Vestibular-induced Modulation Of Leg Motoneuron Pool Excitability In Standing And Prone Positions

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Vestibular-induced Modulation Of Leg Motoneuron Pool Excitability In Standing And Prone Positions

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Abstract

The purpose of this study was to investigate whether vestibular stimulation modulates leg motoneuron pool excitability in standing and prone positions. Galvanic vestibular stimulation (GVS) was delivered to 7 healthy humans in standing and in prone positions. Background EMG activity and H-reflex were recorded from the soleus muscle 100 ms or 200 ms after GVS onset. Background EMG activity and H-reflex excitability were depressed 200 ms after GVS onset on the anodal GVS side in the standing position, although the depression was absent 100 ms after GVS onset. The depression was absent on the cathodal GVS side in the standing position. Furthermore, the depression was absent on both the anodal and cathodal GVS sides in the prone position. These findings indicate that vestibular-induced modulation of leg motoneuron pool excitability is absent in prone position but present in standing position. Head position, postural stability or motoneuron pool sensitivity are possible determinants of this difference.

Introduction

Several studies have investigated the effects of the inclination of body position on the soleus motoneuron pool excitability. This excitability of the soleus motoneuron pool was found to be facilitated as the longitudinal axis of the body came closer to the vertical axis [1]. In contrast, the excitability appears to be depressed as the longitudinal axis of the body comes closer to the vertical axis [2]. Furthermore, it has also been reported that such an effect does not exist [3]. Accordingly, there is no conclusive view concerning the relationship between body position and motoneuron pool excitability.

Changing body position, which previous studies have attempted [1,2,3], involves rotation of the head against gravity. It has been reported that this rotation modulates the vestibular afferent discharge rate [4]. Thus, modulation of the motoneuron pool excitability induced by changing body position is likely to be related to vestibular activity.

Previous studies have applied galvanic vestibular stimulation (GVS) to investigate the body position-dependent vestibular effect on motoneuron pool excitability. Several reports have indicated that GVS does not modulate EMG activity during sitting, but does during standing [5,6]. Another report suggests that GVS induces the polarity-dependent biphasic modulation of the soleus H-reflex excitability during free-standing, while GVS does not induce such modulation during sitting [7]. Accordingly, vestibular-induced modulation of motoneuron pool excitability is likely to be dependent upon body position.

However, these previous studies have some methodological concerns. One is that the body positions used in the previous studies were not as natural as those used in daily living. For example, the head was rotated to one side [5,6,7,8], voluntary contraction was performed [5,6,7,8], the body was inclined forward [5,8], or support surface was tilted [6]. Such unnatural motor tasks may interfere with investigating the relationship between body position and the vestibular effect on motoneuron pool excitability. Another concern is that head position against gravity, which is a determinant of vestibular activity [4], was not altered, because the previous study conducted the experiments in sitting and standing positions. Changing body positions accompanied by changing the head position against gravity is critical to observing clear effects of body position on vestibular-induced modulation of motoneuron pool excitability.

The purpose of this study was to investigate the vestibular effect on lower limb motoneuron pool excitability in different postures. Previous studies have indicated that soleus H-reflex excitability does not change between the body positions on a tilt table [3] but does change between lying and free-standing [3,9,10]. We therefore expected that vestibular effect on motoneuron pool excitability would be different between standing and prone positions. In order to observe the vestibular effect in natural body positions, the head was directed forward; voluntary contraction and frontal inclination of the body were not performed in the present study.

Materials and Methods
Subjects
Seven healthy humans aged between 22 and 33 were recruited. The subjects did not have orthopedic or neurological histories. The experimental protocol was explained, and the subjects gave their written informed consent to participate in this experiment. The Ethical Board of Osaka Prefecture University approved the experimental procedures, and the study was performed according to the declaration of Helsinki.

GVS
Bipolar binaural GVS was delivered via Ag/AgCl surface electrodes affixed to the skin over the mastoid processes [5,6,7,8,11,12,13]; the anodal stimulus electrode was placed on the right mastoid process and the cathodal stimulus electrode on the left mastoid process. The GVS consisted of a 2000-ms square-wave pulse [14,15,16], and the intensity was twice the sensory threshold. It was confirmed that GVS did not produce sensations of pain or flashing behind the eyes, but did produce body sway in standing subjects.

Background EMG and H-reflex
EMG activity was recorded from the bilateral soleus muscles using Ag/AgCl surface electrodes placed on the skin just medial to the medial border of the gastrocnemius muscle, 3 cm apart. The EMG signal was amplified with an amplifier (Nihon Kohden MEG-2100) having a passband filter of 50 Hz to 3 kHz. In order to evoke the soleus H-reflexes, the posterior tibial nerve was electrically stimulated at the popliteal fossa. The stimulus electrodes were Ag/AgCl surface electrodes placed on the popliteal fossa, 2 cm apart. The duration of the tibial nerve stimulus was 1 ms, and its intensity was just above the motor threshold evoking both a small M-wave and an H-reflex. The amplified EMG signal was converted to a digital signal using an A/D converter (AD Instruments PowerLab800s) at a sampling rate of 10 kHz and stored in a personal computer.

Procedure
The subjects stood on a flat floor or lay prone on a bed with both legs extended. When the subjects were standing, the feet were put together. When the subjects were prone, their bilateral ankle joints were firmly fixed in a 90-degree position for plantar/dorsal flexion with braces to prevent movement artifacts. Throughout the experiment, the subjects maintained their heads facing front. The eyes were closed because visual input affected GVS-induced motor output [5,6,12].

While the subjects stood or lay prone, GVS was delivered. The tibial nerve stimulus, evoking the H-reflex, was delivered 100 ms (100-ms condition) or 200 ms (200-ms condition) after GVS onset. The inter-trial interval was more than 10 s. Fifteen trials were conducted for each GVS condition in each position. Eight control trials that did not deliver GVS between the test trials were inserted between the test trials in each position.

Data analysis
The amplitude of the M-wave and the H-reflex were estimated on a peak-to-peak basis. H-reflexes, accompanied by an M-wave whose amplitude exceeded the mean+1SD of the M-wave amplitude of the control trials or was lower than the mean-1SD, were excluded from data analysis, so that all the H-reflexes included in the analysis were evoked under a constant stimulus condition. The H/M ratio, expressed as the H-reflex amplitude divided by the maximum M-wave amplitude, was estimated. The integral electromyography (IEMG) was estimated within the time window of 0 to 50 ms before the test stimulus as a measure of the background EMG activity. EMG was expressed as the percentage of IEMG during maximum voluntary contraction (%MVC). A repeated-measures analysis of variance (ANOVA) was conducted to determine differences in the IEMG or H/M ratio between the three GVS conditions. Alpha was established as 0.05. When ANOVA revealed statistical significance, a post-hoc test was then conducted. The post-hoc test statistically examined differences in the IEMG or H/M ratio between the control condition and the other conditions. The Bonferroni correction was used to set alpha at 0.05/2=0.025.

Results
IEMG in the 200-ms condition was largely decreased compared with that in the other conditions on the anodal GVS side in the standing position (Fig. 2-A). ANOVA revealed significant difference in IEMG between the three GVS conditions in the standing position (P Figure 1 shows specimen records of H-reflexes on the anodal GVS side. The H-reflex amplitude was decreased in the 200-ms condition in the standing position, although such a decrease did not occur in the prone position. Similar to IEMG, the H/M ratio in the 200-ms condition was largely depressed as compared with the other conditions on the anodal GVS side in the standing position (Fig. 2-B). ANOVA revealed a significant difference in the H/M ratio between the three GVS conditions (P Figure 3 shows specimen records of the H-reflex on the cathodal GVS side. The H-reflex amplitude was
decrease the soleus H-reflex excitability, while anodal GVS was found to modulate soleus H-reflex excitability and background EMG in the prone position. Furthermore, ANOVA failed to reveal a significant difference in the H/M ratio between the three GVS conditions in the standing (P=0.81) and prone (P=0.12) positions.

Discussion

Soleus H-reflex excitability and background EMG was depressed 200 ms after GVS onset in the standing position. Biphasic modulation of the soleus H-reflex excitability induced by GVS in the standing position has been reported, but the subjects in that study rotated their head to one side [7]. Another study investigated GVS-induced modulation of EMG activity in standing with the head forward, but failed to detect a significant modulation of EMG activity [11]. Furthermore, forward body inclination [5,8] or tilting support surface [6] was attempted in previous studies investigating the effects of GVS on the soleus motoneuron pool in the standing position. Therefore, our study is the first study to identify GVS-induced modulation of the soleus motoneuron pool excitability in relaxed natural standing.

GVS modulates the firing rate of the vestibular afferent nerve [17]. Thus, GVS-induced depression of the soleus H-reflex excitability should reflect changes in vestibular activity on the soleus motoneuron pool. Furthermore, the concurrent occurrence of decreased EMG activity and soleus H-reflex depression induced by GVS indicates that GVS-induced depression of the soleus motoneuron pool excitability is at least partially due to decreases in the soleus muscle activity levels.

GVS induces body sway in standing [5,6,14,18,19]. The center of pressure is deviated approximately 150 ms after GVS [19], trunk movement begins 150-180 ms after GVS onset [5], and the center of gravity begins to deviate approximately 200 ms after GVS onset [18]. Furthermore, changes in the ankle joint angle occur approximately 200 ms after GVS onset [6]. The delay of these events induced by GVS is similar to the delay in the depression of motoneuron pool excitability induced by GVS in our experiment. Thus, depression of the motoneuron pool excitability induced by GVS is likely to be related to body sway.

In contrast, GVS did not modulate soleus H-reflex excitability and background EMG in the prone position. In a previous study, anodal GVS was found to decrease the soleus H-reflex excitability, while cathodal GVS increased it 100 ms after monaural GVS [15]. On the other hand, the soleus H-reflex excitability was increased 100 ms after binaural GVS in both legs [13]. Accordingly, our present finding and the previous findings are inconsistent. The soleus H-reflex was evoked only 100 ms after GVS in the previous studies [13,15], although it was evoked 100 ms and 200 ms after GVS in our present study. The GVS intensity was determined based on the amount of current flow in the previous studies [13,15]; in contrast, it was determined based on the perceptual threshold in our present study. Despite such minor differences, an essential difference in experimental methods between the three studies was not present. Therefore, a conclusive explanation for the different findings was not found.

Further studies are needed to elucidate GVS-induced modulation of the soleus motoneuron pool excitability in the prone position.

The most important finding of the present study is that GVS-induced modulation of the soleus motoneuron pool excitability is different between standing and prone positions. To our knowledge, this is the first report of the different vestibular effect on the soleus motoneuron pool excitability in natural standing and prone positions. One possible mechanism underlying this difference is the changing of head position against gravity. The vestibular system is a sensory system to detect rotation of the head [4]. Therefore, changes in head position against gravity induced by changing body position may alter vestibular activity, and may therefore cause different vestibular effects on soleus motoneuron pool excitability in standing and prone positions.

The other possible mechanism underlying the difference is the change in postural stability. The soleus H-reflex excitability in unsupported standing is lower than that in lying [3,9,10], although such a difference appears to be absent when comparing the H-reflex excitability between lying and supported upright positions on a tilt table [3]. GVS-induced tilt in the head and trunk in standing is reduced by increasing the stance width [14]. Furthermore, a GVS-evoked biphasic EMG response is present in free standing but is absent in standing with trunk supported [6]. These findings support the hypothesis that the vestibular effect on motoneuron pool excitability in the leg increases as postural stability decreases.

Another possible mechanism is that different background EMG activity and H-reflex size between standing and prone positions. Background EMG level in standing was larger than that in prone, and H-reflex size in standing was smaller than that in prone in this study. The sensitivity to facilitation and inhibition depends on the size of control H-reflex [20].
Furthermore, the muscle activity level may affect the sensitivity of soleus H-reflex excitability to facilitatory or inhibitory inputs, such as descending excitation, contraction-associated sensory feedback, Ib inhibition, or recurrent inhibition [see ref. 21]. Thus, the difference in background EMG activity and H-reflex size may have led to different sensitivity of motoneuron pool excitability to vestibular stimulation in standing and prone positions.

In conclusion, vestibular activity appears to modulate leg motoneuron pool excitability in a standing position but does not in a prone position. These findings indicate that the vestibular effect on motoneuron pool excitability in the leg is different between standing and prone positions. Head position against gravity, posture stability or motoneuron pool sensitivity may be related to the different vestibular effects on the soleus motoneuron pool excitability in standing and prone positions.

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**References**

Illustrations

Illustration 1

Figure 1. Specimen records of H-reflexes on the anodal GVS side. All the traces included for data analysis are averaged for each condition.

Illustration 2

Figure 2. IEMG and H/M ratio on the anodal GVS side. Overall means of the soleus IEMG (A) and H/M ratio (B) are illustrated. Data points indicate means, and error bars indicate standard deviations. An asterisk indicates statistical significance (post-hoc test; P<0.025).
Illustration 3

Figure 3. Specimen records of H-reflexes on the cathodal GVS side. All the traces included for data analysis are averaged for each condition.

Illustration 4

Figure 4. IEMG and H/M ratio on the cathodal GVS side. Overall means of the IEMG (A) and H/M ratio (B) are illustrated. Data points indicate means, and error bars indicate standard deviations.
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