Differences in Beta Oscillation of the Middle Frontal Cortex with or Without Tactile Stimulation in Active Touch Task

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Abstract. Tactile sensation is a valuable feedback for shaping human perception, for instance when using a mobile device or a touch screen. Most studies have used subjective assessments and focused on passive touch. This paper investigates the role of tactile stimulation objectively and quantitatively in active touch task just like real human computer interaction on a tablet device. In this study, participants performed an active touch task to touch virtual guitar lines on a tactile display device. We investigated the difference of neural activities with or without tactile stimulation and found a difference in beta oscillation in the middle frontal area at the late period (from 650 ms to 1000 ms) of the active touch task period. It is assumed that the tactile stimulation felt by the participants' fingertip further induces cognitive processing than the absence of tactile stimulation case. This study provides objective and quantitative evidence that tactile stimulation is able to affect the cognitive processing and top-down control.

Keywords: Haptic interfaces · Neural signal processing
Active touch · Tactile display

1 Introduction

Tactile feedback plays an important role in multimodal feedback [1]. Research on users' multimodal interfaces becomes more important as tablet devices with tactile stimulation are introduced in consumer electronic devices [2]. Touch influences emotion [3], which is known to affect the purchase of products [4]. Active touch refers to the act of touching by applying voluntary, self-generated movements. For instance, comforting active touch is very important for infants to feel secure and stable [5]. However, quantitative and objective evaluation of active touch is lacking. Conventionally, self-reporting methods are utilized, generally after completing the experiment, for evaluating touch experience. However, self-reporting provides limited feedback due mainly to the fact that it evaluates the

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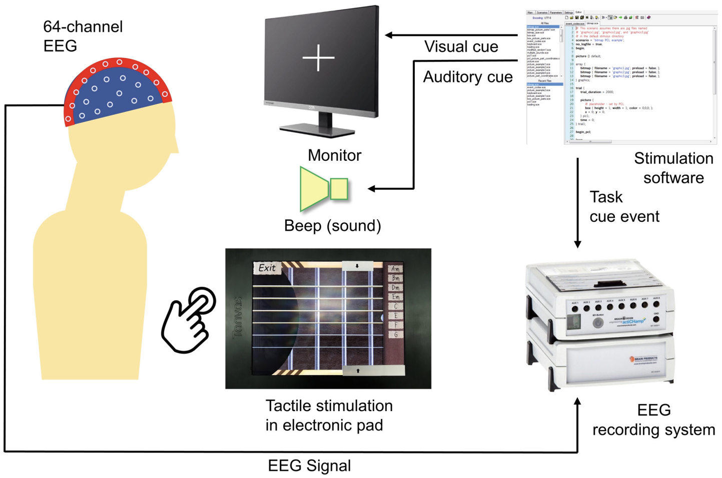


Fig. 1. Block diagram of the experimental setup.

user experience after the experiment is completed rather that what users feel during the experiment. Also, human memory is often exaggerated or distorted [6]. Furthermore, participants sometimes have difficulty in expressing their experiences objectively in the case of ambiguous emotional status [7]. Therefore, a more accurate form of evaluation is needed to better evaluate the effects of active touch on human perception and cognition.

Several studies have shown quantitative brain variations according to tactile sensation using functional magnetic resonance imaging (fMRI) [8,9]. However, the fMRI studies are limited in terms of usability since a real multimodal electronic device can not be used in shielded room. Furthermore, detecting neural activations in fast finger movements using fMRI is very challenging due mainly to low temporal resolution/frame rate [10]. Therefore, it is necessary to study the neural activity using electroencephalography (EEG).

In addition, studies on neurophysiology in touch have focused on passive touch on hairy skin [11–14]. However, when using a tablet device, active touch is realized between the fingertip (with bare skin) and the touch screen. Passive and active touches have been reported to show other brain responses [15,16]. Therefore, it is necessary to study objective and quantitative brain activities depending on the presence or absence of tactile stimulation in active touch during a fingertip interaction. In this paper, we investigate the differences in brain activation depending on the presence and absence of tactile stimulation.

2 Materials and Methods

2.1 Participants

Ten participants (five females and five males) were recruited for this study. All participants met all inclusion/exclusion criteria. The inclusion criteria are: an

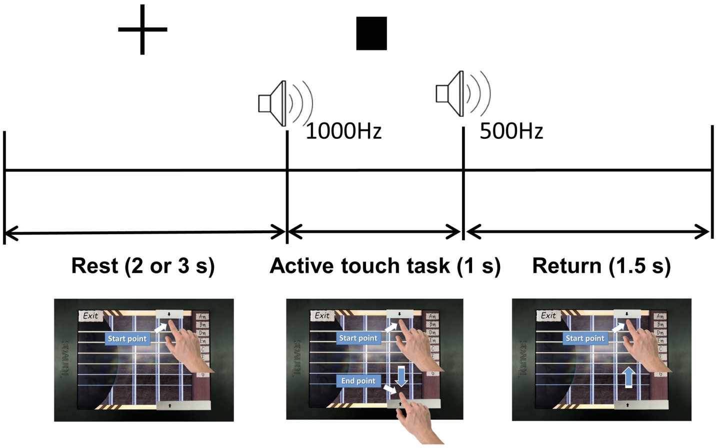


Fig. 2. Schematic diagram of the experimental paradigm.

age range from 20 to 39, right-handedness with no previous knowledge about how to play guitar, and normal or corrected-to-normal vision and hearing. Exclusion criteria included persons with a history of neurological or psychiatric disorders, persons with an orthopedics problem in the right hand, and person with more than 6 months learning experience in playing guitar. We used a virtual guitar for the active touch task, that is why those who play guitar are excluded from the experiment. The experimental procedure and participant recruitment was reviewed and approved by New York University Abu Dhabi Institutional Review Board (IRB #073-2017). Written informed consent was obtained from all participants. All research data were collected and analyzed under IRB guidance.

2.2 Experimental Design and EEG Signal Acquisition

A tactile stimulation electric pad is used in the experiment [17], [18]. We used this device to control the presence or absence of tactile stimulation. Figure 1 shows a block diagram of the experimental setup. The experimental paradigm was presented using the stimulation software (Presentation by Neurobehavioral Systems, Albany, CA, USA). Visual and auditory cues were used, and neurological activities during an active touch task were recorded using a 64-channel EEG device and stored in the EEG recording system (BrainAmp by Brain Products, Munich, Germany). Figure 2 shows the schematic diagram of the experimental paradigm. One trial consists of rest, active touch task, and return periods. The rest period is randomly selected as 2 or 3 s. A fixation appeared during rest period to draw the user attention to the assigned task. The participant places the index finger on the start point and waits for the active touch task as shown in the lower left in Fig. 2. A square shaped visual cue and a 1000 Hz beep sound announce the start of the active touch task. The participants moved their index

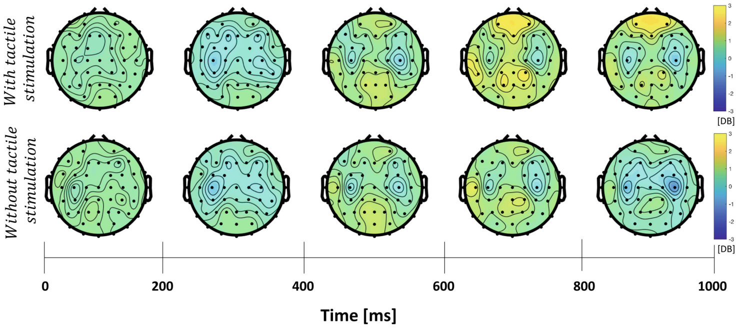


Fig. 3. Topographies of beta power in the active touch task period. The upper figures show the distributions of beta power in the cases of with tactile stimulation mode and the lower figures show that in the case of without tactile stimulation mode.

finger from the start point to the end point within one second of the active touch task. At this time, the tactile stimulation is enabled or disabled by a random counter balancing order. We call these two cases, with/without tactile stimulation mode. However, the visual feedback (guitar strings are shaken) and audio feedback (string sound) are always provided while their fingertip passed through the guitar strings. A beep sound of 500 Hz indicates the end of the active touch task. The return period is for 1.5 s, during which time participants move their index finger to the start point, during which the rectangular visual cues also disappear. Before the experiment, all participants had a training session to reduce the variance of the finger movement time and fit their finger movement time should take full 1000 ms. In the experiment, one trial takes 4.5–5 s and one run takes 48 trials, therefore it takes about 4.5 min. All participants performed four runs and took three short breaks between successive runs. Therefore, we got 96 trial data for each with/without tactile stimulation mode. EEG signals were recorded during all experiment.

2.3 Data Analysis

The EEGLAB toolbox is utilized for EEG signal processing [19]. For preprocessing, EEG signals were down-sampled from 2500 Hz to 1250 Hz. Six EEG data streams corresponding to the outside locations (FT9, FT10, TP9, TP10, PO9, and PO10) were removed. A Zero-phase finite impulse response filter was used for band pass filtering (0.1–55 Hz). A notch filter was applied with a zero-phase digital filter to remove the 50 Hz line noise. The artifact subspace reconstruction method was applied to remove eye movement and muscle artifacts [20]. Then, the filtered EEG signal was divided into epochs corresponding to each with/without tactile stimulation mode. Finally, EEG signals were re-referenced using the common average reference [21]. After preprocessing, spectral power densities of theta (4–7 Hz), alpha (8–12 Hz), beta (13–30 Hz), and gamma (31–50 Hz) bands at each channel were computed via short-time Fourier transform.

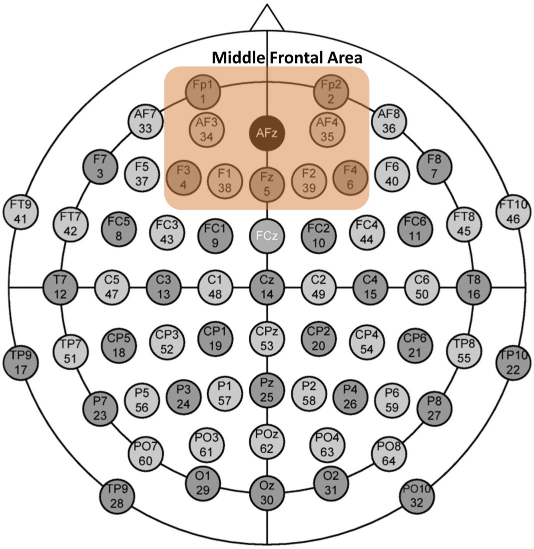
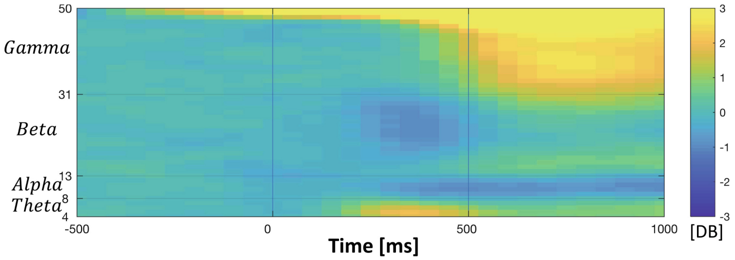


Fig. 4. 64-channel EEG montage. The orange box indicates the middle frontal area. (Color figure online)

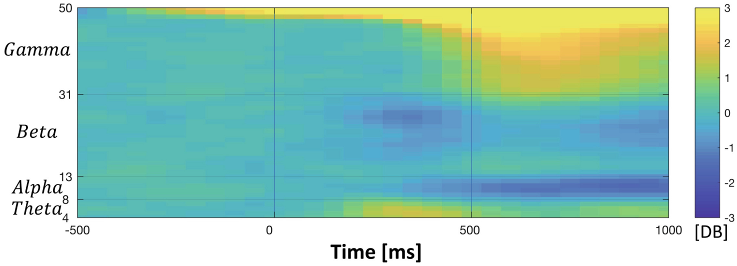
The differences between with/without tactile stimulation modes were analyzed through topography of each frequency band in order to find what areas of the brain are best stimulated by tactile stimulation. Spectrogram analysis was used to examine differences between theta, alpha, beta, and gamma bands for the two modes (with and without tactile stimulation). Changes in spectral power density over time depending on the with/without tactile stimulation mode were also investigated.

3 Results

We first investigated the differences in frequency bands and brain regions depending on with/without tactile stimulation. Figure 3 shows the topographies of beta power according to the 200 ms time windows in the active touch task period. Within 600 ms, there were no significant differences with/without tactile stimulation mode. However, beta power in the middle frontal area (as shown in Fig. 4) in the case of tactile stimulation mode was larger than that in the other case after 600 ms (rank sum test, $p < 0.05$). Therefore, we focused on the middle frontal area and investigated the change of spectral power density with time through the spectrogram in Fig. 5. We also found higher alpha and gamma power in the case of tactile stimulation mode than that in the other case at the late period in the active touch task. However, it was not statistically significant. Figure 6 shows average time course of the spectral power density of the beta band. The desynchronization of the beta power occurs up to 300 ms after the active touch



(a) With tactile stimulation mode



(b) Without tactile stimulation mode

Fig. 5. Spectrogram of active touch task period in the middle frontal area.

task is started. Beta rebound also appeared similarly after 300 ms in both conditions, with and without tactile stimulation. However, in the no tactile stimulation mode, the beta power decreased again after 600 ms. On the other hand, in the tactile stimulation mode, the beta power continuously increased and became larger than the base line after 500 ms. After 650 ms, the beta power difference between the two modes showed a statistically significant difference (rank sum test, $p < 0.05$).

4 Discussion

In the first half of the active touch task, desynchronization and rebound of beta power were observed in the middle frontal cortex, regardless of with/without tactile stimulation as shown in Fig. 6. This phenomenon has been observed in the perceptual processes [22]. The tactile simulation pad provides audio and visual feedback, and even in the without tactile stimulation mode, it provides a sort of tactile feedback because the participants can feel the surface of the screen through the index finger. Thus, we suspect that this sensation triggered perceptual neural processing. However, after 650 ms of active touch task, there was a significant difference according to with/without tactile stimulation (rank sum test, $p < 0.05$). Beta power has risen more than the base line in the case of with tactile stimulation mode. It has been well know that beta oscillation reflects attentional, emotional

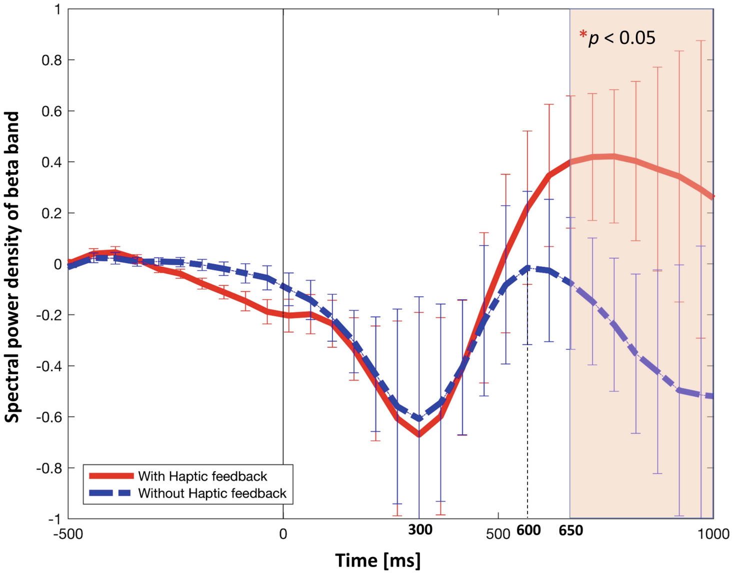


Fig. 6. Grand average time course of the spectral power density of the beta band. Error bars indicate variance. (rank sum test, $*p < 0.05$)

and cognitive processes [23], [24]. In particular, frontal beta oscillations are known to be associated with top-down control [25], [26].

Changes in frontal beta power through an active touch task are observed with animals [27]. The study reported that frontal beta oscillation reflects cognitive control through the monkey experiment. Our results show that tactile stimulation influences not only somatosensory (bottom-up) but triggers top-down control. This result did not reveal any significant difference with/without tactile stimulation in the somatosensory motor cortex. It may be due to the small number of participants in the experiment. This study will be extended in the future by increasing the number of participants in order to investigate such differences further.

5 Conclusion

In this paper we investigated the differences in neural activation with or without tactile stimulation during user interaction with a tablet device providing tactile feedback. As a result, we found differences in beta oscillation in the middle frontal area, although we did not find any significant difference in neural signal in the somatosensory motor area. At the beginning of the active touch task, there were no significant differences with or without tactile stimulation, however there was a significant difference after 650 ms (rank sum test, $p < 0.05$). It is presumed that tactile stimulation triggered the cognitive processing by making the participants more immersed in the interaction. This is a study that provides objective and quantitative evidence of differences in the presence or absence of tactile stimulation.

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