A NOVEL FMRI-COMPATIBLE DEVICE TO QUANTIFY THE CORTICAL RESPONSE TO WALKING-RELATED FOOT SOLE PRESSURES

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Introduction

Foot sole somatosensation is an important source of feedback for the control of balance. Recent studies indicate that some older adults with lower-extremity somatosensory impairment can compensate and maintain balance during standing and walking (1). To enable investigation of the sensori-motor brain networks involved in this type of afferent feedback in health and disease, we aimed to establish a MRI-compatible foot sole stimulator capable of applying controlled forces to the foot sole, thus mimicking those experienced when walking. We recently demonstrated that the application of pressure to a small area of the foot elicits a characteristic pattern of brain activation in healthy adults (2). The purpose of this experiment was to improve upon our previously published device. Specifically, we aimed develop and evaluate a new MRI-compatible system capable of applying a force waveform to the entire foot sole, so as to more accurately replicate those pressures experienced by the foot during the stance phase of the walking cycle.

Materials and Methods

The stimulation system consists of a control unit, an air-compressor and two aluminum pneumatic actuators attached to a support platform (Fig. 1A). Air flow to the two actuators is modulated with a certain phase shift to produce in-plane oscillations with preset frequencies and magnitudes (Fig.1B).

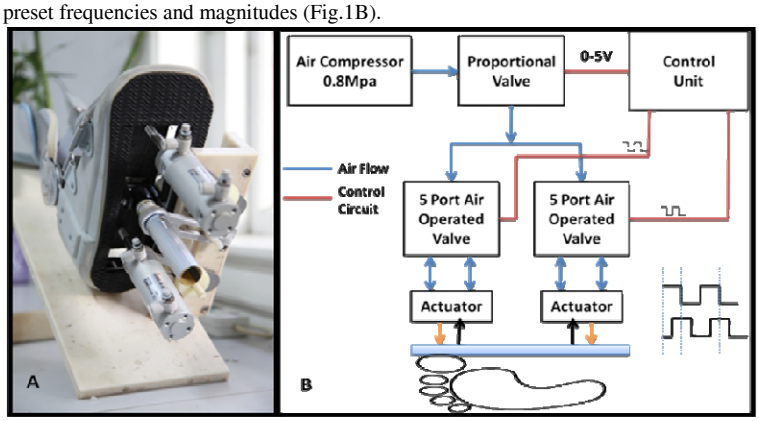

Fig 1. (A) Actuators attached to nylon platform. (B) Control system scheme.

Force Curve Recording:

Four mini sensors (Flexiforce A201, Tekscan Inc. USA) (3) were used to quantify the forces experienced by the foot during over ground walking, and during the replication of walking forces as applied by our device (Fig. 2B). Force curves (i.e., output voltage of the sensors) from one "stance phase" are shown in Fig.2A, for both real and simulated walking.

FMRI compatibility and activation Test:

A gradient-recalled echo planar imaging (GRE-EPI) sequence was utilized on a GE 3T scanner with the acquisition parameters as: TR = 2000ms, TE = 30ms, flip angle = 90°, matrix = 64×64, thickness/spacing = 4mm/1mm, FOV = 24*24 cm, 33 interleaved axial slices. Visual inspection and SNR/SFNR were done to validate the compatibility of the device. Furthermore, a 30s on-off block designed stimulus was applied to the right foot sole for 3.5 minutes on 3 subjects during the functional scan to explore the activation pattern in response to the simulated walking pressure. SPM was applied to calculate the functional activation map. Head Motion was monitored by head motion parameters in SPM.

Results

Standard SNR/SFNR and visual inspection revealed no statistically significance differences with the device powered on, powered off, or absent. Head motion in the three subjects was less than 1mm for every direction and less than 1 degree for any transformation. Head motions about the Z axis were significantly higher than the other directions for all three subjects. The block-designed experiment revealed that foot stimulation activated the contralateral S1,M1,SMA (BA2, BA4 and BA6) and bilateral S2(BA 40), after FWE correction. Moreover, with uncorrected p<0.001, activations were also observed within the cerebellum in all three subjects, and with the bilateral insular in two of three subjects.

Discussion and Conclusion

As compared to previous devices (2,4,5), our foot sole stimulation device enabled accurate replication of the foot sole pressures experienced when walking, while the subject lied motionless in the MR scanner. It did not interfere with image quality and did not cause significant motion artifact. This system is thus feasible for fMRI studies and can be used to explore the functional brain networks involved in the perception and modulation of walking-related foot sole stimuli.

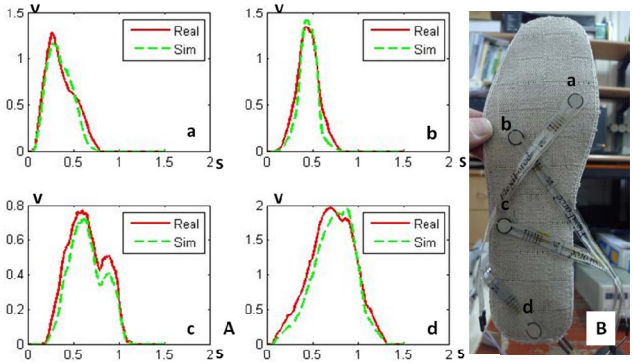

Fig 2.(A) The force curves recorded by mini force sensors during a single stance phase of walking over ground (red line), and as replicated by the foot sole stimulation system (green line) (B) Depiction of the location of the four sensors.

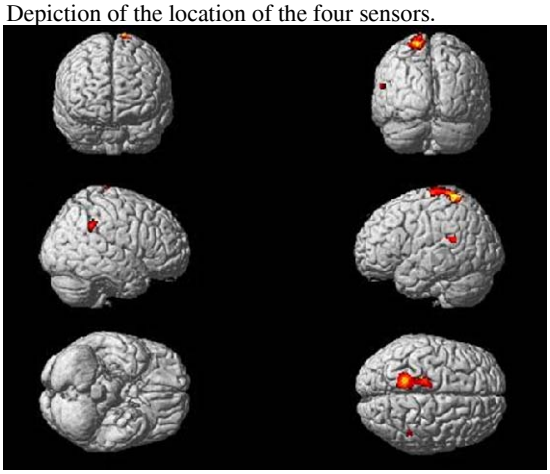

Fig 3 Representative brain activation map reflecting the cortical response to walking-related foot sole pressure stimuli (FWE corrected p<0.05, k>30).

References

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