High Resolution Functional Mapping of Spatiotemporal Vibrotactile Stimuli Reveals Differential Areal and Laminar Activations in Somatosensory Cortex

Robert Friedman[1], Feng Wang[1], Chaohui Tang[1], Anna Roe[1], and Malcolm Avison[1]
[1]*Vanderbilt University, Nashville, TN, United States*

Introduction

The cortical processing of spatiotemporal tactile stimulation of the skin is poorly understood. For instance, is simultaneity of stimulation at different sites on the skin processed differently than sequential stimulation? Is the perceptual window of simultaneity reflected in primary cortical areas? Our functional studies on the tactile funneling illusion suggest yes. However, a comparison between simultaneous and sequential stimulation with inter-stimulus intervals (ISIs) on the order of milliseconds has yet to be performed. To examine the cortical correlates of spatiotemporal information processing, we therefore used high resolution CBV-based fMRI to map cortical responses to vibrotactile stimuli presented simultaneously or sequentially to adjacent digits in isoflurane-anesthetized squirrel monkeys. We observed significantly greater activation in area 3b of somatosensory cortex in response to sequential compared with simultaneous multisite stimulation. Laminar analysis revealed greater activations in infra- and supragranular cortical layers with sequential stimulation.

Methods

Squirrel monkeys were anesthetized (isoflurane 0.5-0.8%), mechanically ventilated, and the head was stabilized in an MR compatible frame. Vital signs were monitored and maintained throughout the imaging session. MR images were acquired with a 9.4T Varian Inova scanner using a 3 cm transmit/receive surface coil positioned over primary somatosensory cortex. T2*-weighted gradient echo structural images (TR/TE 200/16 ms, 16 slices, 512X512 matrix; 78x78x500 μm^3 resolution) were acquired to identify cortical venous structures that were used to locate SI cortex and provide structural features for coregistration of fMRI maps across imaging sessions. Vibrotactile stimuli delivered with piezoceramic actuators (Noliac) consisted of either 1 or 8 Hz trains of 20 ms duration taps. Three adjacent distal finger pads were tapped (20 ms square wave) either: (1) individually; (2) simultaneously, evoking a funneled percept; (3) sequentially with no ISI, eliciting an apparent motion sensation; and (4) sequentially with an ISI of 200 ms that is perceived as a sequential series of taps. Each stimulus was delivered in 7 blocks of 30 s followed by 30 s rest. Activation-associated CBV changes were mapped using conventional multi-slice gradient echo EPI (2-shot, TR/TE 750/10 ms; 4 slices; voxel dimensions 0.625x0.625x2 mm^3). Slice stacks were centered on contralateral area 3b and oriented parallel to the cortical surface to map areal responses, and trans-cortically to monitor the laminar distribution of activation. Functional mapping began 10 minutes after a slow i.v. bolus of MION (12-16 mg/kg). All study procedures were approved by the Vanderbilt IACUC. Data were identically analyzed: individual imaging runs were pre-conditioned using standard high- and low-pass filters for drift correction and removal of high frequency noise, then runs using the same functional contrast were combined to generate functional maps thresholded at $p<10^{-4}$ (uncorrected), k=2. The amplitude and area of activation in different cortical areas were determined and compared.

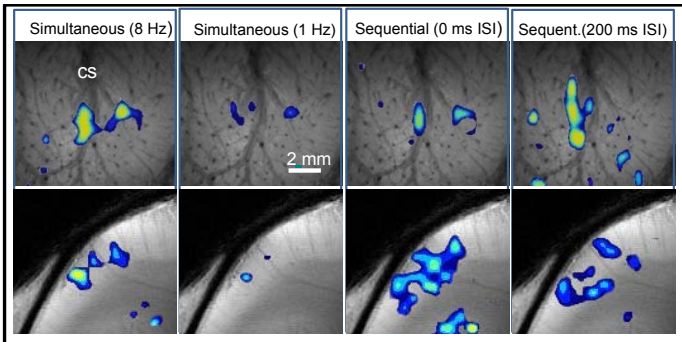

Fig. 1: Activation maps collected under different conditions of spatiotemporal vibrotactile stimulation of 3 adjacent finger pads. **Top Row:** Somatosensory area 3b is located just to the left of the central sulcus (CS); area 1 is on the right. **Bottom Row:** Transcortical coronal slice through area 3b.

Results

Multi-digit stimulation elicited distinct activations in areas 3b and 1. Simultaneous stimulation of all three digits led to an area of activation that was smaller than what would have been predicted from a linear sum of the activations produced by individual digit stimulation. In contrast, sequential tapping led to greater activity in areas 3b and 1 than that expected from individual digit stimulation. Coronal slices oriented trans-cortically through areas 3b and 1 revealed that cortical activation to single finger stimulation or simultaneous stimulation of multiple digits was limited to middle layers, whereas sequential tapping of the digits evoked activation that spanned a wide extent of the gray matter.

Discussion

These findings suggest that the cortical columnar processing of spatial-temporal stimulation differs from single digit or simultaneous multi-digit stimulation. The relationship between the differences in the laminar activity in primary somatosensory cortical areas and the perception of simultaneity, motion and the sensation of sequential stimulation is yet to be determined. Technically, the present data illustrate that at high field strengths, the increased functional contrast of CBV mapping can be exploited to reveal the columnar processing of information in primary sensory areas. Furthermore, CBV-fMRI can reveal differences in temporal neural processing allowing for studies of the dynamics of neural network processing.

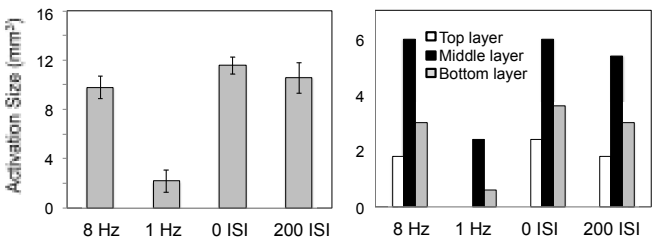

Fig. 2: Influence of simultaneous and sequential multi-digit stimulation on cortical and transcortical laminar volumes of activation in area 3b.