CASE STUDY

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ASYMMETRY OF SOMATOSENSORY CORTICAL PLASTICITY IN PATIENT WITH BILATERAL CARPAL TUNNEL SYNDROME

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ABSTRACT

Background: Following peripheral nerve lesion, the adult somatosensory system showedcortical reorganizational abilities. Previous studies identified the digits' somatotopy map changes and somatosensory cortical plasticity in response to the Carpal Tunnel Syndrome (CTS) that affected the dominant hand only. Objective: Answering the remained question is that what the extent of the cortical plasticity would be in left and right somatosensory cortices in response to CTS affecting the right and left hands simultaneously.

Methods: Cortical representations activated by tactile stimulation of median nerve (index) and ulnar nerve (little) of both dominant and non-dominant hands were evaluated by Magnetoencephalography (MEG) systemfor healthy participants and patient with bilateral moderate CTS. index – little fingers'somatotopy map and inter-digit cortical distance was then mapped and calculated for each participant on the real MRI data and the 3D brain surface image.

Results: in healthy participants, index – little inter-digit somatosensory cortical distance of right hand (dominant) was significantly larger than the index – little inter-digitsomatosensory cortical distance of left hand (11.2±2.1mm vs. 7.0±2.9mm, P = 0.006). However, in patient with bilateral CTS, the index – little inter-digit somatosensory cortical distance of righthand (dominant) was significantly smaller than the index – little inter-digit somatosensory cortical distance of left hand (5.8mm vs. 7.4mm).

Conclusion: our data could be interpreted as the hand use – dependency served more median nerve – cortical territory from the ulnar nerve invasion in the right somatotopy map (left hand) than the left somatotopy map of the right hand.

Keywords: Carpal tunnel syndrome, cortical plasticity, hemispheric asymmetry, use-dependency, Magnetoencephalography

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INTRODUCTION

Carpal Tunnel Syndrome (CTS) is a neuropathy that results from the compression of median nerve sensorimotor fibers at the wrist, and recently it considered as the most frequent type of nerve entrapment or neuropathy [1]. In human, the digits' somatotopy map in the primary somatosensory cortex (SI) undergoes plastic changes and re-arrangement following decreased and aberrant sensory inputs from peripheral receptor and nerve [2].

Recent brain mapping and neuroimaging studies contributed to explore and to identify the SI – cortical plasticity in response to CTS in terms of the changes in the inter-digits somatotopy maps of the CTS affect hands. For example, the somatotopy map of the index (D2) and little (D5) fingers of the CTS affected hand were examined by using the electroencephalography (EEG) [3], the fMRI [4-6], and the magnetoencephalography (MEG) [7,8]. All these studies reported remarkable changes in the D2 – D5 somatotopy map of the CTS affected hand, in which the D5 SI – cortical territory area innervated by the ulnar nerve expanded over the expenses of the D2 cortical territory area innervated by the deprived median nerve (due to the CTS).

On the other hand, previous MEG study [9] reported that the left and the right somatosensory cortices are not symmetrical in terms of hand representation and somatotopy map, in which the inter-digit cortical distance was smaller in the right somatosensory cortex compared with the left somatosensory cortex, and this finding was identified on the healthy participants only.

Consequently, the question is that what the extent of the SI – cortical plasticity and the somatotopy changes would be to the peripheral neuropathy condition such as bilateral CTS affecting both hands simultaneously remain unclear. This is because the previous CTS studies [3-7] identified the functional and the structural of the SI – cortical plasticity in response to either the right hand with CTS or the left hand withCTS only (dominant or non-dominant hand). In addition, in case of a participant with bilateral CTS affecting both hands existed in the previous studies [3-7], they measured the data of the most affected hand and excluded the other hand from their examination.

Therefore, the aim of this study was the using of the MEG brain mapping technique to identify and to compare the cortical plasticity and the inter-digits somatotopy map between the left and the right somatosensory cortices in response to the bilateral CTS condition affecting both the dominant and non-dominant hands simultaneously.

METHODS

Participants

The study was conducted in the Hiroshima University Hospital, where the cortical responses to tactile stimulation were recorded for female patient (58 years old, right handed, house wife) with bilateral moderate CTS, and for five healthy participants (21-30 years old, right handed). The CTS was confirmed by the clinical and electrophysiological examination and its severity were based on the six categories of CTS severity classification [4]. All instruments and tools used in our study were approved by the Japanese Ministry of Health, Labour, and Welfare (No. 20800BZY0027000). The study design, method of data acquisition and analysis, and the tactile stimulation werethe same as of our previous work [10] and approved by the ethical committee of the Graduate School of biomedical and Health Sciences at Hiroshima University.

Data acquisition& analysis

The cortical somatosensory evoked fields (SEFs) responses to the tactile stimuli that applied to the Index finger (D2, median nerve innervation) and little finger (D5, ulnar nerve innervation) pulps of the dominant and non-dominant hands were recorded by using the MEG system. Tactile stimuli delivered by automatic and nonmagnetic stimulator machine that was used in our previous MEG study[10]. The machine was equipped with a plastic piece round and smooth surface of 70mm^2 contact area.The SEFs were recorded by using the MEG system that composed from a helmet shaped of 306 sensors system (Vector View Elekta*Neuromag*, Helsinki, Finland) that attached to multi-superconducting quantum interference device (SQUID), (Figure1).

Each participants underwent four SEF recording sessions, and the MEG data that used for each recording session analysis was 100 cortical SEFs responses (artifact –free) for the tactile stimuli averaged online for each fingerwith band pass filter of 0.1-200Hz and with sampling rate of 600Hz and time window of 1000 and 500 millisecond pre/post tactile stimulus onset, respectively. In addition, the MRI data for all participants was obtained using a GE Yokogawa SIGNA - 1.5Tesla device with slice thickness of 2mm).

The MEG data of healthy participants and patient with bilateral CTS was analyzed to identify four major outcomes, 1) the excited somatosensory cortical region in response to tactile stimuli applied to D2 and D5, 2) the exact location of D2 and D5 in the somatosensory cortex 3) the somatotopy map of D2 and D5, and the D2 –D5 inter-digits cortical distance in the somatosensory cortex.

First, to identify the somatosensory cortical responses of D2 and D5 to tactile stimulation, the MEG data was analyzed using offline band pass filter of 4-100Hz, and was modeled as a single current model that was identified by the least-squares search of a subset of approximately 10-30 channels over the interested rolandicarea of somatosensory cortex, and with dipoles goodness of fit (GOF) ≥90%, (this method is the most powerful method used in the MEG studies and the details is presented in our previous MEG studies [10-12]).

Second, to identify the somatotopy of D2 and D5, the MEG data of each participant was aligned and superimposed over the participant's MRI. This was done by identifying markers in the MRI with a 3D digitizer system (Isotrack; Polhemus Navigation Sciences, USA).

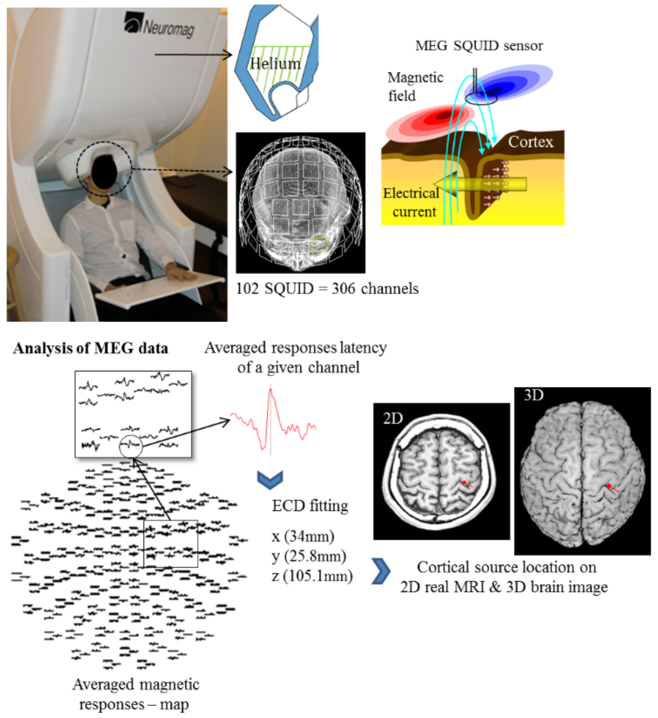

Figure 1: MEG system

Upper Panel: A typical measurement situation with the MEG system. The subject is sitting with his/her head inside the helmet-shaped of 306 sensors attached to superconducting quantum interference devices (SQUIDs).

Right-upper Panel: a view of the position of the helmet-shapes sensor array with respect to the head and the brain of the subject, respectively.

Lower Panel: a brief of MEG data analysis, in which single current model obtained through defining a set of channels over the interested cortical region that could be used to define the cortical location in the real 2D MRI and the structured 3D brain image.

Third, to identify the somatosensory cortical somatotopy map of D2 and D5, the three dimension (3D) brain surface image was built for each participant from the real MRI data using the Hashizume et.al. developed software[13]. Forth, the D2 – D5 inter-digit somatosensory cortical distances (Euclidean distance) in the 3D brain structure was calculated by using the common formula in the brain mapping studies, ($\sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}$)[14].

RESULTS

In terms of the excited cortical regions, tactile stimulation to the D2and D5 of right and left hands was able to evoke the contralateral somatosensory cortex (cSI) in healthy subjects (n=5) and in patient with bilateral CTS.

In terms of the somatotopy map and the inter-digit cortical distances (Euclidean distance), healthy group data revealed that the D2 – D5 inter-digit cortical distanceof the right hand (dominant) was significantly larger than the D2 – D5 inter-digit cortical distanceof the left hand (left somatosensory D2 – D5 inter-digit cortical distance 11.2±2.1mm vs. 7.0±2.9mm in right somatosensory cortex, paired t-test *P*=0.006).

However, in patient with bilateral CTS, our study showed that there were asymmetrical cortical plasticityand somatotopy map changes (left vs. right) in response to bilateral CTS. This is because the somatosensory D2 – D5 inter-digit cortical distanceof the right hand (dominant hand with CTS) was remarkably shortened (5.8mm) compared with the averaged D2 – D5 inter-digit cortical distanceof in the healthy group (11.2±2.1 mm). In addition, the somatosensory D2 – D5 inter-digit cortical distanceof the right hand (dominant hand with CTS) became smaller than the somatosensory D2 – D5 inter-digit cortical distanceof the left hand (7.4 mm, non-dominant hand with CTS).

Moreover, the somatosensory D2 – D5 inter-digit cortical distanceof the left hand (7.4 mm, non-dominant hand with CTS) was almost the same of the averaged somatosensory D2 – D5 inter-digit cortical distance of the left non-dominant hand of the healthy group (7.0±2.9mm) (Figure 2, 3).

DISCUSSION

The aim of this study was to examine the inter-hemispheric differences in terms of somatosensory cortical plasticity and somatotopy map changes in a patient with bilateral CTS in both theright and left hands (dominant vs. non-dominant hands).

In terms of the healthy participants' data, the digits' somatotopy map and the inter-digit cortical distances findings of our study were consistent with those of the previous MEG study [9], where the D2 SI – cortical representation was more laterally located compared with the D5 SI – cortical representation in all participants. In addition, there were a symmetrical D2 – D5 inter-digit cortical distance between the left and the right somatosensory cortices, where the D2 – D5 inter-digits cortical distance in the left somatosensory cortex (dominant hand) was larger than D2 – D5 inter-digits cortical distance of the right somatosensory cortex.

In terms of the patient data with CTS, this study could identify the differences in the extent of somatotopy map changes and the cortical plasticitybetween the left and right somatosensory cortices in response to the CTS that involved equally dominant and non-dominant hands simultaneously, instead of the previous neuroimaging – CTS studies thatexamined only the cortical plastic changes in the unilateral CTS involved one hand only [3-7].

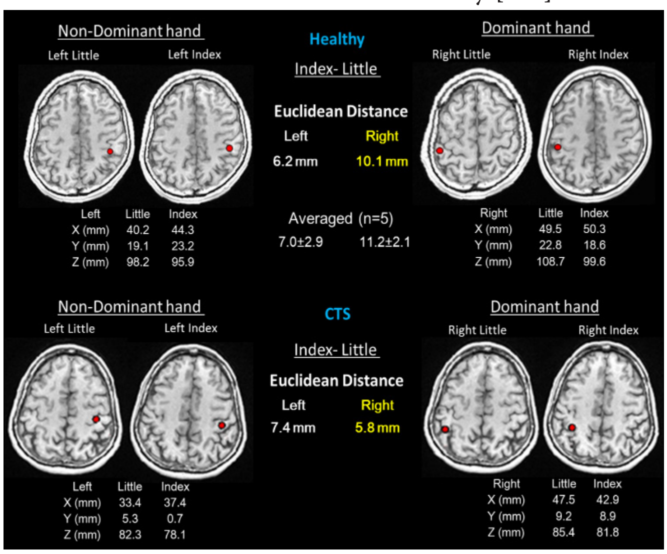

Figure 2: Cortical representation and cortical distance

Axial MRI views of the healthy participant and the patient with bilateral CTS show the somatosensory cortical representations of the index (D2, median nerve) and the little (D5, ulnar nerve fingers), excited by tactile stimulation.

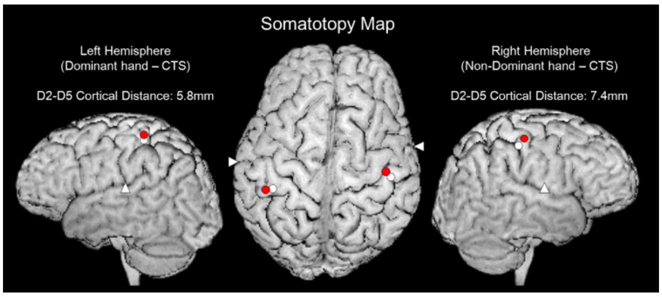

Figure 3: Somatotopy cortical map

The somatotopy map in 3D-brain surface image for the patient with bilateral CTS. The Index (D2, median nerve) showed as white circle; little (D5, ulnar nerve) showed as red circle; central sulcus showed as white triangle.

In terms of the CTS affecting dominant hand (right hand), the digits' somatotopy map and the inter-digit cortical distances findings of this study were consistent with those of the previous neuroimaging studies [3-7], where the D2 – D5 inter-digit cortical distance shortened as a result of the CTS in the left somatosensory cortex (dominant hand) compared with the averaged D2 – D5 inter-digit cortical distance in left somatosensory cortex of the healthy participants data (5.8 mm vs. 11.2±2.1 mm, respectively).

Such shortening in the D2 – D5 inter-digit cortical distance due to the CTS affecting dominant hand could be interpreted by the findings of the previous human and animal studies that revealed that digits' somatotopy map isremodeled by the tactile experience and the neuronal input to the cortical regions, where thecortical territory and region of less or partially deafferenatedsensory input is overcome or occupied by the neighboring cortical region with normally afferent sensory inputs [2,15].Therefore, our patient dependency on the right hand in her daily activities life leads to more unbalanced sensory inputs between the little and index fingers, where normally ulnar nerve input overcome the deprived median input (CTS), and this leads to more spatial shifting of the D5 SI-cortical territory to occupy more of the deprived D2SI-cortical territory in the left somatosensory cortex compared with the right somatosensory cortex, herebythe left D2-D5 SI-cortical distance became smaller.

However, this is not the case in terms of the CTS affecting the non-dominant hand (left hand) since our data revealed for the first time that the extent of the cortical plasticity and the changes in somatotopy map in the right somatosensory cortex differed from those plastic changes in the left somatosensory cortex (dominant hand). This is because the D2 –D5 inter-digit cortical distance of the right somatosensory cortex in patient with CTS (7.4mm) was almost the same of the averaged D2 –D5 inter-digit cortical distance in right somatosensory cortex of the healthy group (7.0±2.9mm).

Such surprised resistance of the D2 cortical territory innervated by deprived median nerve with the less sensory input due to the CTS in the face of the D5 cortical invasion that innervated by the ulnar nerve with normal sensory inputs could be interpreted by the use-dependency theory. This is because previous somatosensory cortical study[16] revealed that if the non-dominant hand and dominant hand underwent use-dependency (have been involved in the daily life activities), the non-dominant hand showed greater cortical excitability than of the dominant hand. In this context, we assumed our patient dependency on dominant and non-dominant hands in daily life activities had been changed in a manner she started to use both hand in the daily life more frequent after the CTS to reduce or to avoid the pain and discomfort that comes from just using mainly the dominant hand, which means that the patient'sright and left hands underwent the use-dependent plasticity [16]. Consequently, D2 cortical source of the non-dominant hand became more excited under the effect of the use-dependency, in turns this greater excitation could serve more median – D2 cortical territory from the invading of the normally D5 cortical source in the right somatosensory cortex compared with what happened in the left somatosensory cortex (dominant hand).

CONCLUSION

To conclude, our study is the first study that highlighted the asymmetrical cortical plasticity capability between the right and left somatosensory cortices in response to peripheral neuropathy condition such as CTS affecting dominant and non-dominant hand simultaneously. In addition, it highlight the importance to consider the mechanism behind such asymmetrical response in our clinicalrehabilitation management, in terms affected hand and in terms of the rehabilitation technique used, an example of the rehabilitation technique that may be considered is the sensory re-education technique that based on the preserving the cortical territory of the deprived nerve using visualization, verbalization and tactile stimulation [17]. However, further research is needed.

Conflict of interest: None

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