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Research Report

Neural correlates supporting sensory discrimination after left hemisphere stroke

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ABSTRACT

Background: Nearly half of stroke patients have impaired sensory discrimination, however, the neural structures that support post-stroke sensory function have not been described. *Objectives:* 1) To evaluate the role of the primary somatosensory (S1) cortex in post-stroke sensory discrimination and 2) To determine the relationship between post-stroke sensory discrimination and structural integrity of the sensory component of the superior thalamic radiation (sSTR). *Methods:* 10 healthy adults and 10 individuals with left hemisphere stroke participated. Stroke participants completed sensory discrimination testing. An fMRI was conducted during right, impaired hand sensory discrimination. Fractional anisotropy and volume of the sSTR were quantified using diffusion tensor tractography. *Results:* Sensory discrimination was impaired in 60% of participants with left stroke. Peak activation in the left (S1) did not correlate with sensory discrimination ability, rather a more distributed pattern of activation was evident in post-stroke subjects with a positive correlation between peak activation in the parietal cortex and discrimination ability ($r=.70$, $p=.023$). The only brain region in which stroke participants had significantly different cortical activation than control participants was the precuneus. Region of interest analysis of the precuneus across stroke participants revealed a positive correlation between peak activation and sensory discrimination ability ($r=.77$, $p=.008$). The L/R ratio of sSTR fractional anisotropy also correlated with right hand sensory discrimination ($r=.69$, $p=.027$). *Conclusions:* Precuneus cortex, distributed parietal lobe activity, and microstructure of the sSTR support sensory discrimination after left hemisphere stroke.

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1. Introduction

During tactile sensory discrimination, the human hand differentiates salient object properties such as shape, texture, size, weight and stimulus location (Bodegord et al., 2001; Klatzky et al., 1985). Sensory discrimination impairment in the contralesional hand is found in approximately one-half of stroke patients in rehabilitation (Carey and Matyas, 2011). Because impaired hand function is associated with a decreased quality-of-life post-stroke, (Nichols-Larsen et al., 2005) there is a pressing need for effective hand rehabilitation. Extensive literature documents the relationship between the brain's structure and function in the post-stroke motor system; however, there is a paucity of literature on post-stroke sensory systems. One report of sensory discrimination recovery post-stroke found no activation within primary (S1)

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and secondary (S2) somatosensory cortex early post-stroke, with re-emergence of S1 and S2 activation as function returned to near normal levels in participants with mild residual impairment (Carey et al., 2002). Another reported increased activation within the post-central gyrus in association with a trend toward better motor function (Schaechter et al., 2006). Interestingly, an fMRI study of sensory-impaired participants with ventroposterior thalamic stroke found reduced activation of the affected sensory cortex, suggesting the need to examine axonal integrity in thalamocortical sensory projections (Taskin et al., 2006).

Functional imaging studies of healthy participants identified a bilateral network of structures activated during sensory discrimination that link S1 and S2 cortices with higher level sensory processing areas (posterior parietal, intraparietal cortices), attention (paracingulate (Hartmann et al., 2008), frontal operculum (Stoesz et al., 2003)), working memory (S2, frontal cortex (Hartmann et al., 2008)), and language centers in the temporal lobe (Kuroki et al., 2006). While there is some variability in this network, dependent on the object characteristics, a dominant role for the right hemisphere is consistently demonstrated, regardless of hand stimulated (Harada et al., 2004; Reed et al., 2004; Van Boven et al., 2005). A right hemispheric lateralization of proprioceptive spatial tasks has also been suggested, with right stroke participants demonstrating significantly more variability in spatial tasks (Dukelow et al., 2010).

Connectivity refers to the physical connections (axons, dendrites, synapses) linking brain regions (Johansen-Berg and Behrens, 2009). After stroke, a loss of connectivity occurs from direct damage to the axons or secondary degeneration of axons proximal or distal to the infarct site. Diffusion tensor tractography (DTT) is a method of modeling white matter pathways in the human brain in vivo. DTT allows quantification of white matter microstructural integrity (Johansen-Berg and Behrens, 2009) with fractional anisotropy (FA) being the most common metric. It is important to note that in vivo metrics of brain structure are indirect, and therefore, a direct relationship to axon structure should not be assumed. DTT has been used to study the relationship between infarct location and sensorimotor pathways, (Yamada et al., 2006) to quantify damage to the corticospinal tract (CST), (Schaechter et al., 2008) and to monitor recovery of motor function (Yang et al., 2008). A strong correlation between structural integrity of the CST and post-stroke motor function has been found. (Cho et al., 2007; Nelles et al., 2008; Schaechter et al., 2008; Yamada et al., 2003; Yang et al., 2008). The sensory component of the superior thalamic radiation (sSTR) includes all afferent connections to the somatosensory cortex, and thus, is the functional analogue of the CST; (Wakana et al., 2004) stroke-related structural changes to the sSTR may have relevance to post-stroke sensory function.

Particularly for the hand, motor and sensory function is inextricably linked, since the hand functions as a haptically-based sensory organ. An improved understanding of the neural substrates that support post-stroke sensory function in the hand is vital to the development of rehabilitation methods to maximize sensorimotor function. This report is an initial look at this understudied system and represents the first analysis of the relationship between functional activation within the sensory discrimination network, the micro- and macro-structural integrity of the sSTR, and post-stroke sensory function. Our hypotheses were straightforward: 1) in participants with left hemisphere stroke, we expected a positive relationship between sensory discrimination ability in the right hand and contralateral S1 activation, during sensory discrimination fMRI; 2) we also expected a positive relationship between sensory discrimination ability in the right hand and the structural integrity of the left sSTR.

2. Results

2.1. *Sensory function*

Sensory discrimination (HASTe) accuracy scores for stroke participants for the right (contralesional) hand ranged from 4 to 14/18 (mean = 10.5) and for left hand ranged from 8 to 16/18 (mean = 11.4). For the right hand, four participants scored in the normal range (>12), 5 participants scored between 8 and 11 indicating mild to moderate impairment, and 1 participant scored ≤ 6 (equivalent to chance), suggesting severe impairment (see Table 1). All participants who were impaired in their contralesional right hand were also impaired in their left hand.

2.2. *Functional magnetic resonance imaging*

The mean group effect (one-sample *t*-test) of brush discrimination for the right index finger indicated that control participants on average had significant activation in left S1, bilateral S2, right and left precentral gyrus, and right and left cerebellum. For the stroke group, the mean group effect was one cluster that peaked in the right superior temporal gyrus and extended to S2 and another peaking in the right cerebellum (Fig. 1a). A direct statistical comparison between stroke and control groups was conducted to look for mean group differences. This analysis used the whole-brain statistical maps and was unmasked, and therefore, not confined to a specific region(s) of interest (ROI). Stroke participants were significantly different in a cluster that peaked in the left precuneus ($z = 3.78$) compared to controls (Fig. 1b). ROI analysis of stroke and control group maps was completed by masking each group map with the left precuneus cluster to determine whether voxels in the ROI were activated or deactivated (positive or negative BOLD response). Mean Z-statistic in this ROI was −3.54 for the control group and −0.94 for the stroke group, indicating that stroke participants are significantly less deactivated in this area compared to control participants. To further explore the extent of precuneus activation, participant's individual statistical parametric maps (SPM) were masked with the precuneus cluster. Z-statistic values for this ROI ranged from 0.8 to 3.5.

2.3. *Diffusion tractography*

The left and right sSTR's were reconstructed from diffusion imaging data for all 10 left stroke participants. Individual participant FA and bundle volume values are listed in Table 1. Mean FA (with standard deviation) of the left sSTR = .414(.04),

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