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Reduced lower leg muscle activity while balancing on cobblestone shaped surfaces

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ABSTRACT

The purpose of this study was to test the hypothesis that muscle intensity and ankle joint motion will be greater when balancing on a surface shaped like a cobblestone pathway than on a smooth surface. Nineteen healthy male and female subjects participated in this study. Electromyographic (EMG) activity of the soleus, gastrocnemii medialis and lateralis, peroneus longus and tibialis anterior and ankle dorsiflexion/plantarflexion and eversion/inversion were recorded for unilateral balancing tasks on a hard smooth (control), soft smooth and two cobblestone shaped balance surfaces. Mean ankle kinematics did not differ between conditions. EMG intensity of the lower leg muscles were significant lower for the cobblestone shaped surface than for the control surface (−40 to −80%; $P < .01$). EMG intensity of the lower leg muscles were significantly higher for the soft smooth surface than for the control surface (+12 to +30%; $P < .01$). Different balance strategies or tendon stretching may be responsible for these differences. Not only material properties but also surface shape of balance surfaces should be considered to optimize training output and tailored to the specific goal of a training regimen.

1. Introduction

Training on unstable and uneven surfaces is a common component of lower leg rehabilitation training and may benefit rehabilitation by improving neuromuscular performance [1–5] and be an effective form of prevention [6]. Indications range from acute athletic injuries [2] to chronic conditions involving balance dysfunction [4]. The concept underlying training on unstable surfaces is to improve neuromuscular control in physiological settings. To maintain balance and prevent falling, the center of mass must remain within the base of support which is achieved through a complex process of position adjustments by muscles acting across joints and controlled by the central nervous system [7]. The sensory input includes visual feedback and feedback from the vestibular organ, stretch and velocity sensitive receptors in joints, muscles, tendons and ligament structures, and cutaneous receptors such as pressure receptors on the foot sole [8–10].

To date, only few studies have investigated the role of cutaneous receptors on the plantar surface of the foot in providing feedback for balance control. For instance, Maurer et al. [11] have shown that in the absence of visual and vestibular cues, somatosensory afferent input from the feet enables subjects to maintain balance. This feedback includes afferent input from receptors on the foot sole, but also input from deep proprioceptive sensors in the muscles and tendon structures. Moreover, Kavounoudias et al. [12] reported that the COP always moved away from the location of the stimulus when the anterior and posterior regions of the foot was stimulated with a vibration stimulus, and concluded that the plantar surface serves as a "dynamometric map" for balance control.

While afferent pathways of the foot sole appear to affect balance control, the specific characteristics of a stimulus that evokes a physiologically meaningful sensation are still unknown. Stimuli can have different intensities and may be applied to different locations and across different size areas. Previous studies [11,12] have applied vibration stimuli either to the forefoot or to the heel region. However, to date the effect of a stimulus applied to the foot arch where the pressure distribution is usually less pronounced than in the heel and forefoot area is unknown. Sensitivity not only depends on the density of the receptor

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distribution but also on the morphological type of the receptors [13]. Slowly adapting receptors are sensitive to skin deformation caused by a longer pressure stimulus. In comparison, rapidly adapting receptors respond to skin deformations lasting between 50 and 500 ms. Moreover, pacinian corpuscles sense the acceleration of skin deformation. The combined afferent sensory feedback is used by the CNS to generate a spatial and temporal movement representation.

Proprioceptive training devices represent a disturbance to the human balance and hence challenge the body's neuromuscular control. A range of proprioceptive devices including different types of balance platforms, tilting mats, and wobbling mats are commercially available. The textures of proprioceptive training devices should ensure a safe interface between the foot and surface, and hence the surface material should minimize sliding effects especially when training barefoot. This is commonly achieved by special surface material or specific structures such as rims or bumps. However, to date the effect of surface structure on neuromuscular control has not been investigated.

The purpose of this study was to determine the effect of surface shape on neuromuscular control during a step-balancing task. We hypothesized that muscle intensity and ankle joint motion will be greater when balancing on a surface shaped like a cobblestone pathway than on a smooth surface.

2. Methods

Nineteen healthy subjects (9 female, 10 male; age: 25.6 ± 1.6 years; body height: 175 ± 8 cm; body mass: 69.1 ± 9.3 kg) participated in this study after providing written informed. The study protocol was approved by the local ethics committee and conducted in accordance with the Declaration of Helsinki.

2.1. Testing procedures

Each subject performed a step-balancing task. Subjects were asked to perform repeated steps onto one leg and to maintain balance for 10 s for each step. Data were recorded for five successive steps for each condition. The first condition was the flat surface of a force plate (Kistler, Winterthur, Switzerland; control condition). For all conditions, the vertical ground reaction force (F_z) was recorded and served as a trigger signal for averaging the electromyographic (EMG) signals relative to the first ground contact. The testing mats were placed on an oval marked area on the Kistler force plate. Trials on the experimental conditions were tested in randomized order.

2.2. Experimental conditions

After the control condition, we tested three experimental conditions. Subjects performed the same balancing tasks on a balance pad (Thera-Band, Dornburg, Germany) and on two mats with a cobblestone shaped surface (Fig. 1). The balance pad was oval shaped with a length of 35.5 cm and a width of 19.5 cm. The cobblestone mats were oval shaped with a length of 43.0 cm and width of 25.5 cm. The mats differed in hardness and in the number of "stones". The yellow surface had a durometer of 30 and 66 convex "stones". The black mat was harder (durometer of 70) with 62 "stones". The stones in both mats had a 4 cm diameter and an average height of 1.5 cm.

2.3. Electromyography

Surface EMG was recorded from the right soleus, medial and lateral heads of the gastrocnemius, tibialis anterior and peroneus longus muscles. The surface electrodes were placed over the muscle belly of the corresponding muscle following the recommendation of the SENIAM project group (www.seniam.org) [14]. Before placing the electrodes, the area of skin was shaved and rubbed with fine sandpaper to minimize skin impedance. Inter-electrode distance was 2 cm. EMG signals, force curves and goniometer signals were recorded using the Telemyo 2400T system (Noraxon USA, Scottsdale, AZ) and stored on a PC for further processing and analysis. The recording frequency was 1500 Hz for all channels. An integrated band pass filter of 10–500 Hz was applied to the EMG signals to avoid noise artifacts. Further analysis was performed using the software Myoresearch (Noraxon USA, Scottsdale, AZ). The EMG signals were rectified, and a trigger was set to ground contact from the Kistler plate. For the step-balancing task, mean amplitude was calculated for 500 ms before and 10 s after ground contact for each channel and for each step. Data for all steps were averaged for each condition. Because EMG data were

Fig. 1. Photograph of the experimental conditions. From left to right: balance pad (green), soft cobblestone mat (yellow), hard cobblestone mat (black). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)