The Role of the Suprasprinal Center during Soleus Stretching Reflexes with Simultaneous Vibration

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Abstract. [Purpose] We examined whether monoaminergic brain stem centers contribute to reflexive soleus (Sol) activity when vibration is applied to ankle joints on a moving platform. [Methods] Ten male subjects (23–35 years) stood with their eyes closed on a movable platform. Vibrators (92 Hz) were applied to the malleolus and Achilles’ tendon. Sol electromyographic (EMG) responses of short- (SLR) and medium-latency reflexes (MLR) during platform movement were collected under the control, Sol vibration (SV), and malleolus vibration (MV) conditions. The SLR, MLR areas and their latencies were measured. [Results] The Sol SLR and MLR onsets were significantly delayed under the SV and MV conditions compared to the control condition. The intercept of the regression line under the MV conditions was significantly greater than under the SV condition. [Conclusion] Delays of SLR and MLR onset under the SV and MV conditions might correspond to the length of time required for temporal summation of α-motoneurons due to inhibition of afferent fibers. A rise in the intercept of the regression line under the MV condition means an increase of MLR area. That is, the monoaminergic brain stem centers compensated for stimulation of the group II interneuron via ankle joint afferents acting against the inhibition of the stimulation of Sol α-motoneurons.

Key words: Ankle joint, Group II fibers, Medium latency reflex

INTRODUCTION

Signals mediated by Ia and group II afferent fibers from peripheral leg muscles contribute to two component reflexive homonymous muscle responses during static and dynamic standing. It has been shown that a sudden toe-up rotation on a platform being used for standing produces two peak electromyogram (EMG) responses mediated by Ia and group II afferents during stretching of the soleus (Sol) and flexor digitorum brevis (FDB) muscle 1-3). The first component is a short-latency reflex (SLR) that takes place at about the latency of the monosynaptic reflex arc. It originates in the spindle primaries and is mediated by group Ia large afferent fibers. The second component is a medium-latency reflex (MLR) that is transmitted to the spinal cord from spindle secondary terminations by group II afferent fibers 3). Several studies have reported abnormal SLR and MLR activities of Sol and FDB in the legs of subjects who have peripheral neuropathy cause standing postural instability 4-6). According to the major results of recent studies of reflexive Sol and FDB activities during static standing, Sol and FDB activities are affected by not only afferent signals from homonymous muscle spindles, but also by sole cutaneous afferent signals. However, little is known about the influence of afferent signals from ankle joints on reflexive peripheral muscle activity in the upright posture. One study examined whether afferent signals decreased by local anesthesia of the ankle joint affected the stability of upright posture. Errors of passive position sense were significantly increased in comparison to active position sense errors, and the difference in stability of one-leg standing between the pre- and post-anaesthetic block was not significant 7). Thus, the afferent signals from ankle joint may thus play a dominant role on passive position sense, to which afferent signals from the muscle spindle do not contribute, even though muscle spindle afferents are predominantly involved in the stability of static standing. No study has yet examined the changes in SLR and MLR activities of peripheral muscles in the leg while standing on one-leg with the ankle joint under...
anesthesia. If the afferent signals from the ankle joint affect the detection of passive movement, SLR and MLR activities of peripheral muscles would be influenced when the feet are perturbed during static standing. Accordingly, we have to consider whether the SLR and MLR activities of peripheral muscles are affected by decreased afferent signals from the ankle joint under unstable conditions.

We also have to consider that the supraspinal center affects stimulation of α-motoneurons of peripheral muscles when a person stands. The amplitude of MLR in leg muscles is sensitive to whether or not the subject can predict the postural task and whether the posture of the standing subject is stabilized or not\(^{10,11}\). When a standing subject’s balance is perturbed and the subject unable to predict the postural task, MLR activity of the leg muscles significantly increases compared to stable standing with predictable conditions for the postural task\(^{12}\). It has been concluded that monoaminergic brain stem centers selectively modulate the stimulation of the interneuronal pathways through group II afferents from homonymous spindle secondaries. However, it is not clear whether MLR activity of the peripheral muscles are affected by modulation from monoaminergic brain stem centers, if presynaptic or disynaptic inhibitions occur in afferent fibers connecting with the ankle joints during ankle vibration.

To cause hypoesthesia, mechanical vibrations were applied to Sol and malleolus of the subjects\(^{13-15}\). Vibration applied to peripheral leg muscles causes presynaptic inhibition of Ia and group II afferent fibers, and then stimulates the α-motoneurons of homonymous muscles via a decrease in interneuron numbers\(^{16,17}\). In contrast, vibration applied to the malleolus raises the activation thresholds of the ankle mechanoreceptors making it harder to stimulate the receptors because of the receptors’ raised threshold\(^{18}\). Information on the level of the vibration frequency used in several studies was helpful for our research. The vibration frequency which effectively raises the thresholds of muscle spindles and mechanoreceptors is approximately 100 Hz\(^{14,19,20}\).

Therefore, we examined whether vibration near 100 Hz of the Sol and ankle joint affects Sol SLR and MLR activities during platform movements. We also examined whether monoaminergic brain stem centers modulate Sol MLR activity when vibration is applied to the Sol and ankle joint.

### SUBJECTS AND METHODS

Ten healthy male subjects (aged 23–35 years, with a mean age of 27.9 years of age) participated in the experiments. The subjects gave their informed consent and the study conformed to the Declaration of Helsinki. The current research began after approval was obtained from the ethical committee of the Health Science Center of Kyushu University.

The subjects were asked to stand with their eyes closed, arms by their side with both feet on a movable platform (Equi-test version 8.1, NeuroCom Inc. USA). The center of mass (COM) of the subject was observed on the anterior-posterior and medial-lateral axes on a computer screen. The dot point, which indicates the COM of the subject, was observed before the platform perturbation. The COM was placed at the intersection point of the coordinate axes by the tester. The feet were grounded and the subject’s height on the platform was taken into account. The movement of the platform was a backward displacement, which induces stretch and consequent reflex responses in the Sol muscle. Table 1 shows the amplitude of the movement of the platform. One series of measurements included 18–21 trials and the time interval between each trial within a series varied randomly from 1.5 to 2.5 seconds.

The vibrators contained a DC motor with an eccentric the embedded in rectangular plastic case, 3 cm wide, 6 cm long and approximately 2 cm high (MCL-1701, Alinco Inc. Japan). Vibrators (92 Hz) were bilaterally fixed to the Achilles’ tendons (Sol vibration condition, SV) and to the lateral and medial malleolus (malleolus vibration condition, MV) by elastic bands. The vibrators were turned off in the control condition (without vibration). In the SV and MV conditions, vibration was applied for one minute before the beginning of platform movements and was continued for 18 to 21 trials (about six minutes respectively). The vibrator produced a peak-to-peak force of about 4 N (4.13 ± 0.12 N), as measured by the strain gauge (EM-555, Noraxon Inc. USA) that was placed between the skin and the vibrator\(^{14}\).

Three trials on the platform comprised a single unit. The subject executed a single unit 6 or 7 times (18–21 trials) without rest. In each unit, the interval between each trial was randomly set to vary from 1.5 to 2.5 seconds. Each condition was examined randomly. Noda et al.\(^{13}\) reported that 5 minutes of conditioning vibration applied to the malleolus of normal subjects increased the vibratory perception threshold at 10, 60 and 120 seconds, but not at 5 minutes. Therefore, a rest period of 5 minutes was provided between the measurement series during which the subjects adopted a comfortable sitting position. Sol muscle EMG responses to backward platform movement under each of three conditions were collected for each subject.

EMGs were recorded using surface electrodes. The distance between the surface electrodes was approximately 2 cm. The electrodes were positioned on the skin 3 cm below the bottom of the medial head of the gastrocnemii to record the EMG activity of Sol on the right leg. The EMG signal was amplified (10,000×) and band-pass filtered from 10 to 500 Hz. The analog signal was digitally converted at a sampling rate of 1 kHz, and the onset signal of platform movement was synchronously recorded on a personal computer. All of the identified EMG wave shapes were rectified. The acquisition period was 350 ms, with the platform movement starting at 100 ms from the onset.

All Sol responses of EMG were smoothed (time constant 10 ms), and the onsets of SLR and MLR in Sol were defined as when the EMG signal rose above 2 SDs of the mean value of the background EMG activity before the beginning of

### Table 1. Platform displacement amplitude

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Duration time (ms)</th>
<th>Perturbation (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>large</td>
<td>400</td>
<td>4.6–6.0</td>
</tr>
</tbody>
</table>

The distance of platform movement was related to the height of the subject.
RESULTS

Table 2 shows the overall average of onset latencies of Sol SLR and MLR in response to the platform backward movement under the three conditions. ANOVA revealed the vibration had a significant effect on the latencies of Sol SLR ($F=93.879; \text{d.f.}=2, 561; p<0.0001$) and MLR ($F=36.957; \text{d.f.}=2, 561; p<0.0001$). Vibration caused a significant delay in Sol SLR of approximately 2.5 ms under the SV condition and 2 ms under the MV condition compared to the control value (post hoc test, $p<0.01$ and $p<0.01$, respectively). Vibration induced a significant delay in Sol MLR of 6 ms under the SV condition and of approximately 3 ms under the MV condition in comparison to the control value (post hoc test, $p<0.01$ and $p<0.01$, respectively).

From the analyses of the effects of Sol MLR EMG area with respect to SLR EMG area among the three conditions (ANCOVA), Sol MLR EMG area was affected by Sol SLR EMG area ($F=300.323; \text{d.f.}=1, 561; p<0.0001$) and conditions ($F=3.154; \text{d.f.}=2, 561; p<0.05$). There was not an interaction between covariate of the conditions and independent variable of Sol SLR areas (Table 3).

A slightly positive relationship was found between the Sol MLR and SLR areas under the control condition ($r=1.896 + 0.675x; p<0.0001$). A more positive relationship was found between the two areas under SV ($r=1.605 + 0.809x; p<0.0001$). The regression line under the MV condition was moderately positive between the two areas, but the coefficient of regression was slightly lower than that under the control condition ($r=2.254 + 0.641x; p<0.0001$). The coefficients of regressions were not different between the SV and MV conditions. The intercept under the MV condition rose significantly more than under the SV condition (Bonferroni/Dunn test; $p<0.01$). In Table 3, the intercept of the regression line was lower under the SV condition than under the MV condition.

DISCUSSION

Both Sol SLR and MLR latencies under the SV condition increased. There is accumulating evidence that Ia and group II afferent fibers from Sol muscle spindles show presynaptic inhibition when a vibration frequency of nearly 100 Hz is applied\textsuperscript{13, 14, 21–23}. This evidence will help us to have a thorough understanding of the delay mechanism of Sol SLR and MLR onsets. Delays of Sol SLR and MLR onset might correspond to the delay of temporal summation of α-motoneurons due to presynaptic inhibition of Ia and group II afferent fibers.

The onset latency of Sol SLR and MLR was also extended under the MV condition. It is documented that afferent fibers from the ankle joints have disynaptic connections to α-motoneurons of the quadriceps femoris muscles\textsuperscript{29}. From these delays of Sol SLR and MLR latencies under the MV, the afferents from the ankle joints are also assumed to constitute the pathways to α-motoneurons of Sol. The afferent fibers from several mechanoreceptors of the ankle joints are group I and II afferent fibers\textsuperscript{29}. Thus, excessive afferent signals from the ankle joint under vibration seem to
inhibit interneurons (disynaptic inhibition) via group I and II afferent fibers from the ankle joint. These clear delays in Sol SLR and MLR onsets under MV support the notion that disynaptic inhibition of interneurons connected to group I and II afferent fibers from the ankle joint extend the time required temporal summation of Sol α-motoneurons.

In the regression analyses of the Sol MLR and SLR areas under the three conditions, the coefficients regression of the SV and MV conditions were not different. In contrast, the intercept under the MV conditions was greater than under the SV condition. Therefore, this result indicates that Sol MLR activity increases when vibration is applied to the ankle joint but decreases when vibration is applied to the homonymous muscles. It is documented that the Sol SLR and MLR areas with toe-up rotation, during Achilles tendon vibration of 90 Hz, of standing subjects exhibited significant decreases in comparison to the absence of vibration.

However, the intercept of the regression line was higher under the MV condition than under the SV condition. This result does not support the theory of disynaptic inhibition alone, because the Sol MLR area during the MV condition increased. When subjects support themselves by holding onto a stable frame, then the same foot rotation elicits responses of a smaller magnitude, of less than 20% on the average of the control value. This finding led to the conclusion that monoaminergic brain stem centers selectively modulate the stimulation of the interneuronal pathways responsible for the transmission of group II input.

We should point out that compensatory modulation from the supraspinal centers had little effect on the Sol MLR area under the SV condition similar to the MV condition.

### Table 2. One-way analysis of variance of differences among the control, Sol vibration and malleolus vibration conditions of the onsets of Sol SLR and MLR

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control</th>
<th>Sol vibration (SV)</th>
<th>Malleolus vibration (MV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onset of Sol SLR (ms)</td>
<td>38.1 ± 0.2</td>
<td>44.6 ± 0.4</td>
<td>41.2 ± 0.4** ††</td>
</tr>
<tr>
<td>Onset of Sol MLR (ms)</td>
<td>68.5 ± 0.6</td>
<td>74.6 ± 0.4</td>
<td>71.6 ± 0.5** ††</td>
</tr>
</tbody>
</table>

†† indicates significant difference (p<0.01) between control and SV conditions in post hoc test (The Bonferroni/Dunn test). ** indicates significant difference (p<0.01) between control and MV conditions in post hoc test (The Bonferroni/Dunn test). †† indicates significant difference (p<0.01) between SV and MV conditions in post hoc test (The Bonferroni/Dunn test).

### Table 3. Coefficient and intercept values of the linear regression models of loge Sol MLR area (dependent variable), loge Sol SLR area (independent variable), and condition (covariance) with analysis of covariance

<table>
<thead>
<tr>
<th>Condition (Covariance)</th>
<th>Control</th>
<th>Sol vibration (SV)</th>
<th>Malleolus vibration (MV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression Coefficient</td>
<td>0.68**</td>
<td>0.81**</td>
<td>0.64**</td>
</tr>
<tr>
<td>Intercept</td>
<td>1.90**</td>
<td>1.61**</td>
<td>2.25**††</td>
</tr>
</tbody>
</table>

Loge MLR area, loge SLR area and condition are the dependent variable, independent variable and covariance, respectively. **: significance of regression coefficient and intercept (p<0.01). ††: significant difference (p<0.01) of intercepts between SV and MV conditions in post hoc test (The Bonferroni/Dunn test).
discrepancy might be caused by the character of the perturbation. The perturbation used in our present study was the backward perturbation of a platform. It is known that the decrement of afferent signals from the ankle increases error in passive position sense of the ankle joint, but does not affect stability during static standing because of compensatory inputs from muscle spindles as a result of the anesthetia of the ankle joint\textsuperscript{9}. The afferent signals from Sol muscle spindles would contribute to stability during static standing, however the afferent signals from the ankle joint rather than from Sol muscle spindles might contribute to reflexive Sol activity during passive movement of the feet. Therefore, supraspinal centers might not participate in modulating the stimulation of interneuronal pathways involved in Ia and group II afferent fibers from Sol muscle spindles under SV, even if the afferent fibers from Sol muscle spindles resulted in presynaptic inhibition during Achilles’ tendon vibration.

Another point we must notice is the composition type and motor units of the Sol muscle fibers. Previous investigations have demonstrated that the Sol fibers consist of 81% type I, 16% type IIa and 0% type IIb fibers\textsuperscript{10}. Moreover, it has been proposed that α-motoneurons that innervate fiber types I and II mainly have connections with group I and group II afferent fibers in the peripheral nerves\textsuperscript{11}. Since the fiber type of Sol is mostly type I fiber, group II afferent fibers from the ankle joint and other group II afferent fibers from Sol muscle spindles that mediate Sol MLR activity might form concentratative synaptic connections with Sol α-motoneurons innervating type I fibers. Therefore, monoaminergic brain stem centers might provide compensatory stimulus to the α-motoneurons of Sol, even though the Sol MLR area would be expected to decrease with disynaptic inhibition of group II afferents under MV.

REFERENCES

3) Schiappati M, Nardone A: Group II spindle afferent fibers in humans: their possible role in the reflex control of stance. Prog Brain Res, 1999, 123: 461–472. [Medline] [CrossRef]