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Modulation of soleus H reflex due to stance pattern and haptic stabilization of posture

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Abstract

The quiet stance is a complicated motor act requiring sophisticated sensorimotor integration to balance an artificial inverted pendulum with the ankle musculature. The objective of this study was to characterize the effects of stance pattern (bilateral stance vs. unilateral stance) and directional influence of light finger touch (medial–lateral vs. anterior–posterior) in unilateral stance upon responsiveness of the soleus H reflex. Sixteen healthy volunteers (mean age, 24.25 ± 1.77 years) participated in four postural tasks with the eyes open, including the bilateral stance (BS), the unilateral stance without finger touch (USNT), and with finger touch in the medial–lateral direction (USML) and anterior–posterior direction (USAP). Meanwhile, the soleus H reflex, the pre-stimulus background activity of ankle antagonist pairs, and center of pressure (CoP) sway were measured. In reference to the BS, the USNT resulted in a significant stance effect on suppression of the soleus H reflex (H/M_{max}) associated with enhancement of CoP sway. Among the conditions of unilateral stance, there was a marked directional effect of finger touch on modulation of the H/M_{max}. A greater disinhibition of the H/M_{max} in consequence to light touch in the ML direction than in the AP direction was noted (H/M_{max}: USML > USAP > USNT). This directional modulation of the soleus H reflex concurred with haptic stabilization of posture in unilateral stance, showing a more pronounced reduction in CoP sway in the USML condition than in the USAP condition. However, alteration in postural sway and modulation of the soleus H reflex were not mutually correlated when stance pattern or touch vector varied. In conclusion, gating of the soleus H reflex indicated adaptation of an ankle strategy to stance pattern and haptic stabilization of posture. Relative to bilateral stance, postural maintenance in unilateral stance relied less on reflexive correction of the soleus. When finger touch was provided in line with prevailing postural threat in the lateral direction, postural stability in unilateral stance was better secured than finger touch in anterior–posterior direction, resulting in more pronounced disinhibition of the monosynaptic reflex pathway.

Keywords: H reflex; Postural balance; Unilateral stance; Fingertip touch

1. Introduction

For maintenance of stance equilibrium, continuous corrective modulation of torque in the ankle joint against gravity aligns the center of mass within the base of support. Although postural control is hieratically organized to coordinate the trunk and lower limbs, it has become popular to capture the dynamics of human stance conceptually with an inverted pendulum model (Winter et al., 1998). During the bilateral stance, the ankle strategy of stance control calls for adaptive regulation of the reflex gain of the soleus muscle (Chalmers and Knutzen, 2002; Hayashi et al., 1992; Katz et al., 1988; Runge et al., 1999), which modulates the stiffness of the ankle joint principally in the anterior–posterior direction (Winter et al., 1998, 2003). When a subject raises the unsupporting leg, stance equilibrium may be impaired due to a predominant increase in lateral postural sway

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(Era and Heikkinen, 1985). Such a threat to postural equilibrium in the medial–lateral direction is better secured with the hip strategy (Gribble and Hertel, 2004a). However, whether the ankle strategy, in which the medial and lateral sides of the foot are elevated, plays a supplementary role in the unilateral stance is still debatable (Tropp and Odenrick, 1988). Some researchers have argued that fatigue to ankle musculatures is of little significance to increases in the excursion of the center of pressure during the unilateral stance (Gribble and Hertel, 2004a,b), whereas other reports have claimed that fatigue to ankle plantarflexor/dorsiflexsor musculature undermines postural control because of the large extent of increments in lateral postural sway amplitude (Lundin et al., 1993; Yaggie and McGregor, 2002).

Contact cues at the fingertip appear to attenuate postural sway (or excursion of the center of pressure) in various stance conditions (Clapp and Wing, 1999; Rabin et al., 1999), even if the contact force is too subtle (contact force under 1 N) to afford adequate physical support of the body (Holden et al., 1994). One possible explanation of this stabilization of a stance is light touch that can facilitate cutaneous feedbacks through skin surface deformation (Jeka and Lackner, 1995). Cutaneous feedbacks fortify perception of spatial information concerning the alignment of the body in reference to the external environment (Jeka and Lackner, 1994), and therefore a subject is able to effectively update postural control against postural threat from the richness of contact information. An interesting question is raised as to whether cutaneous inputs from the fingertip are capable of regulating appropriate innervation of the soleus muscle, according to proprioceptive information that signals body motion in an unstable plane.

In light of the modulation of the responsiveness of the soleus H reflex and postural sway, the first objective of the present study was to reexamine the involvement of ankle strategy in stabilizing the unilateral stance, which is widely used in postural control tests with greater challenges in the medial–lateral direction than in the anterior–posterior direction (Era and Heikkinen, 1985). If the soleus H reflex of the stance leg is modulated when one raises the unsupported leg, the ankle strategy can hardly be precluded from the maintenance of the unilateral stance. Next, the present study sought to examine whether a light touch at the fingertip during unilateral standing provides a spatial cue to stabilize the unsteady stance by modulating the reflex response of the ankle. It is hypothesized that the finger touch in unilateral stance would mediate soleus H reflex in relation to the vector of finger touch. Finally, the relationship between H reflex modulation and change in postural sway was assessed to clarify the significance of reflex response for postural control under demanding stance conditions.

2. Methods

The study was conducted in 16 healthy volunteers (8 males; 8 females; mean age 24.25 ± 1.77 years) who signed personal consents forms in accordance with institutional guidelines to protect the rights of human subjects. There were four stance conditions in this study, including bilateral stance (BS), unilateral stance without finger touch (USNT), unilateral stance with finger touch in the medial–lateral direction (USML), and unilateral stance with finger touch in the anterior–posterior direction (USAP).

Each subject was requested to keep a stable stance while barefoot on a force platform (Model 9286AA, Kistler, Switzerland). In the BS condition, subjects were instructed to stand upright, head facing forward, and to remain as still as possible with their heels separated medio-laterally by a distance equal to the individual's bilateral shoulder width. In the other three unilateral stance conditions, all subjects stood on the force platform with the dominant foot (right), and the left foot was positioned similar to the position in the BS condition but without support (Fig. 1). In the USML and USAP conditions, subjects placed their right index finger tips on the touch plate connected to a digital force gauge (Model 9800, AIKOH Engineering, Singapore) in the medial–lateral or anterior–posterior direction, respectively. The touch force of the fingertip was carefully controlled between 0.49 and 0.98 N, which was too subtle to provide mechanical support. The height of the touch plate was adjusted to match the individual subject's height so that subjects were able to maintain their right arm in a standardized position by placing the right index on the touch plate with the elbow flexed 90° and slightly out to the side without contacting the body. In the conditions without finger touch (both BS and USNT), the subjects adopted a similar arm position as they had in the USML and USAP conditions, except that contact with the touch plate was prevented.

The postural sway during the four stance conditions (BS, USNT, USML, and USAP) was characterized with anterior–posterior and medial–lateral movements of the center of pressure (CoP) using the force platform. The soleus H reflex of the dominant (stance) leg was recorded to assess the reflex sensitivity of the muscle in response to different stance needs. An electrical stimulator (Model S88, Grass Instruments, USA) was used to elicit soleus H reflexes by delivering single rectangular pulses of 1 ms duration. An adhesive anode (4×4 cm) was placed over the patella, and a bar cathode was fixed over the posterior tibial nerve. The muscle activity of the soleus was monitored with a bipolar surface electrode unit (1.1 cm in diameter, gain = 365, CMRR = 102 dB, Imoed Inc., USA). An additional surface electrode was placed on the tibialis anterior to monitor antagonist activity in stance. At the beginning of each postural task, three maximum M responses (M_{max}) of the soleus muscle were averaged and obtained by gradually increasing the stimulus intensities until the direct M responses were finally ceased to increase.

There were eight successful recording trials for all four stance conditions. For each trial of all stance conditions, subjects were motivated to maintain steady stance during the experiment. The displacement of CoP was recorded for 20 s, and then an electrical shock was superimposed to elicit soleus H reflex at the end of CoP collection. To secure stimulation consistency against change in contact pressure of the stimulating electrode, the subjects wore a knee brace to minimize a potential change in knee joint position due to concurrent contraction of the gastrocnemius following electrical shocks to elicit soleus H reflex. In addition, in order to have efficacious exploration of motoneuronal excitability with less fluctuation in H reflex amplitude (Hwang and Tsai, 2002), the present study adopted the stimulus intensity at which H reflexes with the accompanying M response in the range of $10 \pm 3\%$ of M_{max} was elicited. The elicited EMG response was conditioned