Functional MRI of Somatosensory Gating

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Introduction

Somatosensory attention depends on a network of brain structures that selectively inhibits (gates) task-irrelevant sensory inputs and facilitates task-relevant inputs [1]. Damage to this network (e.g. due to stroke) can result in *extinction*, a difficulty detecting contralesional tactile stimuli in the presence of simultaneous ipsilesional stimuli [2]. To explore somatosensory gating and the brain structures involved, a tactile fMRI paradigm, modelled after Chao and Knight's auditory distraction experiments [3], was tested in healthy, young adults. The presence of a left-handed distractor as well as the delay between the right-handed cue and probe were varied in this event-related, delayed tactile discrimination paradigm.

Methods

Ten healthy, right-handed volunteers (6 male, 4 female; mean age 22.0 years) participated in the study. Magnetomechanical vibrotactile devices (MVDs) [4] were taped under the thumb of each hand for stimulus presentation, and subjects made right-handed responses using a response pad with two buttons (Fig. 1). The MVDs and the response pad were connected to a computer running Labview (National Instruments, Austin, TX). All imaging was performed with a Signa VH/i 3.0 T scanner and quadrature birdcage head coil (GE Medical Systems, Waukesha, WI). A single-shot spiral sequence [5] was used for BOLD fMRI (TR/TE/flip = 2000 ms/30 ms/70°, matrix 64 × 64, FoV 20 cm, and 26 axial slices 5 mm thick).

The stimulus amplitude was fixed for each subject at seven times their perceptual threshold. The stimulus frequency was 25 Hz for the cue and the distractor, and either 25 Hz (Same) or 25 + f Hz (Different) for the probe, where f (≤ 10) was determined during practice trials to yield an 80% correct accuracy rate. Each 30 s experimental trial began with a 2 s cue to the right thumb, followed by either a 2 s (Short) delay (in half the trials) or an 8 s (Long) delay. After a 2 s probe to the right thumb, which could be either a Same probe (in half the trials) or a Different probe, the subject responded with the right index finger or middle finger, respectively. In a quarter of the trials, the probe was accompanied by a distractor presented simultaneously to the left thumb. Subjects were instructed to respond as quickly as possible after the offset of the probe while maintaining high accuracy. Each of four runs consisted of 16 trials, (3 No Distractor + 1 Distractor) × 2 Delays × 2 Probes, in random order, for a total of 64 trials.

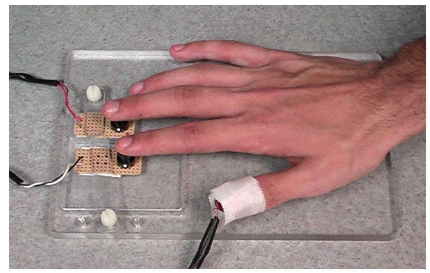

FIG. 1. MVD for tactile stimuli to thumb and response pad for button responses.

Accuracy (% correct) was calculated for each condition and subjected to repeated measures ANOVA (SPSS; SPSS, Chicago) with a full within-subjects Distractor × Delay × Probe model. Mean response times (for correct responses only) were analyzed similarly, using a maximum likelihood algorithm to account for missing data (BMDP-5V; BMDP Statistical Software, Los Angeles). The reconstructed fMRI data were processed in AFNI [6]. For each subject, the images were motion-corrected and a deconvolution procedure was used to estimate the system response to the probe in each condition. Percent change maps were formed from the integrated responses, normalized to Talairach-Tournoux space, and blurred with a 5 mm FWHM Gaussian filter. Linear contrasts of these maps for all subjects underwent one-way t-tests to generate group maps for all Distractor × Delay × Probe main effects and interactions. Finally, the group maps were thresholded at $t(9) > 2.82$, $p < .02$, retaining activated clusters larger than 1.9 ml for an estimated overall $p = .05$ [7].

Results

In the accuracy data, there were significant main effects of Distractor, $F(1, 9) = 16.77$, $p = .003$; Delay, $F(1, 9) = 6.97$, $p = .03$; and Probe, $F(1, 9) = 6.50$, $p = .03$. The presence of the distractor, the Long delay interval, and the Different probe all led to lower accuracy. These effects were qualified by a significant Delay × Probe interaction, $F(1, 9) = 8.55$, $p = .02$, in which presentation of the Different probe led to lower accuracy only at the Long delay. In the response time data, only the main effect of Distractor was significant, $F(1, 9) = 13.91$, $p = .005$, but the direction of the effect did not suggest a speed-accuracy tradeoff. In the fMRI data, the presence of the distractor led to widespread increased activation in the bilateral medial, inferior, and superior parietal lobules, the right superior and middle temporal gyri, the left middle frontal gyrus, the right insula, and the right middle and medial frontal gyri (Fig. 2a). The distractor also led to decreased activation in the left precentral gyrus hand motor region. Interestingly, a Distractor × Delay interaction was observed in the right thalamus and posterior cingulate in which the distractor caused increased activation but only at the Short delay (Fig. 2b).

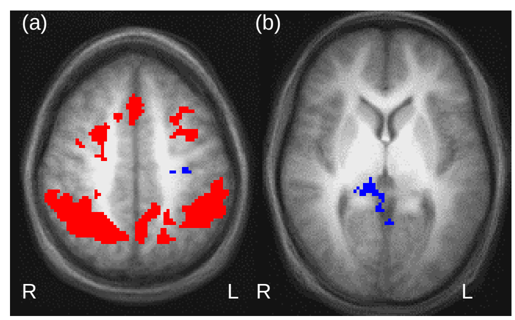

FIG. 2. Activation maps: (a) Distractor, (b) Distractor × Delay. Red = increased activation; Blue = decreased activation.

Discussion

As demonstrated by the effect of the distractor on both accuracy and response time, the tactile discrimination paradigm successfully engaged and challenged the somatosensory gating network even in healthy, young adults. Several relevant brain structures were identified in the activation maps, including parietal areas commonly associated with the sensorimotor system and frontal and temporal areas associated with motor action monitoring and spatial awareness. Of particular relevance to sensory gating was the Distractor × Delay interaction in the thalamus, an area associated with somatosensory extinction in humans after stroke [2] and that is often difficult to visualize with fMRI. This paradigm may therefore prove useful in the assessment of such stroke patients and their recovery. With more subjects, more detailed analyses of the role of distraction in somatosensory gating and working memory are possible.

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