insulated to avoid direct contact with the participant's foot. Lipsitz et al. (2015) has previously described the vibratory insole device in detail. The electrical circuit components and control software for each insole were tethered to the participant by a 30-foot cable. These cables were routed along the legs and away from the participant to allow the study task to be conducted safely without the risk of tripping. The vibrating insole devices used in this study are still investigational. All devices have been approved by the Harvard Medical School institutional review board and labeled as non-significant risk devices.

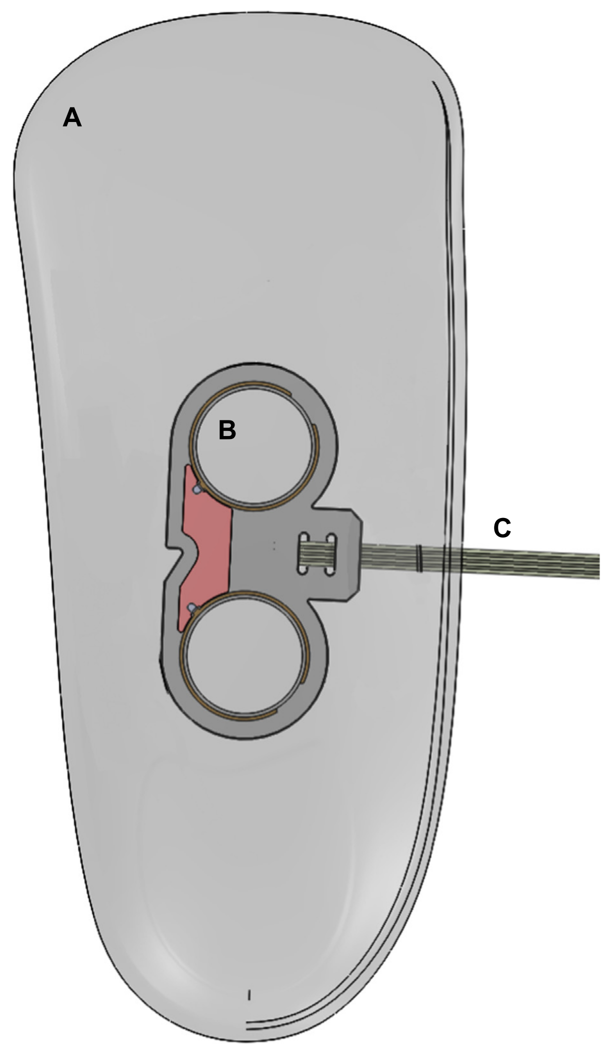

Fig. 1. The top view schematic of the ¾ length insole (A) device. The two circular piezoelectric actuators (B) are seated in a custom harness that is embedded in the urethane foam and double insulated to avoid direct contact with the participant's foot. A cable (C) exits the medial side of the insole and connects the piezoelectric actuators to the computer tablet control software.