● RESEARCH ARTICLE

Difference in cortical activation during use of volar and dorsal hand splints: a functional magnetic resonance imaging study

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Abstract

There have been no studies reported on the difference in cortical activation during use of volar and dorsal hand splints. We attempted to investigate the difference in cortical activation in the somatosensory cortical area during use of volar and dorsal hand splints by functional magnetic resonance imaging (fMRI). We recruited eight healthy volunteers. fMRI was performed while subjects who were fitted with volar or dorsal hand splints performed grasp-release movements. Regions of interest were placed on the primary motor cortex (M1), primary somatosensory cortex (S1), posterior parietal cortex (PPC), and secondary somatosensory cortex (S2). Results of group analysis of fMRI data showed that the total numbers of activated voxels in all ROIs were significantly higher during use of volar hand splint (3,376) compared with that (1,416) during use of dorsal hand splint. In each ROI, use of volar hand splint induced greater activation in all ROIs (M1: 1,748, S1 :1,455, PPC: 23, and S2: 150) compared with use of dorsal hand splint (M1: 783, S1: 625, PPC: 0, and S2: 8). The peak activated value was also higher during use of volar hand splint (*t*-value: 17.29) compared with that during use of dorsal hand splint (*t*-value: 13.11). Taken together, use of volar hand splint induced greater cortical activation relevant to somatosensory function than use of dorsal hand splint. This result would be important for the physiatrist and therapist to apply appropriate somatosensory input in patients with brain injury.

Key Words: *nerve regeneration; functional MRI; hand splint; somatosensory function; dorsal hand splint; volar hand splint; neural regeneration*

Introduction

Various somatosensory inputs using vigorous rubbing, clapping, pressure, vibration, and icing have been referred to as somatosensory stimulation (Bohls and McIntyre, 2005; Jang et al., 2013). Somatosensory stimulation has long been used in neuro-rehabilitation because neural stimulation by somatosensory input is necessary for induction of plastic change of the brain (Pedretti, 1996; Ashburn, 1997; Bohls and McIntyre, 2005; Jang et al., 2013). By contrast, restriction of somatosensory stimulation is often necessary during neuro-rehabilitation; for example, reducing spasticity is necessary in patients with brain injury (McPherson et al., 1982; Rose and Shah, 1987; Pizzi et al., 2005; Basaran et al., 2012; Copley et al., 2013). During neuro-rehabilitation, patients with brain injury are obliged to be exposed to somatosensory stimulation. Consequently, clarification of the relationship between somatosensory stimuli and brain response has been an important topic in the field of neuro-rehabilitation. However, it has not been clearly elucidated so far (Jang et al., 2013).

Hand splint has been widely used for rehabilitation in patients with brain injuries, including stroke, cerebral palsy, and traumatic brain injury (Neuhaus et al., 1981; Lannin and Herbert, 2003; Lannin and Ada, 2011; Tyson and Kent, 2011). The purpose of use of hand splint in patients with brain injury is to control spasticity, reduce pain, maintain range of joint motion, and enhance motor control (Neuhaus et al., 1981; Lannin and Herbert, 2003; Pitts and O'Brien, 2008; Lannin and Ada, 2011; Tyson and Kent, 2011; Copley et al., 2013). According to the location of the supporting bar, hand splints are divided into volar and dorsal types (McPherson et al., 1982; Rose and Shah, 1987; Basaran et al., 2012). Despite controversy, it has generally been acknowledged that volar hand splint can increase spasticity by increasing somatosensory stimulation (McPherson et al., 1982; Rose and Shah, 1987; Pizzi et al., 2005; Basaran et al., 2012; Copley et al., 2013). However, very little is known about volar hand splint. To the best of our knowledge, few studies are reported on the differences in cortical activation during use of volar and dorsal hand splints. A functional MRI (fMRI) study has reported that somatosensory input on the palm, compared with the dorsum, induced greater cortical activation in cortical areas relevant to somatosensory function (Jang et al., 2013). Therefore, in this study, we investigated
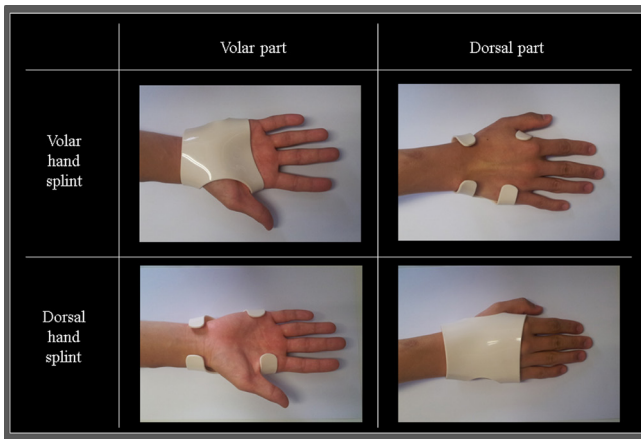
Figure 1 Two types of hand splints.

Table 1 Activated voxels in the regions of interest during use of each hand splint

Region of interest (left hemisphere)	Voxel counts	
	Dorsal hand splint	Volar hand splint
S1 (BA 1, 2, 3)	625	1,455
M1 (BA 4)	783	1,748
PPC (BA 5,7)	0	23
S2 (BA 40,43)	8	150
Total	1,416	3,376

Activated voxel counts calculated by fMRI group analysis. BA: Brodmann's area; M1: primary motor cortex; S1: primary somatosensory cortex; PPC: posterior parietal cortex; S2: secondary somatosensory cortex.

the differences in cortical activation in somatosensory cortical areas during use of volar versus dorsal hand splints in normal subjects, with the purpose of providing valuable reference in selecting appropriate hand splints according to patient's state.

Subjects and Methods

Subjects

We recruited eight healthy right-handed college students, consisting of four males and four females, aged 13.75 (range, 22–27 years) years through volunteer recruitment notice. All these subjects had no previous history of neurological or physical illness. All subjects understood the purpose of the study and provided written informed consent prior to participation. The Edinburg Handedness inventory was used for evaluation of handedness (Oldfield, 1971). The study protocol was approved by the Institutional Review Board of Yeungnam University Hospital, South Korea.

Two types of hand splints

Two types of hand splints (volar and dorsal type) were made based on a cock-up splint and the forearm part of the conventional hand splint was not included in order to avoid somatosensory stimulation from other parts, except for the hand (**Figure 1**). The total size of volar and dorsal hand
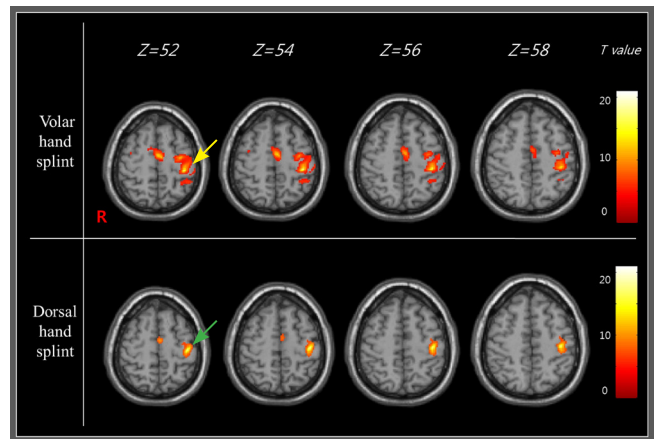

Figure 2 Results of group analysis of functional magnetic resonance imaging data during use of volar and dorsal hand splints.
The result shows that the activation cluster in the primary sensorimotor cortex during use of volar hand splint (yellow arrow) is larger than that during use of dorsal hand splint (green arrow).

splints was adjusted to be the same to provide the same contact area. Volar and dorsal hand splints were designed to be fitted to the subject's hand without a strap, and were made of thermoplastic material in professional production company of South Korea.

fMRI

All subjects were examined while in the supine position with eyes closed, and were secured firmly with the forearm in supination. A hand splint was applied to the right hand and the subject was instructed to perform the task. The task was flexion-extension movement of metacarpophalangeal joint of the hand at a frequency of 1 Hz under metronome guidance. One observer confirmed that there had been no movement of the shoulder and elbow during fMRI scanning. A block paradigm (21-second control, 21-second stimulation) was used in performance of the tasks. Each task was repeated three times and the sequences of wearing one of the two splint types were assigned randomly. The subjects rested for 5 minutes between tasks.

A 1.5-T Philips Gyroscan Intera scanner (Hoffman-La-Roche, Best, the Netherlands) and a standard head coil were used in performance of blood oxygenation level dependent (BOLD) fMRI. BOLD-weighted Echo Planar Imaging (EPI) parameters were as follows: repetition time (TR)/ echo time (TE) = 2 seconds/60 milliseconds, field of view (FOV) = 210 mm, flip angle = 90°, matrix size = 64 × 64, and slice thickness = 5 mm. The EPI BOLD images were acquired over the 20 axial sections for each epoch. A total of 1,200 images were acquired parallel to the inter-commissure line between the anterior and posterior commissures. For anatomical reference image, 20 axial, 5-mm thick, T1-weighted spin echo images were obtained with a matrix size of 128 × 128 and an FOV of 210 mm. SPM 8 software (Wellcome Department of Cognitive Neurology, London, UK) implemented in the MATLAB environment (The Mathworks, Natick, MA, USA) was used in performance of fMRI data analysis; all images were realigned, co-registered, and normalized. A Gaussian

kernel at a full width at half maximum (FWHM) of 8 mm was then used for smoothing of images. For detection of changes in BOLD signals, data on control conditions were subtracted from data on stimulated conditions. Differences in brain activation during performance of tasks were compared using random-effect group analysis. SPMt-maps were computed, and voxels were considered significant at an uncorrected threshold of $P < 0.001$. Activations were based on clusters larger than five voxels. Quantitative comparisons between stimulations were made by comparing changes in BOLD signals.

For analysis of volume data mapped to the cortical surface, we projected functional group results onto the left and right hemispheres of the Human Colin surface-based atlas mapped to the PALS-B12 surface ('Population-Average Landmark- and Surface-Based'-atlas) (Nakahara et al., 2001; Van Essen et al., 2001; Van Essen, 2005). Data values in voxels that intersected the cortical surface were mapped directly to the vertices of each participant-specific fiducial cortical surface using the intersections of enclosing voxels and nodes. Nodes representing an individual hemisphere were deformed to the standard PALS-B12 atlas sphere with 73,730 nodes using selective landmarks and spherical alignment (Van Essen, 2005). fMRI activation results for the groups were mapped on the flatmap template of the PALS-B12 using version 5.61 of the Computerized Anatomical Reconstruction and Editing Toolkit (CARET: Washington University, St. Louis, MO, USA) (Van Essen, 2002). Regions of interest (ROIs) were placed on cortical areas relevant to the somatosensory function as follows: the primary motor cortex (M1: Brodmann's area (BA) 4), primary somatosensory cortex (S1: BA 1, 2, and 3), posterior parietal cortex (PPC: BA 5 and 7), and secondary somatosensory cortex (S2: BA 40, 43) (Forss et al., 1999; Cramer et al., 2000; Ramachandran, 2002; Jang et al., 2010). Voxel count was measured that CARET showed the result value in each ROI.

Results

The results of group analysis of fMRI data showed that the total numbers of activated voxels in all ROIs were higher during use of volar hand splint (3,376) than that (1,416) during use of dorsal hand splint (**Table 1**, **Figure 2**) in result value using CARET. Regarding cortical activation in each ROI, use of volar hand splint (M1: 1,748, S1: 1,455, PPC: 23, and S2: 150) induced greater activation in all ROIs than use of dorsal hand splint (M1: 783, S1: 625, PPC: 0, and S2: 8). The peak activated value was also higher during use of volar hand splint (*t* value: 17.29, location: *x*: −38, *y*: −28, *z*: 56) than that during use of dorsal hand splint (t value: 13.11, location: *x*: −38, *y*: −22, *z*: 54).

Discussion

In the current study, we investigated total numbers of activated voxels in somatosensory cortical areas during use of volar and dorsal hand splints. Although the task of using a hand splint is the combination of motor and somatosensory function, we attempted to investigate total numbers

of activated voxels only by the somatosensory input during use of the two splints by controlling the motor task to be the same. Because the purpose of this study was to investigate the difference of cortical activation relevant to somatosensory function, we confined the ROIs to the cortical areas that are directly relevant to somatosensory function: M1, S1, PPC, and S2. Although the M1 is the main origin area of the corticospinal tract, we included the M1 as a ROI because it is already well-known that the M1 is closely related to the somatosensory function by obtaining somatosensory input from the S1 or thalamus directly, and overlapping of M1 and S1 for somatosensory function (Desmedt and Cheron, 1980; Dinner et al., 1987; Canedo, 1997). Accordingly, our findings were as follows: (1) the total numbers of activated voxels in all ROIs during use of volar hand splint (3,376) were over twice higher as much as that (1,416) during use of dorsal hand splint; (2) use of volar hand splint (M1: 1748, S1: 1,455, PPC: 23, and S2: 150) induced greater activation in each ROI than use of dorsal hand splint (M1: 783, S1: 625, PPC: 0, and S2: 8); and (3) the peak activated value was also higher during use of volar hand splint (*t* value: 17.29) than that during use of dorsal hand splint (*t* value: 13.11). Consequently, we concluded that use of volar hand splint induced greater activation in cortical areas relevant to somatosensory function than use of dorsal hand splint.

Several studies have reported on the difference of the clinical effect of volar and dorsal splints (McPherson et al., 1982; Rose and Shah, 1987; Basaran et al., 2012). McPherson et al. (1982) compared the effect on reduction of hypertonus with dorsal and volar splints in 10 patients with wrist hypertonus (stroke in six patients, traumatic brain injury in one patient, and cerebral palsy in three patients). The maximum splint wearing time was 2 hours/day, and hypertone (measured by spring scale) was evaluated every week during 6 weeks. However, significant difference was not observed between the groups (McPherson et al., 1982). Rose and Shah (1987) compared the immediate effects (passive range of motion, resistance to passive extension, spontaneous wrist flexion) of dorsal hand splint, volar splint and no splint in spastic hemiplegic patients (three patients: cerebral palsy and twenty-seven patients: stroke) during 2 hours of wearing. Use of dorsal and volar hand splints significantly reduced hypertonicity of wrist as measured by passive range of motion and resistance to passive extension. However, the hypertonicity of wrist as measured by spontaneous wrist flexion was reduced only in dorsal splint (Rose and Shah, 1987). Basaran et al. (2012) compared the effects (MAS, passive range of motion) of dorsal splint, volar splint and no splint in 39 stroke patients. Patients were asked to perform exercise (reach and grasp a cup or can, 10 repetitions, three times a day), stretching (wrist and finger flexor, 10 repetitions, three times a day), and a 10 hour splint wearing, every day for 5 successive weeks. However, Basaran et al. (2012) could not observe significant difference between groups. Like abovementioned, most of previous studies have focused on the effect of use of volar and dorsal hand splints on the hypertonus. Therefore, to the best of our knowledge, few studies have reported on the

difference in cortical activation in somatosensory cortical areas during use of two types of hand splints. Recently, Jang et al. (2013) compared brain activation patterns by somatosensory stimulation on the palm and dorsum of the hand using fMRI. Their results showed that touch stimulation on the palm of the hand resulted in production of more activated voxels in the somatosensory cortical areas than touch stimulation on the dorsum of the hand. Activated voxel counts by stimulation on the dorsum versus palm were 2,282:5,875 in the primary sensorimotor cortex (BA 1, 2, 3, 4), 0:63 in the posterior parietal cortex (BA 5, 7), 267:237 in the secondary somatosensory cortex (BA 40, 43), 2,549:6,175 in total. Results from this study suggest that the palm of the hand might have larger somatotopic representation for touch in the cerebral cortex than the dorsum of the hand. Our results appear to coincide with the findings from an abovementioned fMRI study, although use of a hand splint is the combination of the motor and somatosensory stimulation.

In conclusion, we investigated the difference in cortical activation relevant to somatosensory function during use of two types of hand splints, and found that use of volar hand splint induced greater cortical activation in cortical areas relevant to somatosensory function than use of dorsal hand splint. We believe that our results have important implications for the physiatrist and therapist. For patients who need more somatosensory stimulation, the volar hand splint can be recommended, rather than the dorsal hand splint, whereas for patients who need restriction of somatosensory stimulation, the dorsal hand splint can be recommended. Use of volar hand splint rather than dorsal hand splint should be recommended for patients with hypotonic hand, and use of dorsal hand splint rather than volar hand splint should be recommended for patients with spastic hand. Consequently, our results would provide reference values in selecting hand splints according to the patient's clinical state. Nevertheless, this study has a few limitations. First, task performance (flexion-extension movement of metacarpophalangeal joint) during fMRI was so simple. Second, standard head coil does not benefit decreasing EPI distortion using parallel imaging and the reduction of signal-to-noise ratio. Third, sample size was small and there was no patient group. Therefore, further studies involving various tasks that simulate the real activities of daily living, using a multiple channel receiver coil, and recruiting a larger number of subjects and patients should be encouraged. In addition, measurements both prior to and after wearing a hand splint should be considered.

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