Human physiological response to intensity of somatosensory stimulation Applied to the ankle tendon

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Abstract. In order to maintain postural balance, the somatosensory system contributes to balance providing the information on each part of body and its relative position by the receptors of the muscles and joints spread throughout the body. The relationship between the somatosensory system and postural balance has been reported from the experiments that confirmed the increase of postural stability and the decrease of the body's sway were achieved by stimulating somatosensory system. In this study, two hypotheses were established in order to investigate a sense of postural balance and to study human body reaction by quantitative somatosensory stimulation. The somatosensory stimulation system and brain wave analysis system were used and 7 male adults who are without any neurological diseases participated in the experiment. Somatosensory stimulation device was attached on the tibialis anterior tendon and the Achilles tendon of the subjects and sensory threshold(100%), sub-threshold (90%) and supra-threshold(110%) stimulation was applied. The course of changes in brain activities when the somatosensory stimulation was applied on the tibialis anterior tendon and Achilles tendon was similarly observed regardless of the intensity of somatosensory stimulation. And the tendency of amplitude change by somatosensory evoked potential was found in all experiment conditions similarly regardless of intensity of the somatosensory stimulation. The results of this study will become the useful material along with results from the previous studies, which can promote development of somatosensory stimulation devices for the enhancement in the sense of postural balance.

1 Introduction

Postural balance is defined as the ability to keep the state of postural stability when maintaining the center of gravity in the static position or dynamic movements. In order to maintain postural balance, the body is constantly provided with information from the environments or the movements of the body by somatic sense, vestibular sense, and visual sense. Among them, the somatosensory system contributes to balance providing the information on each part of body and its relative position by the receptors of the muscles and joints spread throughout the body[1-2].

The relationship between the somatosensory system and postural balance has been reported from the experiments that confirmed the increase of postural stability and the decrease of the body's sway were achieved by stimulating somatosensory system of the subject who was in the standing state or walking state[3-5]. However, these previous studies were conducted by stimulating the single form of somatosensory stimulation regardless of the subject's physical characteristics or individual differences and the intensity of somatosensory stimulation was not delineated. After that Priplata et al. have stated the ability of human postural balance can be affected by slight mechanical stimulation that either could be sensed by the individual or not in respect to an individual's threshold[6]. However, this study applied the combination of the mechanical stimulation and white noise, which could not explain the response of human body by pure mechanical stimulation.

Besides the studies conducted as above to investigate the relationship between the somatosensory system and the postural balance, various experiments on the body's reaction induced by somatosensory stimulation have been performed. In these studies, the impacts of somatosensory stimulation on the body have been identified in the dimension of neurological mechanisms by the analysis of the EEG frequency and amplitude evoked potential by the stimulation of somatosensory system. The responses of the brain against mechanical vibration were observed in humans and animals and the process of exercise and sense, and mental activities were described through the somatosensory evoked potential[7-9].

Therefore in this study, two hypothesis were established in order to investigate a sense of postural balance and to study human body reaction by quantitative somatosensory stimulation and they are; first, different human body reactions will be induced depending on the location of the incoming somatosensory stimulation and second, somatosensory stimulation even with sub-threshold would significantly affect the human body. The two hypotheses were validated by observing brain waves.

2 Method

2.1 Experiment design

This experiment was performed in a dark room to minimize interference from the outside. For this experiment, the somatosensory stimulation system to inflow stimulation on the subject was produced by using a linear vibration device(DMJBRN1036AH, Samsung Electro-Mechanics Co.) generating mechanical vibrations. It was designed to enable adjustment of the strength of incoming somatosensory stimulation by controlling the voltage applied to the vibration device with adjustable ankle-band which allows the exact spot of stimulation regardless of the thickness of the subject's ankle.

In addition, BrainVision(Brain Products GmbH, Germany) were used to gather and collect brain waves and BESA(BESA GmbH, Germany) were used to observe changes in the brain waves followed by inflow of somatosensory stimulation.
The somatosensory simulation system and brain wave analysis system in the experiment were synchronized with the trigger signal to navigate the changes in brain waves by the inflow of somatosensory stimulation.

2.2 Procedures

The experiment was conducted subject to 7 male adults(23.8±1.32 years) who are without any neurological diseases. The experiment started with procedure of attaching the EEG electrodes on the subjects' scalp. The subjects sat comfortably in chairs and wore brain caps and the electrodes were injected electrode paste with a syringe to lower the impedance. Then, somatosensory stimulation device was attached on the tibialis anterior tendon and the Achilles tendon of the subjects and sensory threshold(100%) of the subjects was found by repeatedly increasing and decreasing the intensity of vibration and based on this, the intensity of sub-threshold (90%) and supra-threshold(110%) were calculated to be used in the experiment. Somatosensory stimulation that were setup in advance were applied on the Achilles tendon and the tibialis anterior tendon of the subjects while their brain waves were simultaneously measured. The intensity of somatosensory stimulation was performed in a random order to minimize the impact of the factors other than the somatosensory stimulation.

2.3 Data Analysis

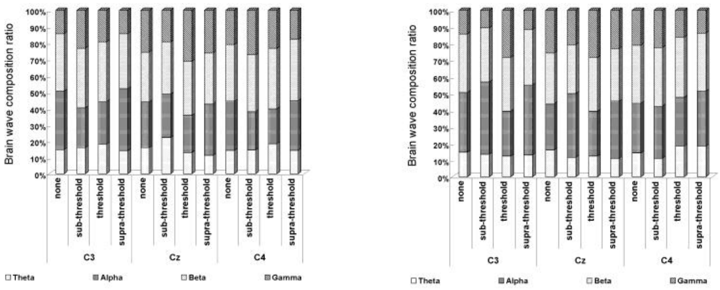
In this experiment, 62-EEG, ECG and EOG were collected through 64-channel EEG acquisition system and EEG was analyzed with the BESA program.
Data analysis was divided into two types: the frequency analysis for the brain activity and the amplitude analysis for the brain recognition and different processes were applied to carry out each type of the analysis. To analyze the brain activity, measured EEG was separated to frequency components using FFT to be converted into composition ratio affecting each wave. To analyze the brain recognition, the size of SEP amplitude between 100~150ms (N150) and 20~350ms (P260) was extracted from the measured EEG based on the marker created at the point of inflow stimulation.
Extracted composition ratio and the size of SEP amplitude were obtained statistically using SPSS ver.12.0 and the verification for the statistical data was conducted in t-test dependent on the nature of the computed data.

3. Results

3.1 Frequency Analysis of EEG According to the Somato-sensory Stimulation

Fig.1 shows the changes in brain activities when the stimulation was applied on the Achilles tendon and tibialis anterior tendon.

When the somatosensory stimulation was introduced in the tibialis anterior tendon, it was found that β-wave classified to be the fast wave was increased at Cz and C4 electrodes and there was a tendency of β-wave and γ-wave to simultaneously increase at C3 electrode. When the stimulation was applied to the Achilles tendon, α-wave which is classified to be the slow wave was increased at C3, Cz and C4 electrodes and θ-wave was increased at C4 electrode. The course of changes in brain activities when the somatosensory stimulation was applied on the tibialis anterior tendon and Achilles tendon was similarly observed regardless of the intensity of somatosensory stimulation. In other words, the course of change in frequency was observed in sub-threshold and in threshold, and the two values were found to be similar with each other.

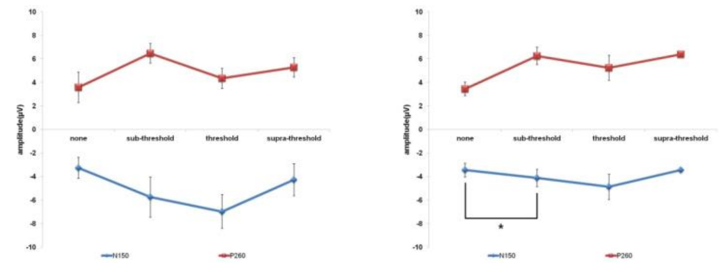


(a) (b)

Fig. 1. Changes of brain wave composition ratio (a) when somatosensory stimulation were applied on the tibialis anterior tendon and (b) when somatosensory stimulation were applied on the Achilles tendon.

3.2 Amplitude Analysis of EEG According to the Somato-sensory Stimulation

Table 1 and Fig.2 shows the changes in amplitude evoked by the somatosensory responses when the stimulation were applied on the tibialis anterior tendon and the Achilles tendon.



(a) (b)

Fig. 2. Changes of SEP(N150 and P250 component) amplitude at (a) C3 and (b) Cz electrode when somatosensory stimulation were applied on the tibialis anterior tendon. (* : $p<0.05$)

When the stimulation were applied on the tibialis anterior tendon, increase of N150 component was observed at C4 electrode and of P250 component at C3, Cz, and C4 electrodes. When they were applied on the Achilles tendon, both N150 component and P260 component were found to be increased at all C3, Cz, and C4 electrodes.
The tendency of amplitude change by somatosensory evoked potential was found in all experiment conditions similarly regardless of intensity of the somatosensory stimulation. In other words, the amplitude change pattern observed in this experiment was appeared to be all similar in the settings of sub-threshold intensity and of threshold.

Table 1. SEP(N150 and P250 component) amplitude at the Central electrode when somatosensory stimulation were applied on the tibialis anterior tendon and Achilles tendon. (* : p<0.05)

		N150				P260			
		None	Sub-T	T	Sup-T	None	Sub-T	T	Sup-T
tibialis anterior tendon	C3	-3.25	-5.74	-6.97	-4.26	3.57	6.47	4.35	5.27
	Cz	-3.44	* -4.12	-4.87	-3.43	3.44	6.26	5.24	6.39
	C4	-3.91	* -3.55	-2.87	* -2.81	3.47	6.11	6.38	6.14
Achilles tendon	C3	-3.25	-8.20	-5.31	-4.67	3.57	9.98	6.63	7.04
	Cz	* -3.44	-6.05	* -6.51	-4.62	3.44	8.06	5.48	7.44
	C4	* -3.91	-6.03	* -5.78	-4.69	3.47	10.14	5.73	7.28

4. Discussion

In this study, the change in EEG by somatosensory stimulation, which was introduced into the body for promoting a sense of postural balance, was analyzed to examine body responses with quantitative somatosensory stimulation. During the process of standing, walking, and maintaining postural balance, somatosensory stimulation was applied to the tibialis anterior tendon and Achilles tendon. From that results, it was found that γ-wave and β-wave representing the fast wave tend to increase when stimulation were applied to the tibialis anterior tendon and α-wave and θ-wave representing the slow wave tend to increase when applied to the Achilles tendon. This response is different from the usual reaction of the brain, in which β-wave that occurs when the motor system is in the standby state increases by the inflow of sensory stimulation[10]. The results from this experiment can be explained in two ways.
First, it can be explained through pathways of somatosensory stimulation that flows into the tibialis anterior tendon and Achilles tendon. The somatosensory stimulation into the tibialis anterior tendon and Achilles tendon intensifies the innate senses via muscle spindle, joint receptors, and skin receptors[11-12] and it can be induced that the somatosensory stimulation even with the same kind and intensity can cause different body responses depending on the location of the inflow. Location of the sensory endings vary within the primary receiving area because the acceptance regions and the pathway of somatosensory stimulation are different by the inflow location of the somatosensory stimulation[13].

The second way of explanation is by α-wave frequency that is induced from the somatosensory stimulation on Achilles tendon. The α-wave frequency from the experiment appeared between 12~ 13Hz, which was classified as fast-α wave that is usually induced while contracting muscles or paying attention[14]. This is a state of α-wave approaching to be β-wave but the frequency of α-wave appears more recurrently, and as a result, high percentage of α-wave was shown. Therefore, if supposed that α-wave which occurs with the somatosensory stimulation on Achilles tendon has similar properties as β-wave and it does not follow the classification scheme of EEG that is commonly known, it can be said that the somatosensory stimulation on two different locations has caused similar effects.

On the other hand, body reaction is generally known to be induced by the EEG of somatosensory stimulation and the experiment showed that the body reaction by somatosensory stimulation with sub-threshold intensity on tibialis anterior tendon and Achilles tendon appeared to have similar patterns with one in threshold intensity. The amplitude of N150 component and P260 component[9,15] among the EEG evoked with sub-threshold intensity, showed similarities with the change in amplitude by stimulation on threshold intensity. Such results are different from the typical conception that physiological reactions cannot be induced by the stimulation in sub-threshold. The results of this experiment can be explained by the anatomical structure of tibialis anterior tendon and Achilles tendon where the somatosensory stimulation is applied. These locations have spread joint receptors and skin receptors. These receptors are activated as producing action potentials by the external stimulation[16]. At this time, the point with stimulation intensity that can produce action potential is called the stimulation threshold and in a case of a single receptor, it does not respond to the external stimulation with the intensity less than the threshold because it typically follows all-or-none law[13,17]. However, the subject locations for this experiment or the tibialis anterior tendon and Achilles tendon where the somatosensory stimulation was applied have anatomical structures in bundles of single receptor, the all-or-none law of single receptor will not apply in the dimension extended for the tibialis anterior tendon and Achilles tendon. If it is supposed that the sensory stimulation activating most of the receptors in tibialis anterior tendon and Achilles tendon is the stimulation threshold, then some of the single receptors have individual stimulation threshold that is less in the strength of the overall stimulation threshold. The responses of individual receptors are accumulated and it may induce a week body reaction.

The results obtained from the experiment above can be applied to the development of somatosensory stimulating device applicable to the disabled with difficulties in walking due to the weakened muscles or the nervous system disorders or the elderly with weakened body due to aging. The first results from the experiment, where different body reactions were induced by the stimulation inflow location, combined with the studies on the reaction of the musculoskeletal system[4-5,18] would become the rationale to neurologically explain the body reaction of the somatosensory stimulation. Therefore, musculoskeletal reaction which increases postural stability or reduce the fluctuation of the body can be extended to the level of neurology and explained. Furthermore, it can be used as a basis material to setup the position to apply somatosensory stimulation in account of the interaction between the skeletal muscles and the nervous system. From the second results from experiments in which the body reaction was observed by the intensity of somatosensory stimulation, it was found that the body reaction can be induced by activating the sensory receiving areas of the cerebrum even with the stimulation which cannot be recognized by the body since they are below the stimulation threshold. And this might solve the problem that the vibratory stimulation are recognized as the change of external environment disrupting the postural balance[19]. In other words, utilization of the vibratory stimulation below stimulation threshold can be applied in the development of technology that can stimulate the somatosensory while the body cannot recognize for improvements of postural balance.

5. Conclusions

In this study, the body reaction by the somatosensory stimulation which was entered in the body for the improvement of the postural balance was observed and the body reaction of the different inflow location for somatosensory stimulation and of different inflow intensity were analyzed with EEG. From the analysis, conclusions were obtained as follows.

1. The brain response of the somatosensory stimulation on tibialis anterior tendon and Achilles tendon, or the structures that play an important role in walking activity was shown differently by the inflow location of the somatosensory stimulation. In case of the stimulation on tibialis anterior tendon, the ratio of fast wave increased and on Achilles tendon, the ratio of slow wave increased.
2. On the other hand, the brain response for the somatosensory stimulation on the tibialis anterior tendon and Achilles tendon appeared similarly regardless of the stimulation intensity. It was observed that the change of amplitude on somatosensory evoked potential with sub-threshold intensity appears to be similar to that with threshold intensity.

The results from this experiment are sufficient to support the initial hypothesis of the research that the somatosensory stimulation entered into the body for improvement of postural balance induces different body reaction by the inflow location and even the sensory stimulation with intensity below threshold may affect the human body. In addition, it can be combined with a variety of previous studies regarding the somatosensory stimulation to become a basis material to identify the human body response mechanism by the somatosensory stimulation that is entered into the body for enhancement of a sense of balance. If additional advanced studies regarding the intensity of somatosensory stimulation are carried out, it is expected to be utilized in development of various assistive and rehabilitation system for the elderly and people with disabilities.

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