A Novel MRI-compatible Tactile Stimulator for Cortical Mapping of Foot Sole Pressure Stimuli with fMRI

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Introduction: Foot sole somatosensation plays a critical role among the active feedback loops that contribute to the control of balance when standing and walking. Aging and disease often impair foot sole somatosensation, and consequently, decrease balance and increase the risk of falling [1, 2]. The neural circuits underlying foot sole somatosensation, their relationship to balance control and the mechanisms of neural adaptation that optimize behavior in the presence of acute and sensory impairment are poorly understood. The purpose of this study was to develop and evaluate an MRI-compatible tactile stimulator system capable of applying controlled patterns of pressure to the foot sole designed to mimic those experienced when standing or walking.

Methods: The foot sole stimulator consists of a control unit, an aluminum pneumatic actuator, foot supports, and platform made from non-ferromagnetic materials (Figure 1). A control unit (i.e., computer program, AD/DA interface, and voltage-controlled current amplifier) governs an air compressor, which drives the pneumatic actuator to apply pressure to the foot sole with specific amplitude and frequency characteristics. The subject's leg and foot is secured to the foot support. The ankle is fixed in a comfortable position, and the hip and knee are flexed in order to minimize movements of the head during pressure application. To test MRI-compatibility, scans (see acquisition parameters below) were acquired from a spherical NaCI phantom under the following conditions: 1) foot sole stimulator in the room, powered off; 2) foot sole stimulator in the room, powered-on; 3) no stimulator presents (control). To determine functionality of the stimulator, a gradient-recalled echo planar imaging (GRE-EPI) sequence was completed in 4 healthy adults (2 women, 2 men, aged 23-25), using a block design protocol. 30sec blocks of stimulation were alternated with 30sec blocks of no stimulation for 6min. Stimulation consisted of a oscillating force (1Hz) applied to approximately 10% of the foot sole surface over the head of the first metatarsal, with maximum force equal to 10% of the subject's body weight. Imaging parameters were: TR=2000ms, TE=30ms, flip angle=90°, matrix=64 X 64, thickness/spacing=4/1mm. We acquired 33 interleaved axial slices. Functional images were motion-corrected and co-registered on corresponding T1-weighted anatomical images to facilitate transformation to Montreal Neurological Institute (MNI) T1 template and resampling of functional images to isotropic $2\times2\times2 mm^3$ voxels. The regional BOLD response to stimulation was determined by general linear model (GLM).

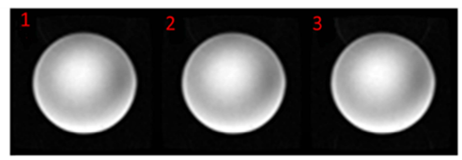

Figure 2: Effects on imaging quality tested by EPI scans acquired from a spherical NaCl phantom: 1) foot sole tactile stimulator in the room, powered off; 2) foot sole tactile stimulator in the room, powered-on; 3) no stimulator present (control).

Results: Image quality was not affected by the foot sole stimulator in either the "on" or "off" position (Figure 2). Foot sole pressure stimulation resulted in the cortical activation pattern illustrated in Figure 3. Activation was observed contralaterally within the primary somatosensory cortex S1 (postcentral gyrus, Brodmann area (BA) 2, 1) and paracentral gyrus (BA 4); and bilaterally within the secondary somatosensory cortex S2 (inferior parietal lobule, BA 40) and cerebellum regions (Uncorrected cluster level $P<0.001$, $k>20$).

Conclusions: The foot sole stimulator does not interfere with MR image quality and does not cause motion artifacts with applied load. Applied foot pressures produced significant brain activation as evidenced from BOLD imaging in healthy young adults. This device is therefore feasible for use in MR imaging experiments designed to study functional brain networks involved in the perception and modulation of foot sole somatosensation related to human walking.

References:

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[2] Novak P, Novak V: Effect of step-synchronized vibration stimulation of soles upon gait in Parkinson's disease: A pilot study. Journal of NeuroEngineering & Rehabilitation, May 3:9, 2006.

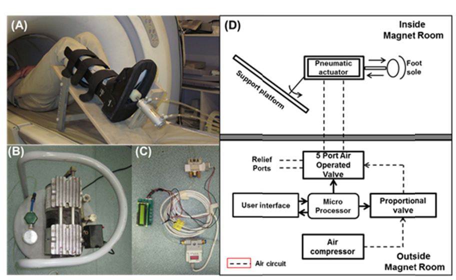

Figure 1: Foot sole pressure stimulation is applied to the foot via an aluminum pneumatic actuator attached to a support platform (A). The frequency and magnitude of stimulation is regulated by a micro-control unit (C), which is outfitted with electronic valves (C) that are driven by an air compressor (B). The micro-control unit and air compressor are located outside of the magnet room (D, lower panel) and attached to the non-ferromagnetic actuator and platform (D, upper panel) via plastic air tubes.

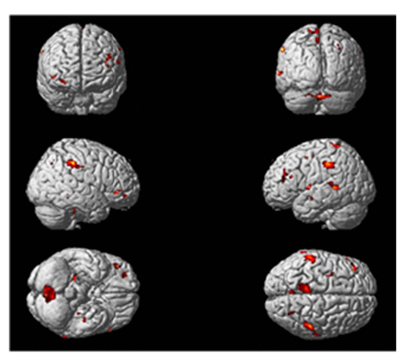

Figure 3: The BOLD response to pressure stimulation on the foot sole in healthy young adults.