Functional Neuroplasticity Related With Shoulder Proprioception In Patients With Recurrent Shoulder Instability

Hitoshi Shitara, MD, PhD, Daisuke Shimoyama, MD, Tsuyoshi Ichinose, MD, PhD, Atsushi Yamamoto, MD, PhD, Tsutomu Kobayashi, MD, PhD, Toshihisa Osawa, MD, PhD, Kenji Takagishi, MD, PhD.

1Department of Orthopaedic Surgery, Gunma University Graduate School of Medicine, Maebashi, Japan, 2Department of Physical Therapy, Takasaki University of Health and Welfare, Takasaki, Japan, 3Department of Orthopaedic Surgery, National Hospital Organization Takasaki General Medical Center, Takasaki, Japan.


Introduction: Shoulder stability is maintained by dynamic/static stabilizers in the periphery, and by sensory feedback (proprioception) to the central nervous system (CNS). Proprioception can be divided into three different modalities, which are important for goal-directed movements and joint stability: the sense of joint position, motion (kinesthesia), and force or tension. Several studies have reported proprioceptive deficits in patients with recurrent anterior shoulder instability (RSI), both in terms of sensing joint position and kinesthesia. Consistent with this, functional neuroplasticity including proprioception has been shown to occur in patients with anterior cruciate ligament deficiency (ACL). Despite the crucial contribution of the CNS in exerting control over the shoulder joint, only peripheral assessments of patients with RSI have been made. However, there was no study about functional neuroplasticity by proprioception from injured shoulder in patients with RSI. Evaluating changes in brain function in patients with RSI is crucial for understanding RSI pathophysiology, preventing recurrent dislocation after surgery, and determining when patients can return to sporting activities. Here, using fMRI, we tested our hypothesis that neural adaptations in proprioception occur in patients with RSI as a compensatory mechanism for shoulder dysfunction.

Methods: Twelve healthy volunteers (8 men; mean age, 23.2 ± 3.2 years) and 14 patients with RSI (11 men; mean age, 28.2 ± 8.6 years) participated in this study. Brain activity was examined by fMRI. A 3-Tesla whole-body MRI scanner equipped with a head coil was used in the experiment. FMRI was obtained via an echo planar imaging sequence using the following parameters: whole brain, TR = 2500 ms, TE = 30 ms, FA = 90°, 64 × 64 matrix, 38 slices, FOV = 192 mm, voxel size 3 × 3 × 3 mm.

Experimental tasks

Active right shoulder motion task
To elucidate the effect of shoulder motion on CNS function, participants performed isometric flexion, abduction, or external rotation of the right shoulder during fMRI. A custom-made, nonmagnetic splint was fixed tightly with non-elastic bandages to the hand, wrist, and elbow joints on the right side in order to restrict joint movement and to limit any effect of antagonistic muscles due to stretching. Each shoulder motion lasted 20 s and was triggered randomly by a visual presentation.

Passive right shoulder motion task
To detect brain activity associated with proprioceptive afferents from the shoulder, participants’ right shoulders were passively rotated in an external and internal motion with approximately 90° abduction in an MRI scanner.

**fMRI data analysis**

Imaging data were preprocessed and analyzed using SPM8. We computed summary images reflecting the effects of interest on fMRI signals by applying linear contrasts to the parameter estimates. A second-level random-effect group analysis was then performed to identify voxels that showed a significant difference in activity between the movement condition and rest, and between the passive motion condition and rest. In all comparisons, the threshold was initially set at a voxel-wise height-level of P controls, and for controls > patients with RSI. Differential activity between groups was set to a threshold of P < .05 corrected and P < .001 uncorrected for multiple comparisons.

**Results:** Active shoulder motion task

Compared to controls, patients with RSI showed significantly elevated brain activity in the supplementary motor area (SMA); bilaterally in the inferior parietal lobules, angular gyri, superior parietal gyri, middle frontal gyri, Rolandic operculum, middle temporal gyri, inferior frontal gyri, and precentral gyri; in the left superior frontal gyrus, superior medial gyrus, and precuneus; and in the right postcentral gyrus, superior occipital gyrus, cuneus, insula, amygdala, and cerebellum (Figure 1). Conversely, in the controls > patients with RSI comparison, brain activity was significantly elevated in the superior temporal, postcentral, and fusiform gyri on the left side.

**Passive shoulder motion task**

Significantly elevated brain activity was widespread in the SMA, left premotor cortex, M1 and S1, and in the right cerebellum of controls. On the other hand, in patients with RSI, brain activity was significantly elevated only in the left premotor cortex (Figure 2).

**Discussion:** Active shoulder motion task

The present study demonstrated that the RSI group exhibited higher activity in brain regions consisting of sensorimotor and visuo-motor networks in comparison with the control group. Heroux and Tremblay revealed resting motor threshold asymmetry in patients with ACL injuries, indicating the presence of enhanced excitability of corticomotor projections that targeted muscles adjacent to an immobilized or painful joint. Our results are consistent with the previous study and show that neuro-adaptations occur in the CNS to compensate for right shoulder dysfunction caused by RSI. In contrast to enhanced activity, one previous fMRI study demonstrated that patients with ACL deficiency exhibited diminished activity of several brain regions compared with controls. Our findings are partially consistent with this in that patients with RSI displayed decreased activity in the contralateral S1. Furthermore, statistically significant higher brain activity was observed in the amygdala and Brodmann’s area 44. Amygdala function has been well-characterized in the formation of memories for unpleasant, fearful, emotional stimuli, while Brodmann’s 44 is associated with the expression of emotional information, episodic long-term memory, and motion after-effects. The higher activity seen in these regions might indicate that shoulder motions evoked the unpleasant memory of shoulder dislocation in patients with RSI, despite the fact that there were no adverse reports during task performance.

**Proprioceptive afferents**

Proprioceptive afferents carry critical information for somatosensory-motor integration. In primates, proprioceptive sensations reach cortical motor areas, including the M1, presumably via the thalamus.
and S1. Previous studies are consistent with our findings that proprioceptive afferents from the shoulder were mainly located in the primary motor area. Zuckerman et al. reported that in patients with recurrent traumatic anterior instability, a significant deficit in proprioception was found when the unstable side was compared with the uninvolved side. This study is consistent with our present results with respect to decreased proprioceptive sensitivity.

**Significance:** RSI can cause functional neuroplasticity of the brain. This suggests that RSI might be a neurophysiological dysfunction rather than a simple peripheral musculoskeletal injury. Proprioceptive afferents from the injured shoulder were decreased in patients with RSI, which related to physiological dysfunction of shoulder joint stability.