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Effect of Weight Bearing on the Soleus H-reflex During Upright Standing Under the Head-out Water Immersion Condition in Humans

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Abstract: To test our hypothesis that somatosensory inputs inhibit the soleus Hoffmann (H-reflex) circuit during upright standing, ten subjects were investigated under the head-out water immersion (HOWI) condition. Subjects maintained an upright standing without any activity in the soleus, tibialis anterior and vastus lateralis muscles. Testing was conducted (1) dry condition, (2) neck level water immersion to reduce the gravitational effect by 95% by buoyancy (HOWI condition) and (3) 95% of the subject's body weight bearing under HOWI condition (weight-load condition). The test soleus H-reflex and motor (M) response was elicited at a stimulation intensity of 1.05 times the motor threshold. No significant differences in the recruitment profile of the M response were observed. The amplitude of the H-reflex normalized by the maximum M response (M_{max}) was significantly different, even while the stimulation intensity remained constant. The H-reflex in the HOWI was significantly stronger as compared with its strength in the dry condition, while the H-reflex in the weight-load condition was significantly weaker as compared with its strength in the HOWI condition. It was concluded that somatosensory inputs due to gravity exert an inhibitory effects on the soleus H-reflex circuit during upright standing in humans.

Key words: soleus H-reflex, upright standing, weight bearing, water immersion, human

During the upright standing posture in humans, the central nervous system (CNS) receives visual, vestibular and somatosensory inputs, and in turn, sends postural commands to anti-gravity muscles (e.g. the soleus muscle). Previous studies have suggested that somatosensory inputs due to gravity play a major role in the maintenance of a static posture on earth (Diener et al, 1984; Dietz, 1989). Studies have been reported where the effects of gravitational forces were experimentally diminished by buoyancy under the water immersion condition (Mano et al, 1970; Dietz, 1989; Egawa et al, 2000). It is assumed that under this condition, the somatosensory inputs due to gravity are reduced, without any changes in the other sensory inputs (Dietz, 1989; Egawa et al, 2000).

The Hoffmann reflex (H-reflex), an electrically evoked monosynaptic reflex, is a measure of the final common pathway, or the motor output. The H-reflex of the soleus muscle, which is an anti-gravity muscle, is highly modifiable by peripheral sensory inputs and the descending postural commands from the CNS (Schieppati, 1987). We previously reported that postural modulation, defined as a change in the amplitude of the H-reflex during static tilt from the supine to the standing position, is observed on land, but not under the head-out water immersion (HOWI) condition (Egawa et al, 2000). This result suggested that somatosensory inputs due to gravitational forces influence postural modulation of the soleus H-reflex so as to allow a static posture to be maintained with the same changes in the vestibular input under the two conditions. Thus, to elucidate the vestibular inputs, the soleus H-reflex was examined during the upright standing posture (Egawa et al, 2003). The results showed that the amplitude of the soleus H-reflex is increased under the HOWI condition. From these data, we hypothesized that somatosensory inputs inhibit the soleus H-reflex circuit during the upright standing posture in humans. The purpose of the present study was to test this hypothesis

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using weight bearing under the HOWI condition.

Methods

1. Subjects:

The subjects of this study were ten healthy males without any neurological disorders, aged 21 to 30 years old, with a mean height of (standard deviations) 172.4 (3.6) cm, and a mean weight of 66.2 (5.8) kg. All the subjects gave informed consent prior to the commencement of the experiment, and the experiment was approved by the local ethical committee of the Research Institute of Environmental Medicine, Nagoya University.

2. Head-out water immersion (HOWI) condition:

A simulated microgravity experimental device (Shimadzu Co., Ltd., Kyoto, Japan) was used for the study. The temperature of the water was adjusted to, and maintained at 34°C (physiologically neutral temperature). In a sub-tank (0.7 m wide, 0.7 m in deep, and 2.5 m high), the subject, wearing a pair of shaded goggles with eyes open, was instructed to maintain an upright standing posture on a supporting bed. It was inclined at 5° posteriorly to support the subject's back. The body was fixed to the bed, using Velcro belts for the knees and chest, so as to ensure maintenance of a constant posture in the water. The ankle joint was kept at an angle of approximately 90° using a footplate.

The tank was filled with water up to the neck level of the subject within a minute. In this condition, the buoyancy of the water leads to a 95% decrease of the body weight (Egawa et al, 2000). The subject's body was completely waterproofed by wrapping it with a double-polyethylene bag (LLD-PE, 70 cm × 40 μm, Ikedo vinyl company, Nagoya, Japan). We checked that the water had not leaked into the bag before and after the experiment. The subjects were instructed to recline on the bed and to maintain an upright standing on both legs during all the measurement periods.

3. Weight-bearing condition:

Weight-bearing clothes with fifty pockets (a vest and a pair of trousers, Forest, Osaka, Japan) were used to counteract the buoyancy in the water. Each of the pockets could accommodate a 2-kg lead weight. Weights equivalent to 95% of the subject's body weight were used on both sides. Before the measurements in the weight-bearing condition, the clothes of the subject were suspended by a chain block so as to keep the load off the subject. The weight load was monitored and adjusted to counteract the buoyancy under the HOWI condition, using a force plate (ECG-1010DS5, Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan).

4. H-reflex testing:

Surface electromyography (EMG) was recorded in the right soleus, tibialis anterior and vastus lateralis muscles with Ag/AgCl electrodes placed at an interelectrodes distance of 5 cm. The soleus H-reflex was elicited by stimulating the tibial nerve in the popliteal fossa, using an isolator (SS-104J, Nihon Kohden, Tokyo, Japan) and an electric stimulator (SEN-3301, Nihon Kohden, Tokyo, Japan). A constant-current rectangular pulse (1 msec duration) was used. The intensity was increased from the H-reflex threshold to the supramaximal for the motor (M) response.

The background EMG (full-wave rectified and integrated over a duration of 100 msec before the pulse) in the muscles, the H-reflex and the M response were monitored using a data acquisition system (DataShuttle Express, Amtec Co., Ltd., Chiba, Japan sampling frequency, 2 kHz). The peak-to-peak amplitude of the H wave and the M wave was calculated for further analysis.

5. Experimental protocol:

The order of the measurements was 1) dry, 2) HOWI , and 3) weight-bearing conditions. The measurement under each condition was completed in 15 minutes.

6. Statistical analysis:

The amplitude of the H-reflex and the M response at a test stimulus intensity 1.05 times that of the M response threshold (1.05 × MT) was normalized for the amplitude of the maximum M response (M_{max}). The normalized M response was defined as the M size, and reflected the stimulation efficacy for the mixed nerve.

One-way repeated measures analysis of variance (ANOVA) was used for both the H-reflex and the M size (SPSS for Windows 11.5J, SPSS Japan Inc., Tokyo, Japan). Intra-subject's contrast test was also used to detect statistical differences between the dry and the HOWI conditions, and between the HOWI and the weight-bearing conditions. $p<0.05$ was considered significant throughout the study.

Results

No background EMG activity was observed in the soleus, tibialis anterior or vastus lateralis muscles in any of the subjects. The adequacy of the waterproofing procedure was confirmed. Raw traces of the H wave and the M wave are shown in Figure 1, and the recruitment curves are shown in Figure 2. The waveforms of the H wave and the recruitment curve for the M response remained unchanged during the three measurement conditions.

There was a significant main effect of the condition for the H-reflex ($p<0.01$), while no significant effect was found for the M size ($p=0.70$). The contrast test revealed significant differences between the dry and the HOWI conditions (p<0.01), and between the HOWI and the weight-bearing conditions (p<0.01), as shown in Figure 3.

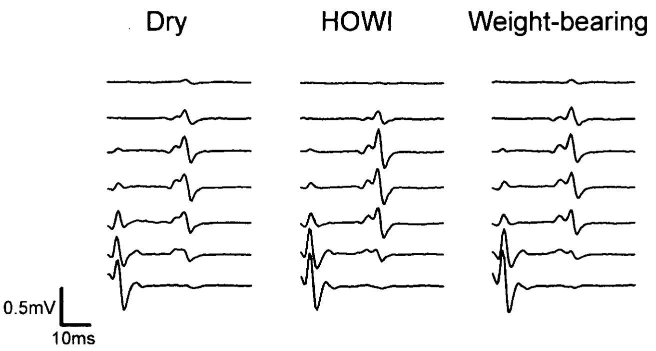

Fig. 1 Raw EMG traces from one subject under the dry (control), the head-out water immersion (HOWI) and the weight-bearing conditions.

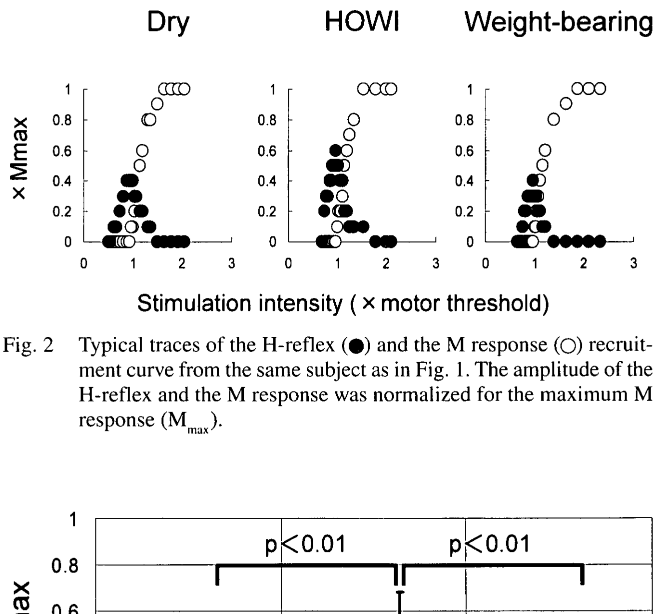

Fig. 2 Typical traces of the H-reflex (●) and the M response (○) recruitment curve from the same subject as in Fig. 1. The amplitude of the H-reflex and the M response was normalized for the maximum M response (M_{max}).

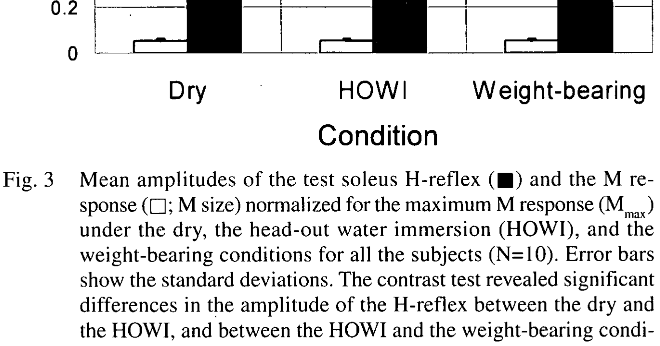

Fig. 3 Mean amplitudes of the test soleus H-reflex (■) and the M response (□; M size) normalized for the maximum M response (M_{max}) under the dry, the head-out water immersion (HOWI), and the weight-bearing conditions for all the subjects (N=10). Error bars show the standard deviations. The contrast test revealed significant differences in the amplitude of the H-reflex between the dry and the HOWI, and between the HOWI and the weight-bearing conditions. On the other hand, the M size remained small under all the conditions, with no significant differences being detected.

Discussion

The results showed 1) that the amplitude of the soleus H-reflex increased under the HOWI condition, and 2) that the amplitude of the H-reflex decreased under the weight-bearing condition when a weight load that could counteract the buoyancy was used. The former directly supported our previous data, which showed that the amplitude of the soleus H-reflex increased significantly under the HOWI condition (Egawa et al, 2000; Egawa et al, 2003). Concerning the latter finding, little evidence has been published until date. Knikou and Conway (2001) reported that tonic mechanical loading of the plantar aspect of the foot sole was associated with a significantly depressed amplitude of the soleus H-reflex in both healthy subjects and subjects with complete spinal cord injury ($T_{5\text{-}12}$ level). Therefore, it is possible that cutaneous receptors in the area (*e.g.* Ruffini corpuscles) responsible for inhibition of the soleus H-reflex circuit during the upright standing posture.

Ali and Sabbahi (2000) reported that the amplitude of the soleus H-reflex was significantly reduced during standing, loading (to +20% of the body weight) and unloading (to −25% of the body weight), as compared with that in the prone condition. There were no significant differences in the amplitudes among the standing, loading and unloading conditions. The possible reason for this is that under the loading condition, the H-reflex is facilitated by holding the weight on both arms (*i.e.* Jenderessik's maneuver). If this were assumed to be true, the H-reflex would be expected to be smaller under the loading than the other conditions. They suggested three possible sources that could modulate the soleus H-reflex circuit: 1) the vestibular system, 2) homonymous (from soleus) facilitation, and 3) mechanical compressive forces in the spinal nerve roots. In this study, the pitch axis of the body was constant: no background EMG activity was observed in the leg muscles . Therefore, pressure receptors within the vertebral column and joints, such as the ankles, knees, hips and neck joints possibly activate the inhibitory interneurons converging on the α-motoneurons (Dietz, 1989).

The present study clarified the effect of weight bearing along with the cephalocaudal axis of the body on the soleus H-reflex circuit during the upright standing posture in humans. From the results, we propose that somatosensory inputs due to gravity inhibit the soleus H-reflex circuit. Segmental and supraspinal factors are possibly responsible for this phenomenon. The segmental factors consist of inhibitory interneurons and presynaptic inhibition of the Ia terminal. A recent study revealed that both cutaneous afferents and corticospinal axons converge together on the inhibitory interneurons in humans (Iles, 1996). On the other hand, transcranial magnetic stimulation studies revealed supraspinal (descending) modulation of the soleus H-reflex circuit under various postural conditions, such as the supine, sitting and standing postures

(Schieppati, 1987). Finally, these factors may be integrated in a presynaptic manner in the spinal cord to modulate the excitability of the α-motoneuron pool of the soleus to allow a static posture to be maintained in humans.

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