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Effects of Short and Medium Latency Reflexes of the Plantae Muscle with Ankle Vibration during Sudden Foot Movement

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Abstract. [Purpose] This study examined the influence of signals from ankle joint afferent fibers on the reflexive plantae muscle activity during standing subjects. [Subject] Ten male healthy adults participated in this study. [Methods] The subjects stood with their eyes closed on a movable platform that was moved backward. Vibrators (about 90 Hz) were applied to the medial and lateral malleolus of both legs. The vibrators were turned off in the control condition. In the malleolus vibration (MV) condition, vibration stimulus was applied for one minute before the beginning of trials and was continued during the trials (about six minutes). The short (SLR) and medium latency reflex (MLR) of the flexor digitorum brevis muscle (FDB) electromyogram (EMG) responses of the left leg during the platform translations were measured under the control and MV conditions. [Results] The latencies of the FDB SLR and MLR during MV condition were observed to increase significantly in comparison to the control. The integration EMG response values (iEMG) of the SLR and MLR significantly decreased during MV condition. [Conclusion] Excessive afferent signals from the ankle articular mechanoreceptors may participate in the reduction of the reflexive FDB SLR and MLR activities during standing postural perturbation due to changes in the excitability of inhibitory interneurons.
Key words: Ankle articular mechanoreceptor, Short and medium latency reflexes, Postural perturbation

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INTRODUCTION

It has been shown that a sudden toe-up rotation of a platform being used for standing elicits two peak electromyogram (EMG) responses in stretching of the soleus muscle[1–4)]. The first EMG activity is a short latency reflex (SLR) mediated by group Ia afferent fibers from the primary ending of the muscle spindle, and a medium latency reflex (MLR) following SLR occurs as the second EMG activity. MLR is caused by transmission via group II afferent fibers from muscle spindle secondary terminations to alpha-motorneurons in the spinal cord[2,4)]. It is known that both SLR and MLR contribute to the static and dynamic standing stability of humans[5,6)]. In experiments related to the postural instability of patients with diabetic or sensory neuron disease, who had predominant impairments in the structure or function of group I and II afferent fibers, the displacements of the center of pressure (CoP) in both static and dynamic standing under the eyes closed condition increased, and this increase in the CoP displacement was related to a delay in the onset and a decrease of SLR and MLR EMG activities in the soleus [7,8)]. It is obvious that the SLR and MLR of the soleus are affected by homonymous muscle spindles and group I and II afferent fibers, whereas the precise effects of the SLR and MLR that occur via heteronomous sensory signals are still unclear.

Anatomical and histological studies have identified Ruffini and Pacini receptors in the ankle joint capsule, and Ruffini and Golgi receptors are reported to be expressed in the ankle ligaments of humans[9)]. The diameter of the afferent fibers from Golgi receptors (large afferent fibers) is similar to group I afferent fibers, and that from Pacini and Ruffini receptors (middle afferent fibers) resemble the group II afferent fibers originating from the muscle spindle[10–12)]. Based on these findings, it can be concluded that the reflex EMG burst of leg muscles is influenced not only by signals from homonymous group I and II afferent fibers but also the articular and cutaneous afferent fibers[13)]. It has been assumed that the afferent signals from sensory receptors which exist in the ankle joint affect the reflexive muscle activity of the lower extremity during human standing.

Vibratory stimulation of the mechanoreceptor of the ankle joint leads to presynaptic and/or disynaptic inhibition in the spinal cord because of excessive afferent signals flowing into the spinal cord[3,14]. Consequently, there is an increase in the receptor threshold[15]. It should be possible to experimentally examine the delays and decreases of the SLR and MLR activities of the leg muscles by applying vibration to a leg joint while a healthy human subject is in the standing position. In a previous study, the soleus SLR and MLR EMG activities and anterior CoP sway during posterior perturbation of the feet were examined after applying vibration to the ankle joint of healthy subjects. It was observed that the arrival time of the maximum anterior CoP displacement and soleus MLR EMG activity was increased significantly by the vibration, although the maximum anterior CoP displacement was not significantly different between the vibration and normal conditions[16]. These results suggest that an increase in the reflexive soleus activity compensates for the decrease in the reflexive plantae muscle activity resulting from the decrease in the ground reaction force. However, it is uncertain whether the SLR and MLR EMG activities of the plantae muscle are influenced by vibration of the ankle joint. The afferent fibers from the ankle joint might connect with alpha-motorneurons of plantae muscles via interneurons more than the soleus muscle, though the function of the reflexive neural circuit has not been clarified. We hypothesized that the SLR and/or MLR EMG activities of the plantae muscle during sudden translation of the feet would be decreased by the vibration of the ankle mechanoreceptors.

The present study investigated whether the application of vibration to the bilateral malleolus would increase the ankle articular mechanoreceptor threshold, increase the disynaptic inhibition in the spinal cord with the activity of ankle afferent fibers, and decrease the excitability of the plantae muscle motoneurons through inhibitory interneurons.

SUBJECTS AND METHODS

The subjects of this study were 10 healthy adults (age 23–35 years, mean 27.9 years of age), who provided their informed consent. The study had the approval of the ethics committee of Kyushu University.

The subjects were asked to stand wearing a blindfold with their arms by their sides and both feet on a movable platform (Equi-test version 8.1, NeuroCom Inc. USA). Each foot on the platform was placed according to a position calculated based on the subjects' height. The platform was moved by backward translation, which induced body anterior tilting. The intensity of the platform translation was limited to a distance of 4.6 cm to 6.0 cm and the duration time was 400 ms.

Vibrators were fixed to the lateral and medial malleolus of both legs by elastic bands in both the control and malleolus vibration (MV) conditions. The vibrators contained a rectangular eccentric motor embedded in plastic, 3 cm wide, 6 cm long and 2 cm high (MCL-1701, Alinco Inc. Japan). The frequency of the vibration was approximately 90 Hz, using an 80 to 100 Hz bandwidth for the vibratory stimulus applied to the mechanoreceptors[17–20]. The vibrators were turned off in the control (without vibration) condition. In the MV condition, vibration stimulus was applied for one minute before the beginning of platform translation and was continued from 18 to 21 trials (about six minutes). A pressure gauge (Flexi-Force, A201-100, NITTA Inc. Japan) was placed between the skin on the malleolus and vibrator. The vibrator produced a peak-to-peak force of approximately 4.0 to 5.0 N (4.53 ± 0.12 N) during the MV condition[3].

Three trials on the platform comprised a single-unit. The subject executed a single-unit condition 6 to 7 times without rest. In each unit, the interval between each trial was automatically and randomly set to vary from 1.5 sec to 2.5 sec. Each condition was examined randomly and a rest period of 5 minutes was provided between the series when the subjects adopted a comfortable sitting position. The flexor digitorum brevis (FDB) and one of the plantae muscles was used as the target muscles of EMG measurement. EMG responses of FDB to backward platform translations were collected under the control and MV conditions for each subject.

EMG activity of FDB was recorded using surface electrodes that were attached to the sole of the right foot. The distance between the electrodes was about 2 cm. The EMG signal was amplified (10,000×), band-pass filtered (10–500 Hz), and converted from analog-to-digital at a sampling rate of 1 kHz. The onset signal of the platform translation was synchronously recorded on a personal computer. All of the recorded EMG waves were rectified. The acquisition periods were 100 ms and 250 ms before and after the platform translation onset, respectively.

The latencies of SLR and MLR onsets in FDB were measured from the onset of the platform translation. All FDB responses of EMG were smoothed (time constant 10 ms) and the onsets of SLR and MLR in FDB were taken when the EMG signal rose above 2 SDs of the mean value of the background EMG activity before the beginning of platform translation. EMG activities of SLR and MLR in FDB were integrated using the average of the rectified and filtered EMG traces. In our pilot study, the time of SLR and MLR EMG activities in FDB were respectively 30 ms and 50 ms of the averages (unpublished). The integration values (iEMGs) of SLR and MLR in FDB were respectively measured in acquisition periods of 30 ms and 50 ms from the onset of the response (Fig. 1). The same acquisition periods were used to calculate the SLR and MLR iEMGs in each single trial. The FDB SLR, MLR and background iEMGs of each subject were normalized with respect to recorded EMG activity during maximal voluntary isometric contraction (MVIC) of the FDB before comparing the control and MV conditions of all subjects. The anteroposterior CoP displacement was also measured 100 ms before the platform translation onset to ensure that the leg position at the beginning of the measurement was the same position between the control and MV conditions. The displacement of anteroposterior CoP was recorded by a personal computer synchronously with the EMG of FDB at a sampling rate of 1 kHz, in addition to sampling FDB EMG. The EMG activity of MVIC was measured for 5 sec. The

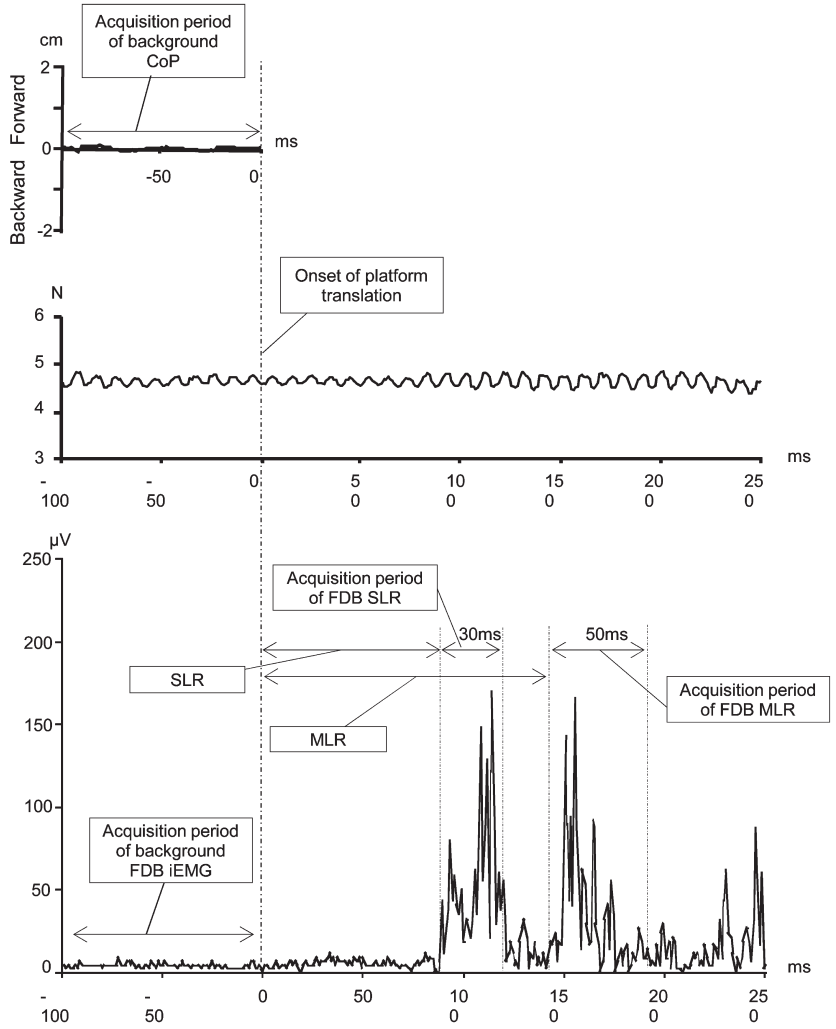

Fig. 1. Measurement of the vibration's force at the malleolus, CoP displacement and rectified FDB EMG

The upper panel indicates a sample anteroposterior CoP displacement before and after platform perturbation of a subject. The middle panel shows the vibration pressure at the malleolus. The background CoP displacement value of each 1 ms in one trial was extracted. The lower panel shows a sample of the rectified FDB EMG during backward platform translation of a subject. The measurement items are background FDB iEMG, the latencies of FDB SLR and MLR onsets and %MVIC of the SLR and MLR iEMGs. The iEMG indicates integration of acquisition period of FDB EMG activity. The %MVIC shows the maximal voluntary isometric contraction. CoP and FDB are center of pressure and the flexor digitorum brevis muscle, respectively.

EMG activity of MVIC during the middle 3 sec, from 1 sec the beginning of measurement, was adopted.

The paired t-test was used to compare the background CoP and EMG activity, latency of the FDB SLR and MLR onset and the iEMGs between the control and the MV conditions. Differences in P values of less than 0.05 were considered to be statistically significant ($p<0.05$).

RESULTS

Table 1 shows the background CoP displacements and iEMGs, the FDB SLR and MLR latencies and the iEMGs under the control and MV conditions. No significant differences were observed in the mean values of the background CoPs and iEMGs between the control and the MV conditions. Both the onsets of the FDB SLR and MLR EMG activities in the MV conditions were significantly delayed in comparison to the control condition ($p<0.05$). Furthermore, the FDB SLR and MLR iEMGs under the MV

Table 1. Background CoP displacement and FDB EMG activity, Latencies and Areas of FDB SLR and MLR EMGs

	Control condition	Malleolus vibration condition	t value
Background CoP displacement (cm)	0.012 ± 0.01	0.015 ± 0.03	
Background EMG activity (%MVIC)	12.1 ± 11.5	12.6 ± 12.2	
Latency of FDB SLR (ms)	77.9 ± 7.2	81.4 ± 10.5	*
Latency of FDB MLR (ms)	127.2 ± 10.6	138.8 ± 10.0	*
Area of FDB SLR EMG (%MVIC)	48.9 ± 21.3	44.1 ± 27.4	*
Area of FDB MLR EMG (%MVIC)	47.4 ± 20.5	43.5 ± 25.1	*

Values are mean ± standard deviation (SD). CoP: center of pressure, FDB: Flexor Digidorum Brevis muscle, SLR: Short Latency Reflex, MLR: Medium Latency Reflex, MVIC: maximal voluntary isometric contraction. * Significant difference between the control and malleolus vibration conditions ($p<0.05$) using the parametric t-test.

condition were also significantly decreased in comparison to the control condition ($p<0.05$).

DISCUSSION

We examined whether the ankle articular afferent signal affects reflexive plantae muscle activity during backward perturbation in standing of healthy adults. The application of medio-lateral malleolus vibration did not change the mean value of the background FDB iEMGs from that of the control. Moreover, the mean values of background CoP displacements between the conditions were not significantly different. These findings indicate that the body was at a similar location in both conditions, and that the incline angles were the same between the conditions. Therefore, the background EMG activity of FDB was not different between the control and MV conditions.

The FDB SLR and MLR latencies increased in the MV condition. The presence of a significant delay in the onset latency during vibration suggests that the group I and II afferent fibers from the ankle joint were suppressed by excessive activity induced by MV, and that EMG activity of FDB was less responsive to the platform-induced muscle stretch. This phenomenon suggests that heteronymous group I and II afferents may converge on inhibitory interneurons, and the excitability threshold of the FDB alpha-motorneurons may be increased by disynaptic inhibition[21,22]. In a previous study of animals, it was suggested that a threshold increase in the expression of Pacini and Ruffini receptors influenced the latency of the FDB SLR and MLR because it had been reported that the threshold of these mechanoreceptors increased by 60 Hz or more when a vibratory stimulus was applied[23]. The differences between the control and the MV conditions of the mean FDB SLR and MLR latencies were respectively 3.5 ms and 11.6 ms. This finding indicates that group II afferents, the conduction velocity of which is slower than group I afferents, may be easily influenced by vibration. Therefore, the delay of the FDB MLR with respect to the FDB SLR latency under the MV condition may be because the conduction velocity of group II afferent fibers is slower than group I afferent fibers.

In the MV condition, the FDB SLR and MLR iEMG also decreased, in addition to the delay of the FDB SLR and MLR latencies. Group I and II afferent fibers can attach to the capsule and ankle ligaments[10,24], and mechanoreceptors in particular (Ruffini, Pacini and Golgi receptors)[25]. The presynaptic inhibition of group I and II afferent fibers may occur due to excessive activity of these fibers[14]. Although the presynaptic inhibition has been reported to occur by group I and II afferent fibers from homonymous muscle[26,27], the influences of FDB SLR and MLR activities via the afferent fibers from the ankle joint are not known. Moreover, the size of the H reflex of the quadriceps muscle may be limited by disynaptic inhibition when conditioning stimuli are applied to articular afferents in the knee[28,29]. This may explain why FDB SLR and MLR iEMGs were decreased in the present study. The excitability threshold of the FDB alpha-motorneurons would have been increased by excessive signals from the ankle articular afferents increasing the excitement of inhibitory interneurons during MV condition, and it was thought that thereby decreasing FDB SLR and MLR iEMGs. In our previous study, performed using the same conditions, we assumed that the increase in soleus activity was due to compensation for the decrease in the FDB activity because the soleus MLR activity and the time to reach maximum CoP displacement increased more under MV than under the control condition[16]. Moreover, in our pilot study, the amplitudes of the H reflex was significantly decreased and the MLR of FDB was significantly delayed in response to Evoked-Potential (MEB-9404, Nihon-Kohden Inc., Japan) whenmalleolus vibration was applied to healthy standing subjects compared to the control condition (unpublished). These findings suggest that the afferent signals from mechanoreceptors of the ankle joint elicited by malleolus vibration may affect the reflexive FDB SLR and MLR activities more than soleus activity during sudden translation of the feet. We consider the compensatory increase in soleus MLR during backward perturbation is potential mechanism for the decrease in SLR and MLR of FDB.

In conclusion, we consider that excessive afferent signaling from ankle articular mechanoreceptors leads to reduction in FDB SLR and MLR activities and postural responses during sudden backward perturbation of the feet.

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