872. Effects of muscular response for the intensity of vibratory stimulus applied on the ankle tendon

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Abstract. The present study was conducted to measure the individual threshold value for the somatosensory system of the human body, the thresholds value of vibratory stimulus were assessed through the ascent and descent methods. In the interests of the attainment of this study`s goal, comparing the thresholds value measured and change of state of the muscles when applied on the ankle tendon connected to muscles, changes in threshold measurement accuracy due to the differences in measuring methods were discussed.

The experiment was conducted by constructing systems to stimulate somethetic sensibility by vibratory stimulus, ultrasound imaging system and EMG system. Five adult males were involved in this experiment.

According to the results of experiments, the threshold value of somatosensory stimulation measured by the ascent method was greater than the threshold values measured by the descent method. And the muscular response to the somatosensory stimulation applied to the tibialis anterior tendon showed a larger rate of change with the ascending stimulus than with the descending stimulus.

The results of this study could serve as a basis to discuss the reliability of the measurement method of the human body's individual threshold value for the somatosensory system through the ascent and descent methods and can be used as reference data for the integration and performance threshold measurement methods.

Keywords: vibratory stimulus, somatosensory stimulation, threshold value, muscular response.

Introduction

The human body's postural stability is maintained by the interaction of a variety of human sensory organs and the musculoskeletal system. The equilibrium of sensory information and movement is affected by various factors such as age and the environment. The body's physiological, psychological, emotional and behavioral changes caused by the environment and age tend to cause physical changes which can be extended to the changes in the behavior and features of the human body. The various complementary technologies and enhancement techniques for degraded function are being studied as a solution to kinematic-morphological and kinematic changes in walking and movement features that may occur through the changes and loss of function in the body. Particular focus has been placed on efforts to recover the degradation of musculoskeletal function by taking advantage of externally applied vibratory stimulus for somethetic sensibility. A study by Bongiovanni et al. [1] confirmed a force increase when applying somatosensory stimulation to the tibialis anterior tendon at submaximal contraction, and a study by Brendan et al. [2] confirmed a force increase during the maximum voluntary contraction of the knee extensor after applying somatosensory stimulation to the femoral. In addition, various studies have shown that muscle function changes due to somatosensory stimulation and that the function of the musculoskeletal system is strengthened through somatosensory stimulation [3-7].

The prior studies focused on the change in the body response caused by the characteristics and the applied location of somatosensory stimulation. In particular, the efforts to induce the desired body responses, such as a stable gait and postural control, through changes in the frequency, amplitude, and contact area of vibratory stimulus formed the majority of the research. However, the researchers could not provide that the relationship between intensity of the somatosensory stimulation, which depends on the individual's threshold value and human body responses, because the individual threshold values to the changes of the characteristics of somatosensory stimulation were not considered.

Since then, Priplata et al. [8] reported that the reaction of the human body caused by minute stimulus than subject's individual threshold value. Simeonov et al. [9] discussed the individual threshold value of the human body to the vibration characteristics of somatosensory stimulation, reporting that postural sway occurs instead by randomly applied somatosensory stimulation when considering the subject's individual threshold value. As such, the individual threshold value for the somatosensory stimulation is a very important factor in that it may determine the intensity of somatosensory stimulation entering the body and quantify the physical size of vibratory stimulus. However, to date, a measurement method of the body's individual threshold value for the somatosensory stimulation has not been determined. Thus, the evaluated individual threshold value for somatosensory stimulation lacks reliability. In addition, the accuracy of the threshold value due to differences in measurement method is not sufficient.

In the present study, to measure the individual threshold value for the somatosensory stimulation, the threshold values of somatosensory stimulation were assessed through the ascent and descent methods used in previous studies. Moreover, by comparing the thresholds measured when applied on the ankle tendon connected to muscles, changes in threshold and threshold measurement accuracy due to the differences in measuring methods were discussed. The results of comparing methods for threshold measurment can be used to determine the intensity of the stimulus in the application of person-specific somatosensory stimulation and are expected to be utilized as the standard for the integration of individual threshold measurement methods.

Experimental methods & equipment

The experiment was conducted by constructing systems to stimulate somethetic sensibility by vibratory stimulus, ultrasound imaging system and EMG system in a dark room in order to minimize interference from the outside, which experimental methods and equipment set up are shown in Fig. 1.

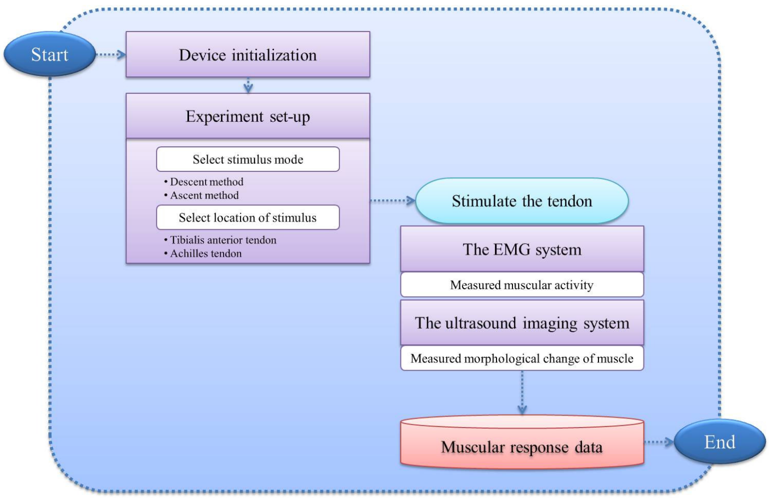


Fig. 1. Block diagram of the system for application of vibratory stimulation and measurement of muscular response

The somatosensory stimulation system for applying vibratory stimulus to the subject was constructed using the linear vibration motor (DMJBRN1036AH, Samsung Electro-Mechanics Co.) to generate mechanical vibrations. The somatosensory stimulation system was designed to allow the intensity of somatosensory stimulation entering into the human body to be adjustable through the control of electrical characteristics of the input power driving the vibrating device. In the experiment, regardless of the contact area, a stimulus with a vibrational frequency of 250 Hz, the highest absolute sensitivity [10], was used, and somatosensory stimulation was applied to the tibialis anterior tendon and Achilles tendon in order to stimulate the tibialis anterior muscle and gastrocnemius muscle which are responsible for extension in the ankle and play a major role in maintaining the balance of the body.

In order to observe the changes in muscular response according to the application of the somatosensory stimulation, the EMG system was constructed using a 2-channel EMG module of the biological information signal acquisition system Biopac (BIOPAC System Inc., USA). EMGs of the tibialis anterior and gastrocnemius muscles were obtained using Ag/AgCl surface electrodes, and EMG data sampling frequency was set at 1 KHz. In addition, an ultrasound imaging system for the analysis of morphological changes in muscle activity, the AccuvixV10 (Samsung Medison Co., Korea) was utilized, and a linear catheter for the ease of observing muscle tissue was used.

Experimental procedure

The experiment was performed on five adult males free of musculoskeletal or neurological disease. Before starting the experiment, the contents of the experiment were fully explained to the subjects, and voluntary consent was obtained.

To measure the body's threshold value considering individual differences, the ascent and descent methods used in previous studies were utilized. The ascent or descent input voltage of 0.1 Vrms to generate vibration for the somatosensory stimulation, the starting point of the subject's perception of the vibration, was considered as the threshold value to somatosensory stimulation. To ensure reliability, the measurement was repeated three times. Subsequently, utilizing the same ascent or descent method, the intensity of somatosensory stimulation applied to the Achilles and tibialis anterior tendon, EMGs of the tibialis anterior and gastrocnemius muscle were measured, and ultrasound images were acquired. The measuring of the threshold values of somatosensory stimulation and EMGs were conducted in random order to minimize the impact caused by other factors.

Data analysis

In the present experiment, using the ascent and descent methods, the body's threshold values for somatosensory stimulation were measured. The tibialis anterior muscle and gastrocnemius muscle activity, changed by applying somatosensory stimulation, were measured using EMGs and ultrasound images.

To remove noise from the EMGs, a band-pass filter of 60-500 Hz was applied. To remove the noise caused by the inducement of the AC, a 60 Hz notch filter was used. Measured EMG data were analyzed after being divided into time and frequency domains using the Biopac analysis program (AcqKnowledge ver 3.7).

As the individual threshold value of the human body is correlated with the intensity of the somatosensory stimulation, instead of the absolute physical quantity, the relative physical quantities of somatosensory stimulation were applied. Accordingly, in the EMG data analysis, 50 %, 100 % and 200 % of the intensity threshold values were used as units instead of Vrms.

Threshold values for the somatosensory stimulation obtained via the ascent and descent methods was statistically processed by SPSS12.0, and a t-test was conducted to verify the statistical significance of the data.

Results

The results measuring the threshold values of somatosensory stimulation applied to the ankle tendon using the ascent and descent methods are shown in Fig. 2.

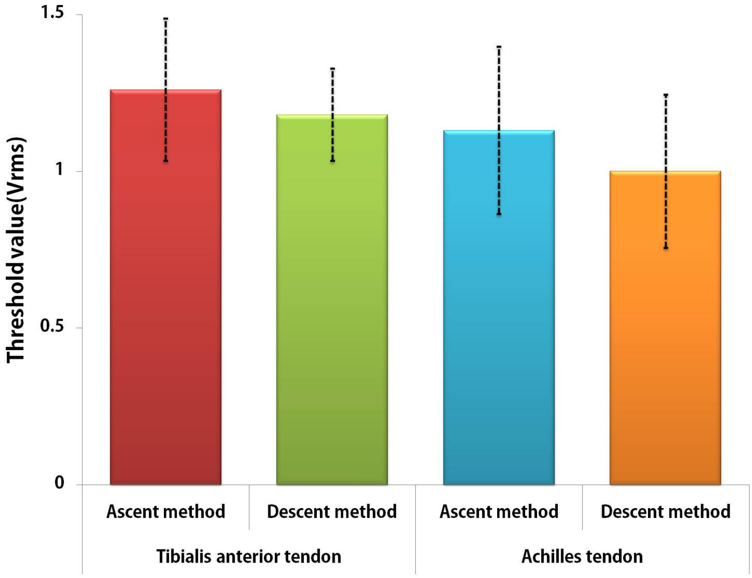


Fig. 2. The measured threshold value of somatosensory stimulation according to difference in stimulus location and measurement methods

The threshold values of somatosensory stimulation measured in the tibialis anterior tendon by the ascent method was 1.26 Vrms, and the threshold values of somatosensory stimulation measured by the descent method was 1.18 Vrms which is 1.06 times the value of the others. The threshold value of somatosensory stimulation measured by the ascent method in the Achilles tendon was 1.13 Vrms and the threshold of somatosensory stimulation measured by the descent method was 1.00 Vrms, which is 1.13 times the value of the others. In both conditions, the threshold value of somatosensory stimulation measured by the ascent method was greater than the threshold measured by the descent method. The threshold value distribution of somatosensory stimulation when measured by the ascent method in the tibialis anterior tendon showed a deviation of 0.45, and that measured by the descent method showed a deviation of 0.29. The threshold value distribution of somatosensory stimulation when measured by the ascent method in the Achilles tendon showed a deviation of 0.53, and that measured by the descent method showed a deviation of 0.48. Therefore, in both conditions, the deviation of the threshold value measured by the descent method was smaller.

The muscular activities caused by the changing intensity of somatosensory stimulation applied to the ankle tendon are shown in Fig. 3. The response of the tibialis anterior muscle to somatosensory stimulation which continues to ascend in strength showed that the larger was the sensory stimulation, the larger was the muscle response. In the response to sensory stimulation which continued to descend, the same proportional relationship between the sensory stimulation and the muscle reaction strength was confirmed.

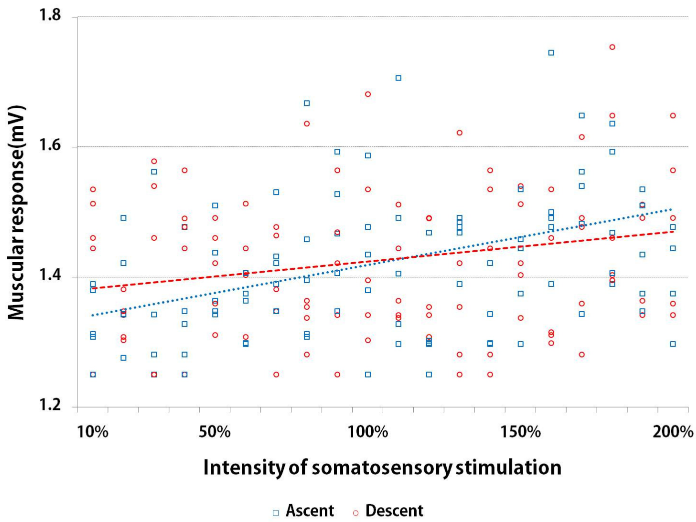
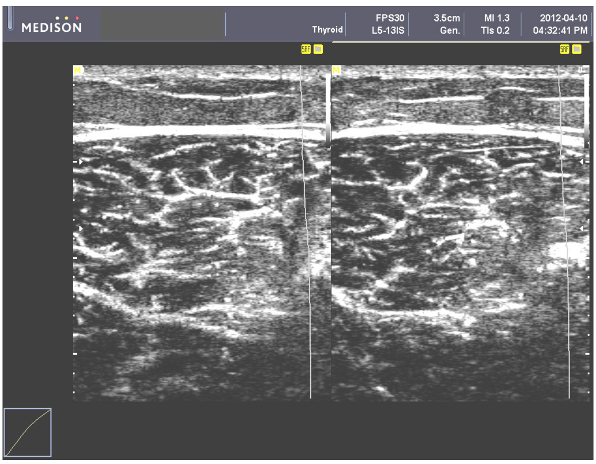


Fig. 3. The changes of muscular response at tibialis anterior muscle measured EMG system by the variations of intensity at tibialis anterior tendon

In the activity response of the tibialis anterior muscle measure when applying ascending somatosensory stimulation, the maximum change rates of muscle activity response were observed when the somatosensory stimulation with the intensity of 70 % threshold measured by the ascent method was applied. In the activity response of the tibialis anterior muscle measured when applying descending somatosensory stimulation, the maximum change rates of muscle activity response were observed when the somatosensory stimulation with the intensity of 90 % threshold value measured by the descent method was applied. The muscle activity response to the somatosensory stimulation applied to the tibialis anterior tendon showed a larger rate of change with the ascending stimulus than with the descending stimulation.

The changes in muscle activity can be seen more clearly in the ultrasound images obtained when the somatosensory stimulation was applied as shown in Fig. 4.



(L) (R)

Fig. 4. The morphological change of tibialis anterior muscle through measured ultrasound images: (L) The somatosensory stimulation was not applied and (R) The threshold value of somatosensory stimulation was applied

The width of tibialis anterior tendon was 2.13 cm when the somatosensory stimulation was not applied, whereas it was increased to 2.14 cm when the threshold value of somatosensory stimulation was applied. According to ultrasound images, arrangement of muscular fiber is evenly when the threshold value of somatosensory stimulation was applied rather than somatosensory stimulation was not applied. These realignments of muscular fibers appear due to muscular contraction, which is caused by the somatosensory.

Analysis and conclusion

The present study was performed to measure the threshold value of somatosensory stimulation through methods testing the individual threshold value of the human body and to discuss the reliability of the sensory thresholds measured by muscular response.

Preferentially, the threshold value differences measured by the ascent and descent methods and the cause of their occurrence are discussed. When the threshold value was measured while applying the ascending or descending somatosensory stimulation to the tibialis anterior tendon and the achilles tendon, the threshold value of the descending somatosensory stimulation was lower than the threshold value of the ascending somatosensory stimulation in both conditions. The distribution of the threshold value of the ascending somatosensory stimulation appeared to be wider than the distribution of the threshold value of the descending somatosensory stimulation. Two major reasons may explain why the difference of the threshold value occurred.

First, the increase of the threshold value may have been caused by the threshold intensity. The sense organs in the tibialis anterior tendon and achilles tendon affected by the somatosensory stimulation are muscle spindles and Golgi tendon organs [11-13]. The somatosensory stimulation generates an electrical signal by exciting the sense organs. At this time, the intensity level that generates the electrical signal is the threshold level that differs depending on the type and individual unit of the sense organs. When the sense organs are excited by the ascending somatosensory stimulation, a threshold level which is greater than the threshold value is required, and when stimulation larger than this threshold level is applied to the human body, the sense organs will receive the stimulation and cause activity. In the case of the descending somatosensory stimulation, however, the stimulation above the threshold level is not required; thus the sense organs can be maintained in an excited state even when the stimulation is smaller than the ascending somatosensory stimulation.

Second, the decrease of the threshold value may be caused by the residual somatosensory stimulation. The sense organs may misidentify the stimulation if they interpret the stimulation as being due to the residual sensory stimulation because the stimulation is lower than the threshold value in situations where the sense organ of the tendon is continuously aware of the stimulation for the descending somatosensory stimulation when applied to the tendon. The residual sensory stimulation cannot be observed in the measurement of threshold value using the descent method; for this reason, the ascent method is very frequently used in measurement of threshold value.

Secondly, the muscular response according to the application of the somatosensory stimulation is discussed. The more intensity of the somatosensory stimulation increase, the more muscular response changes tended to increase in the tibialis anterior muscle when the descending and ascending somatosensory stimulation were applied. The relationship between intensity of the somatosensory stimulation and muscular response showed a larger rate of change when the ascending somatosensory stimulation were applied than when the descending somatosensory stimulation were applied. This relationship between intensity of the somatosensory stimulation and muscular response can be explained by the anatomic structure of the muscle. The muscle spindles and Golgi tendon organs distributed in the tibialis anterior tendon are cognitive of the rectangular change in the shape of the tibialis anterior tendon due to the somatosensory stimulation. These sensory organs can be sensitively responsive and excited by vibration with a frequency of 250 Hz [14-15] and at the same time induce contraction of the tibialis anterior muscle connected to the tibialis anterior tendon. The tibialis anterior muscle has an anatomical structure in which single structures are gathered together in the form of a bundle, and thus the all-or-none law of single receptors would not be applicable. In the case where a single structure comprises the tibialis anterior muscle, if the individual threshold of the single structure is low, the activity will be represented even if the somatosensory stimulation is lower than the threshold intensity obtained by the ascent or descent method. Conversely, the activity shown by the somatosensory stimulation will be higher than the threshold intensity. In the case of the EMG obtained from the surface of the tibialis anterior muscle, these reactions of a single structure are incorporated and apparent, thus the EMG characteristics will change according to the increase in the number of single structures excited, which was assumed to appear as the size of the activity in the present study. This interpretation is supported by evidence that the muscular response was present even in cases where the somatosensory stimulation was much lower than the threshold stimulation obtained through the ascent and descent methods. When comparing to the case in the Fig. 5, when no somatosensory stimulation was applied, when a 10 % threshold level of somatosensory stimulation was applied, the muscular response was shown to be 1.38 times greater; when applying a 100 % threshold level, the sensory stimulation was shown to be 1.43 times greater; when a 200 % threshold level of somatosensory stimulation was applied, a muscular response 1.50 times greater was observed.

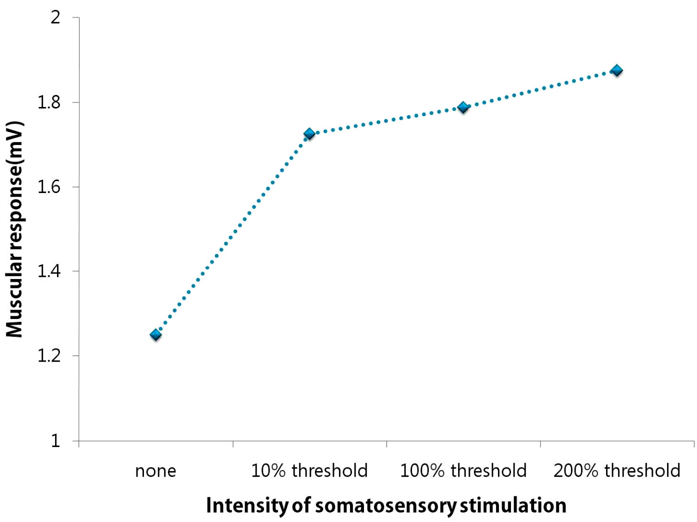


Fig. 5. The muscular response at tibialis anterior muscle measured EMG system by the intensity of somatosensory stimulation at tibialis anterior tendon

The present study has significance because of the comparison of the individual threshold value obtained through the ascent and descent methods used in various studies and for analysis of the body responses when applying the descending and ascending somatosensory stimulation. As a summary of the present study's results, the individual threshold value obtained through the ascent and descent methods differed in size and distribution, and the muscular response from the descending and ascending somatosensory stimulation also showed differences. The results of the present study and the corresponding considerations could serve as a basis to discuss the reliability of the measurement method of the human body's individual threshold value through the ascent and descent methods and can be used as reference data for the integration and performance threshold measurement methods.

Acknowledgements

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