Evaluation of Somatosensory Evoked Responses When Multiple Tactile Information Was Given to the Palm: A MEG Study

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Abstract. In this study, as a part of comprehensive approach to develop an interface for tactile information delivery, we aimed at capturing the relationship between neuronal and perceptual sensitivity characteristics of in human hand as indexed by neuromagnetic and psychometric responses.

Airpuff stimuli were presented to multiple locations on the ventral side of subjects' palm, which somatosensory evoked responses were observed.

As a result, it was observed that the latency and amplitude of the evoked responses in the primary somatosensory area (SI) was not related to the location on the palm. Although mechanoreceptors in the palm area distributed densely at both the center of the palm and the proximal part of the proximal phalanges, no effects on location were found by the amplitude of the evoked responses at SI area. These results suggested that amplitude of the evoked responses at SI did not depend on the distribution of the mechanoreceptors.

Keywords: Magnetoencephalography, Tactile, Airpuff stimuli, Somatosensory evoked responses, Primary somatosensory area.

1 Introduction

People who visually handicapped obtain information about outside world by using braille. It was reported that only 10.6% of handicapped people can use brailles [1]. Hence, tactile display became common as an information presentation device for the visually disabled. Mizugami et al.[2] reported that it was possible to recognize simple characters by a tactile display with at most 9 actuators, used for character presentation. However, National Institute of Vocational Rehabilitation reported that size of characters proportional to the tactile display and individual differences were key issues for obtaining high identification rates [3]. Thus, there have been demands to improve the identification rates for various users. When people perceived the tactile

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stimuli, four types mechanoreceptors with different characteristics detect the stimuli. Sakai, et al.[4] reported that it was important to present information by considering the distribution patterns of cutaneous mechanoreceptors for improving character identification rates. We used magnetoencephalography (MEG) to capture the dynamic changes of information processing in the brain. There have been several studies which evaluated activity of somatosensory areas by using MEGs when tactile stimulation was delivered. Forss, et al. compared MEG responses when electric stimuli were presented to the median nerve and airpuff stimuli were presented to the hairy skin at the dorsum of the proximal phalanx of the middle finger. This study showed that the mean dipole moments for the earliest responses were significantly smaller when airpuff stimuli were given than those when electric stimuli were given [6]. Hashimoto, et al. reported that the amplitude and the latency of the first component of the evoked responses for different areas to the body to clarify distal-proximal relathionship did not change significantly [7]. Thus, many of these studies focused on somatosensory evoked responses when tactile stimuli were presented to the fingertip. On the other hand, there was been little number of reports which investigated the activity of somatosensory areas when tactile stimuli were presented to the palm. Because tactile display is mainly for presenting tactile stimuli to the palm, it is important to evaluate the activity of the somatosensory area by the differences in stimulated locations on the palm. Anatomically, Johansson reported that mechanoreceptors in the palm area distributed densely at both the center of the palm and the proximal part of the proximal phalanges [8]. Mizugami, et al.[9] collected subjective responses when tactile stimuli were presented at various areas of the palm and concluded that the center of the palm had less sensitive than the other part of the palm. In other words, sensitivity of the center of the palm was low, in spite that mechanoreceptors distributed densely at the center of the palm. Hence it is possible to obtain the inference about the mechanism of sensory perception, if there is a relationship between the amount of perception given by tactile stimuli and the amplitude of somatosensory evoked responses. In addition to the distribution patterns of the mechanoreceptors, innervation areas to convey tactile information are different by the locations of the palm. Such differences may appear as the latency of the first component of evoked magnetic responses. In this study, total of 16 locations on the palm were designed to present tactile stimuli, for examining the effect due to the density difference for mechanoreceptors and innervation areas. The aim of experiment is to evaluate the influence about amplitude, latency, and activated location for somatosensory evoked responses when tactile stimuli were presented at the different location of the palm.

2 Method

2.1 Subjects

A total of 6 healthy college students (age range: 20-22 years; right-handed) participated in the experiments. An informed consent was obtained from each subject after the purpose and procedures of the experiment were fully explained.

2.2 Tactile Stimuli Presentation Device

Tactile stimulus presentation device used in the experiment was an air compressor through precision regulator, followed by an electro-pneumatic regulator, and solenoid valve for ejecting air-jet from the nozzle (Fig.1).

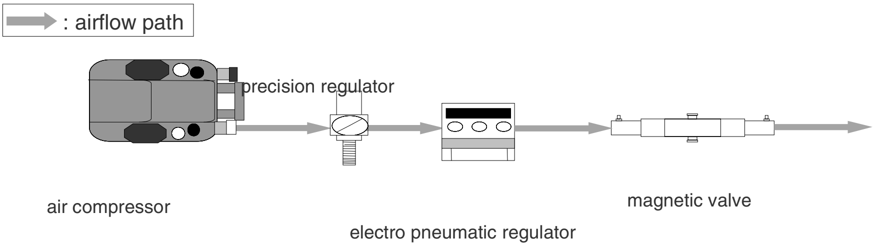


Fig. 1. Airpuff stimuli presentation device

2.3 Presentation of Airpuff as Tactile Stimuli

Airpuff stimuli are medium which spreads stimulus to the areas nearby. The objective of the experiment is to evaluate the effects associated with somatosensory evoked responses when stimulated locations were different. Therefore, it is important to control the diffusion of the airpuff stimuli minimum to establish accurate evaluation for the location difference given by the tactile stimuli. Thus, we made a device whose structure can suppress the stimuli around the skin for minimizing skin deformation over the broad area by the air (Fig.2).

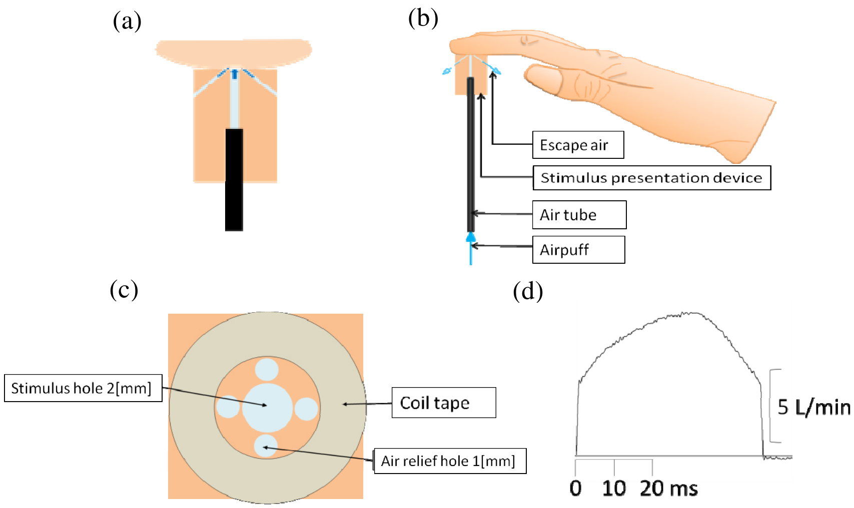
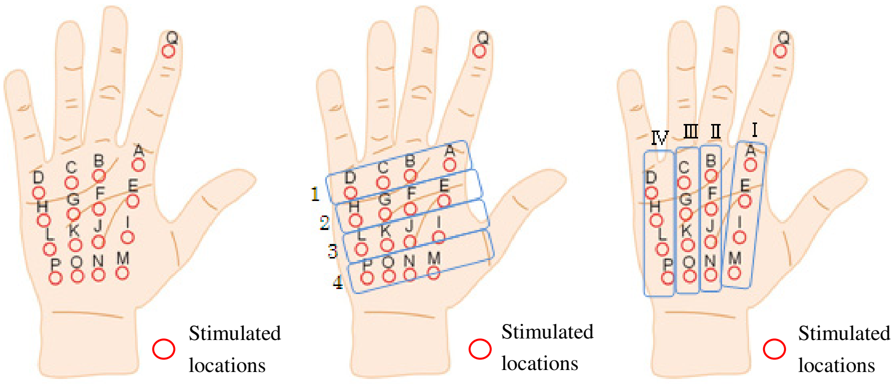


Fig. 2. Device made for the study and the dynamic characteristics of air flow (a), lateral side view (b) schematic, (c) top view, (d) air flow volume given by the new device

2.4 Stimulation Design

By providing the stimulated locations across the palm, the influence of the difference in the stimulated locations of the palm was evaluated. Stimulated locations were divided into two groups, one was aimed for clarifying distal-proximal relationship and the other was for medial-lateral relationship (Fig.3-(b, c)).



(a) Stimulated locations (b) distal-proximal relationship (c) medial-lateral relationship

Fig. 3. Stimulated locations and groups

The airpuff was used to stimulate one location of the palm 100 times repeatedly. As parameters of the airpuff stimulus, the flow volume was set to 20 [L / min], duration was set to 40 [ms], and inter-stimulus interval was set to 3200 [ms]. The experiment was completed in approximately 120 minutes.

2.5 Signal Analysis

The signals recorded by MEG were filtered (High pass filter 0.3Hz: Low pass filter 50Hz). Averaging of 100 trials between -1000 ms and 1800 ms of the offset was performed. Baseline was set to the average amplitude between -100 and 0 ms of MEG signals. Root mean square (RMS) values obtained for evaluating the latency and the amplitude of MEG signals at the somatosensory area. Algebraically RMS was calculated as follows:

$$B_{RMS} = (\sum B_i^2/n)^{1/2} \quad (B_i\text{: Signal of each sensor,} \quad n\text{: Number of sensors})$$

By using the moving equivalent current dipole (ECD) estimation, the localized source for each condition was estimated (Goodness of fit>75%, Confidence Volume<100mm^3). Fixed ECD estimation, used in the previous study [10], was applied to estimate time changes in the intensity of the ECD and the peak latency and the amplitude were obtained temporal changes of the amplitude of the dipole moment were estimated, and the peak latency and amplitude of the ECD were identified.

3 Results

Fig.4 illustrated a typical example for averaged MEG waveforms obtained at whole scalp area when airpuff stimuli were presented.

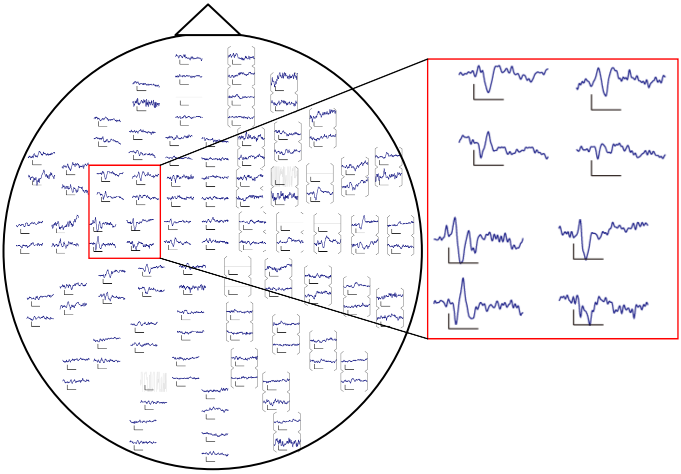


Fig. 4. Evoked MEG waveforms (Subject B, stimulated location A) Vertical axis: Amplitude [fT/cm], Horizontal axis: Time [ms] (from -100[ms] to 500[ms]), close-up wave forms sharply illustrated peaks appeared in the left hemisphere after airpuff stimulus presentation

Characteristic peak signals were found in the channels at the left-hemisphere. RMS analysis was conducted to the channels located at the left hemisphere.

Fig.5 illustrates a RMS-processed waveform.

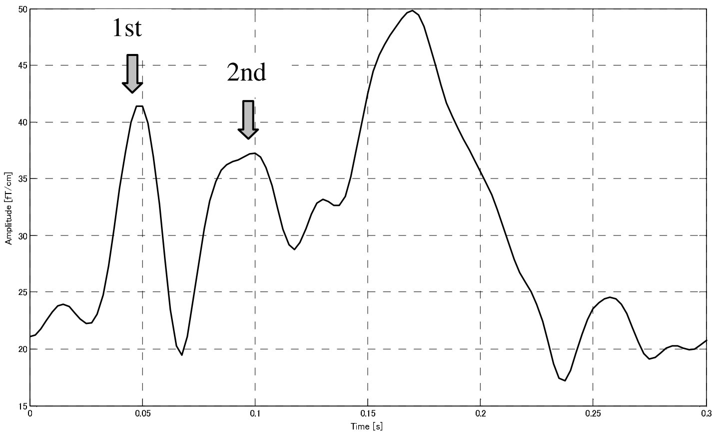


Fig. 5. Waveforms of the left hemisphere as represented by RMS data (Subject B, stimulated location A)

Three peaks were apparent from the RMS waveform. ECD estimation to each peak revealed that the first response was estimated in SI area (6 subjects in 6 subjects) and the second response was estimated in the contralateral secondary somatosensory area (SIIc, 3 subjects in 6 subjects). Fig.6 shows the MRI images, superimposed with ECD activated locations.

(a)
(b)

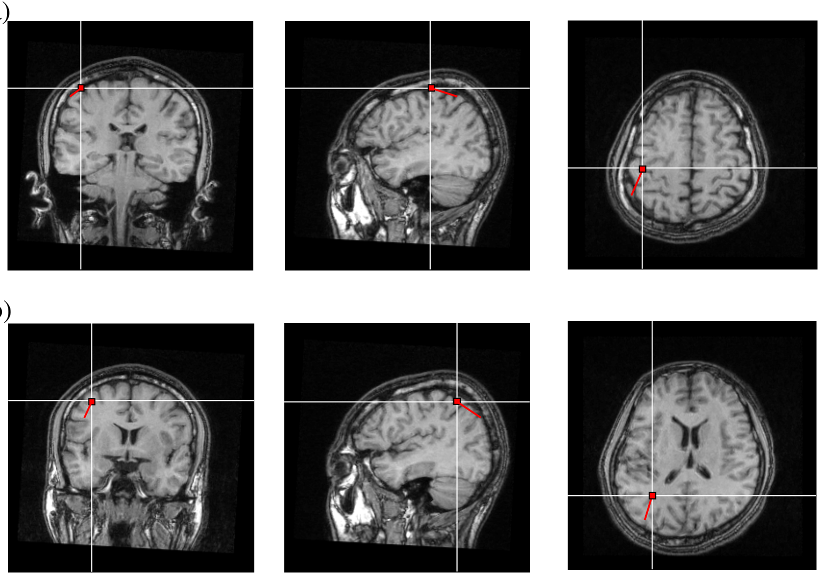


Fig. 6. Source localization for the first component superimpose a with MRI images((a) Subject A, location A, (b) Subject B, location A)

Source localization was estimated to the SI area in which all subjects found peak activities. When evaluating the activity of the SI for each position where the stimuli were presented, a fixed ECD estimation method was used to obtain accurate sources for identifying exact activated locations. Fig.7 shows temporal transition of MEG activities overlapped for all conditions at SI.

Peaks apparently exist at 50 ms after the stimulus onset. This trend was apparent for all subjects. The peak time and the amplitude were extracted from data, and the average latency and amplitude in each stimulated location were estimated. Table 1 summarizes the latency and amplitude of the first component by subjects. Table 2 shows the average latency and amplitude of the first component by distal-proximal relationship. Table 3 shows the average latency and amplitude of the first component by medial-lateral relationship.

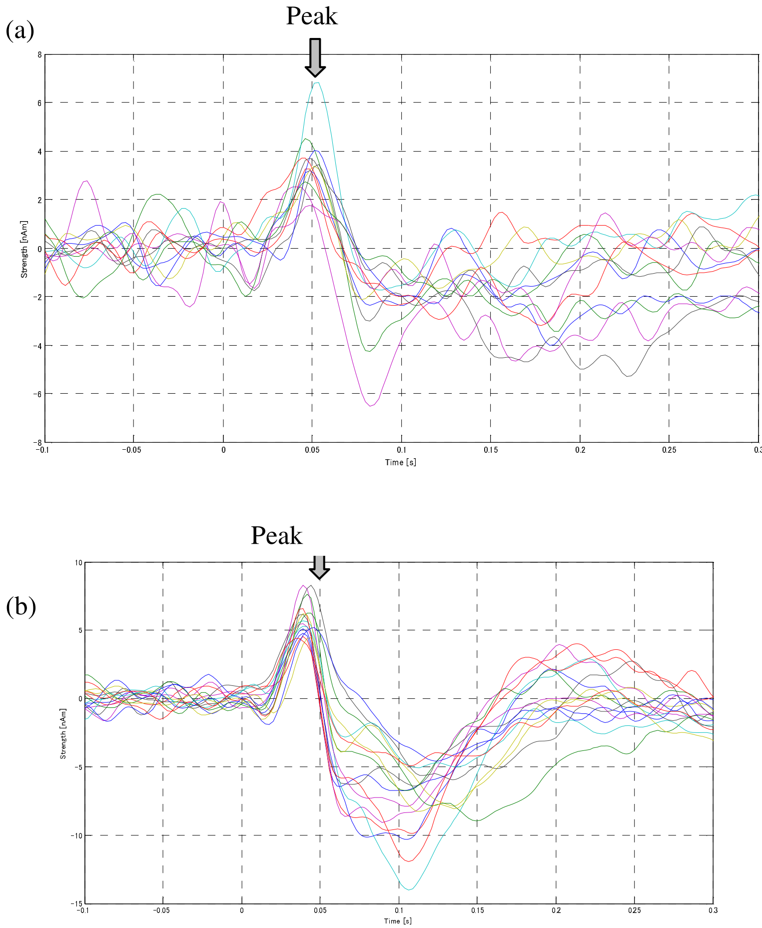


Fig. 7. Temporal transition about MEG activity which focuses on SI for each stimulated location.((a) Subject B, (b) Subject E)

Latency showed large variability between subjects, whereas the amplitude of the activity had small variability between subjects. Analysis of variable (ANOVA) revealed that there were no significant differences on distal-proximal and medial-lateral relationships.

4 Discussion

Peak strength of evoked responses at SI

There were no significant differences in the amplitude of evoked responses at SI by the distal-proximal and the medial-lateral relationships as well as the differences of stimulated locations. It was possibly because the amplitude of evoked responses at SI

Table 1. Latency and amplitude of the first component by subjects

	latency [ms]	strength [nAm]
A	50.8 ± 15.3	6.1 ± 2.7
B	53.2 ± 18.6	5.1 ± 3.6
C	55.6 ± 19.2	5.2 ± 3.1
D	54.4 ± 15.7	4.8 ± 1.2
E	54.8 ± 12.3	5.4 ± 2.4
F	54.8 ± 13.9	6.9 ± 3.1
G	60.4 ± 22.9	5.1 ± 1.7
H	56.4 ± 16.4	5.3 ± 1.4
I	56.0 ± 15.4	5.3 ± 2.6
J	60.4 ± 16.5	5.8 ± 2.6
K	54.8 ± 17.7	5.3 ± 2.5
L	56.8 ± 17.4	4.5 ± 1.4
M	57.9 ± 17.7	3.8 ± 1.2
N	59.4 ± 18.8	5.9 ± 1.1
O	61.3 ± 20.7	5.3 ± 1.3
P	58.4 ± 19.9	4.6 ± 1.2

Table 2. The average latency and amplitude of the first component by distal-proximal relationship

		latency [ms]	strength [nAm]
distal	1	53.5 ± 16.2	5.3 ± 2.7
↑	2	56.6 ± 15.9	5.7 ± 2.2
↓	3	57.0 ± 15.7	5.2 ± 2.2
proximal	4	59.2 ± 17.7	4.9 ± 1.4

Table 3. The average latency and amplitude of the first component by medial-lateral relationship

		latency [ms]	strength [nAm]
medial	Ⅰ	54.7 ± 14.3	5.2 ± 2.3
↑	Ⅱ	56.8 ± 16.1	5.9 ± 2.7
↓	Ⅲ	57.9 ± 18.9	5.2 ± 2.1
lateral	Ⅳ	56.4 ± 16.1	4.8 ± 1.3

reflects the physical quantity of the stimulation. Fujiwara, et al. reported that perceived physical intensity and amplitude of SII were increased whereas there were no differences in the amplitudes of evoked responses in SI when the subjects concentrated on the stimuli [11]. The previous study which investigated the relationship between psychophysical characteristics of the stimulus intensity and somatosensory evoked potentials reported that early responses at SI were correlated with physical intensity of the stimulus, and late responses were correlated with perceptual intensity associated with the stimuli [12]. Mechanoreceptors in the palm area distribute densely at both the center of the palm and proximal part of the proximal phalanges [8], and the amplitude of evoked responses at SI did not change if the stimulated locations were changed. Goodness of fit for the ECDs obtained at SI in this study was set to more than 75% and the criteria for confidence volume was as low as 100mm3, which were more than the criteria used in the previous studies[6]. According to the results, it was suggested that the amplitude of evoked responses at SI did not depend on distribution of mechanoreceptors. Thus, it might be suggested that the differences of stimulated locations did not affect the amplitude of evoked responses observed at SI.

5 Conclusion

When airpuff stimuli were presented to each stimulated location on the palm, neuromagnetic activities were observed at the SI area for all subjects. Goodness of fit for the ECDs obtained at SI in this study was set to more than 75% and the criteria for confidence volume was as low as $100mm^3$, which were more than the criteria used in the previous studies[6]. Although mechanoreceptors in the palm distribute densely at both the center of the palm and the proximal part of the proximal phalanges, no effects on location were found by the amplitude of the evoked responses at SI area. This result suggests that differences in location of the stimulus presentation did not affect the amplitude at SI. In the future, it will be necessary to evaluate latency and amplitude of evoked responses and estimated dipole locations observed at SII on each stimulated location to validate whether difference of the stimulated locations affect the MEG signals. Previous study reported that amplitudes of evoked responses at SII correlated with perceptual intensity associated with stimulus intensity [13]. Also, perceptual intensity for the stimulus intensity may vary with the location on the palm [9]. Therefore, psychological intensity of the MEG signal evoked by stimulus intensity should be further evaluated and the relationship between the amplitudes of evoked responses at SII and perceptual intensity reflected on the stimulus intensity should be examined.

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References

1. Ministry of Health, Labour and Welfare: Field survey of the disabled children (2001)
2. Mizukami, Y., Sawada, H.: A Tactile device using Shape-memory Alloys for the Information Transmission by Higher-level Perception. Transactions of Information Processing Society of Japan (2007)
3. Study of communication support equipment to support the employment of people with disabilities overlapping visual and auditory. National Institute of Vocational Rehabilitation Report, No. 46 (2002)
4. Sakai, T., Tazaki, M., Ito, T.: An Evaluation of an Optimum Stimulus Presentation Method Considering Tactile Sensation on Passive 6-Finger Braile. The Journal of the Institute of Electronics, Information and Communication Engineers. D, Information System J90-D(3), 742–753 (2007)
5. Yamaguchi, H.: Mystery of cutaneous sensation. In: KODANSHA, pp. 26–28 (2006)
6. Forss, N., Salmelin, R., Hari, R.: Comparison of somatosensory evoked fields to airpuff and electric stimuli. Electroencephalography and Clinical Neurophysiology 92, 510–517 (1994)
7. Hashimoto, I., Mashiko, T., Kimura, T., Imada, T.: Are there discrete distal-proximal representations of the index finger and palm in the human somatosensory cortex? A neuromagnetic study. Clinical Neurophysiology 110, 430–437 (1999)

8. Johansson, R.S., Vallbo, A.B.: Tactile sensitivity in the human hand: relative and absolute densities of four types of mechanoreceptive units in glabrous skin. J. Physiol. 286, 283–300 (1979)
9. Mizukami, Y., Uchida, K., Sawada, H.: Presentation of rubbing sensation by a tactile display. The Institute of Electronics, Information and Communication Engineers Technical Report 108(84), 67–72 (2006)
10. Roβ, B., Borgmann, C., Draganova, R.: A high-precision magnetoencephalographic study of human auditory steady-state responses to amplitude-modulated tones. Acoustical Society of America 108(2), 679–691 (2000)
11. Fujiwara, N., Imai, M., Nagamine, T., Mima, T., Oga, T., Takeshitaa, K., Tomaa, K., Shibasakia, H.: Second somatosensory area (SII) plays a significant role in selective somatosensory attention. Cognitive Brain Reseach 14, 389–397 (2002)
12. Hashimoto, I., Yoshikawa, K., Sasaki, M.: Somatosensory evoked potential correlates of psychophysical magnitude estimations for tactile air-puff stimulation in man. Experimental Brain Research 73, 459–469 (1988)