Somatotopic Mapping of Individual Fingers with a novel Vibrotactile Stimulator using BOLD fMRI at 3T

Sunil K. Valaparla[1,2], Hsiao-Ying (Monica) Wey[1,2], William E. Rogers[1], Jinqi Li[1], Geoffrey D Clarke[2], and Timothy Q. Duong[1,2]

[1]*Research Imaging Institute, University of Texas Health Science Center San Antonio, San Antonio, Texas, United States,* [2]*Radiology, University of Texas Health Science Center San Antonio, San Antonio, Texas, United States*

Introduction

Mapping fine-scale spatial layout of the finger areas in the human primary somatosensory (S1) cortex is useful for understanding perception, attention and modulation of sensory inputs to cortex. Precise functional organization of S1 cortex can be produced by high resolution fMRI, essential to illustrate the topographical layout of specific body parts, but also unravel the pronounced disproportions for some neuronal representations that reflect differences in peripheral neurological disorders. Delineating fine-scale somatotopy of the fingers is necessary for understanding certain disorders as in stroke, hypoesthesia, focal hand dystonia, and for drawing parallels between the finger organization in human and nonhuman primates which provide an essential link in understanding the neural basis for human somatic sensation. High-resolution somatotopic mapping using BOLD fMRI remains an active area of research.

In this study, we designed and constructed a MRI-compatible stimulator that is applicable for a wide-range of stimulation frequencies, implemented high-resolution fMRI studies with 1.5 mm isotropic resolution to map human finger somatosensory cortex (S1), mapped out the tuning curve as a function of stimulation frequency, and applied the optimal conditions to map finger somatotopy.

Methods

The vibro-tactile stimulator consists of five units, each housed inside a 10x2.5 cm rectangular casing and a hole of 1.5cm diameter was made on the top end of the casing which functions as the sole region of contact with the subject's fingers. Each unit consists of a flexible mechanical shaft driven by an adjustable microprocessor control box. The use of a shaft for the transmission of the mechanical energy enables exact definition of the vibration frequency and the vibration amplitude. The electrical input to the vibro-tactile device is regulated using a control box and the regulation of the control box occurs via a desktop computer and the control is initiated from the software program. Four BOLD fMRI sessions were performed on three normal subjects (25-30 yo). MRI studies were performed on 3T Siemens TIM TRIO with a 12-channel head coil. BOLD fMRI was acquired using EPI with TR=2s, TE=30ms, FOV=12.8x12.8, 1.5mm isotropic resolution, 24 slices, TA=3min & 20s.

Experiment #1 (tuning curve): Seven fMRI stimulation trials were measured in each session with different vibro-tactile stimulation frequency (10, 20, 40, 60, 80, 100,120 Hz) in a randomized order. Subject was scanned with all the five fingers of the right hand placed on the stimulator, stimulating all at once, and was instructed to keep their eyes opened during the experiment. Stimulation paradigm used a block design of six 20s rest /10 sec activation epochs and end with a rest period.

Experiment #2 (somatotopy): In two subjects, 20 Hz stimulations were applied on each finger of the right hand in a random order (F_1-F_4-F_2-F_5-F_3) using a different experimental paradigm which used a block design of initial 20 sec rest and then each finger was stimulated for 3secs with 1 sec rest between the fingers. The paradigm consists of 20 epochs, 210 dynamics with a total time of 7min & 6s.

Data were processed using FMRIB Software Library (FSL) including motion correction, spatial smoothing (3 mm FWHM), co-registration, and GLM (FEAT). One way ANOVA was used to compare % BOLD at different frequencies. Activation maps were threshold to Z>2.3 (p<0.01).

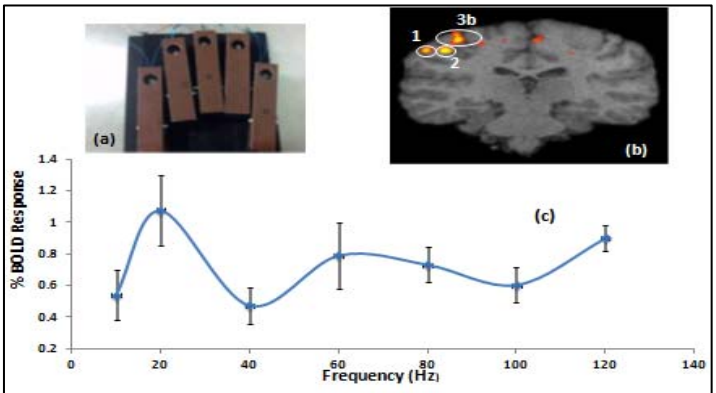

Figure 1. (a) Vibro-tactile Stimulator (b) BOLD fMRI Activation map of 20Hz vibro-tactile stimulation overlaid onto anatomy from a single subject showing Brodmann areas 3b, 1 and 2 on the S1 cortex (c) Group averaged % BOLD Response at various frequencies (mean ± S.D, N = 4, p < 0.01).

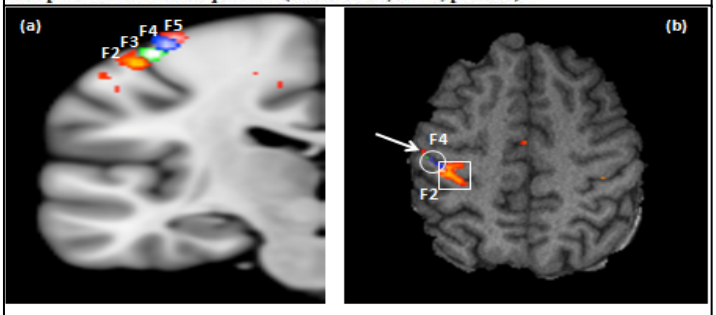

Figure 2. (a) Single subject activation in S1 cortex from stimuli of the index (F_2, red-yellow), the middle finger (F_3, green-white), the ring finger (F_4, blue-white), and the little finger (F_5, red-white) at 1.5^3 mm^3 spatial resolution(z-score: 2.3 - 4.0, p < 0.01) (b) Activation maps of F_2 & F_4 overlaid on the anatomical T1 image of a single subject (arrow : central sulcus).

Results and Discussions The proposed stimulator was constructed entirely from non-ferromagnetic parts, uses magneto-mechanical principles which rely on the Lorentz forces generated from small oscillatory currents through coils in the device to deliver stimulation using computer control, and stimulate the receptors of each finger separately or in combinations to ensure robust somatosensory activations.

Figure 1(a) displays the vibro-tactile stimulator; **1(b)** shows the fMRI activation map from a representative subject at 20Hz. The activation was localized within the central sulcus and the post-central gyrus encompassed area 3b on the primary somatosensory cortex S1, **1(c)** shows the group–averaged frequency-response curve showed a strong peak BOLD response at 20 Hz. At this particular frequency, the Meissner corpuscle responsible for the tap, flatter sensation is activated (5-40 Hz). We also found a peak BOLD response at ~60Hz and at ~120Hz. At frequencies around 60 Hz, a vibratory stimulus also activates muscle spindle endings and the cutaneous Pacinian corpuscles. The signals from these corpuscles are synchronously mediated through the nervous system. The 120Hz peak response has been previously reported to be associated with the optimal frequency for vibration sensation (Pacinian corpuscles) around the range (80-300Hz).

Figure 2 (a) shows the BOLD activation map with right hand four-finger discrimination (F_2-F_3-F_4-F_5) overlaid on the Colin brain template. The locations of the activations were consistent with known finger somatotopic mapping.

Conclusions We implemented high-resolution fMRI protocol with 1.5^3 mm^3 spatial resolution to map the tuning curve and map the finger somatotopy (S1). Studies are ongoing to investigate the spatial discrimination of each finger and combination of fingers based on the talairach co-ordinates of the activation maps and also to calculate the inter-digit Euclidean distance. Future studies will also investigate higher stimulation frequency and mapping digit representation in the cerebellum.

References: 1. Nelson, Cereb Cortex 18, 421(2008) 2. Sanchez-Panchuelo, J Neurophysiol103 (2010) 3. Briggs, MRM 51:640-643 (2004) 4. Weibull, MRI 26:1342-1351(2008) 5. Schweize, NI 42:28 (2008).