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Original Paper

Influence of Active Fingertip Contact with a Stable Surface on Postural Sway and Electromyographic Activities of the Lower Extremity Muscles Immediately after Descending a Step

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Abstract

Recent studies have shown that active contact cues from a fingertip provide information that leads to reduced postural sway during static standing. Although the falling risk increases immediately after descending a step, little is known about the influence of active fingertip contact with a stable surface. The purpose of this study was to investigate the influence of fingertip contact on the sway and the EMG (Electromyographic) activities of lower extremity muscles immediately after descending a step. Nine healthy male volunteers participated in this study. Sway was measured by the center of pressure (COP) and compared under three conditions: (1) standing without touching, (2) standing with the right index fingertip lightly touching (<1N), and (3) standing forcefully touching (5~10N). EMG activities were measured associated with sway and compared. More areas of COP were observed while standing without touching than while standing with light or forceful touching, but there was no significant difference between the two touching conditions. No significant differences in the length of COP and the EMG activities were observed among the three conditions. The results suggested that the fingertip touch contact with a stable surface decreased sway immediately after descending a step by finely controlling the lower extremity muscles.

1. Introduction

Standing balance decreases in elderly people because of age-related physiologic diminution of vestibular function and in many kinds of neuromuscular, musculoskeletal and sensory disorders. Accordingly, their incidence of falling increases. Fear of falling by such people creates a psychological barrier which makes them reluctant to leave their homes leading to an inactive life.

Recent studies have shown that active contact cues from the fingertip provide information that leads to reduced postural sway while standing [1-5]. Clinicians have observed subjects with poor balance control using light touch contact with surrounding objects, such as a desk or a wall to stabilize themselves while standing and walking. Some investigators have reported on the effect of light touch and forceful contacts

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with horizontal surfaces, such as a bar or a desk, on postural sway while standing [4-6]. Although the falling risk and sway increase during or immediately after the dynamic activity, such as descending a step, little is known about the influence of active light and forceful fingertip contacts with a stable surface such as a desk on postural sway and the EMG (Electromyography) activities of the lower extremity muscles [7]. The first purpose of this study was to investigate the influence of active light and forceful fingertip contacts with a stable surface on the postural sway while standing upright immediately after descending a step.

It is well known that lower extremity muscles, such as the quadriceps femoris, the biceps femoris, the tibialis anterior, the gastrocnemius and the soleus muscles, play important roles in maintaining a standing upright position against gravity. Jeka et al. [5] evaluated how electromyographic (EMG) activity in the peroneus longus muscle changed with different levels of fingertip contact force. The soleus muscle plays a very important role in controlling the ankle joint and standing balance. The authors investigated the EMG activity of the soleus muscle while standing quietly [8]. However, little is known about how the EMG activities of other lower extremity muscles according to the soleus muscle are influenced by fingertip contact with a stable surface while standing upright immediately after descending a step. The second purpose of this study was to investigate the influence of fingertip touch on the EMG activities of lower extremity muscles. Our findings provide basic information on the influence of a light or forceful fingertip touch on standing balance immediately after descending a step in subjects with poor balance.

2. Materials and methods

2.1. Participants

Nine healthy male volunteers who had not suffered from any musculoskeletal, neuromuscular, or sensory disorders, or any general systemic diseases participated in this study. Their mean (±standard deviation) age, height, and weight were 21.0±0.8 years old, 169.5±4.8 cm, and 62.1±8.0 kg, respectively. Informed consent was obtained from all the participants.

2.2. Evaluation of postural sway (Figs. 1&2)

Standing balance or postural sway was measured by sway of the center of pressure (COP). Each subject was asked to stand upright quietly on a gravicorder (P07-1712, Kyowa Electronic Instruments Co., Ltd., Japan) immediately after descending a step (a height of 20 cm) under three conditions: (1) standing without touching a stable surface, that is, a force plate (P08-1713, Kyowa Electronic Instruments Co., Ltd., Japan) simulating the touching of it, (2) standing with the right index fingertip lightly touching (<1N) the stable surface, and (3) standing with the right index fingertip forcefully touching (5~10N) the stable surface. The first position served as the control. In the second and the third positions, subjects were instructed to touch the stable surface at a distance 30 cm external to the right foot. Each subject stood for 10 sec under each condition watching a round mark 2 cm in diameter, placed two meters in front of their eyes. The three experimental conditions were randomly arranged for each subject. The amount of COP sway was calculated by measuring the length, the rectangular area and the environmental area of COP for four sec. immediately after descending a step. We decided to measure for four sec. according to the previous study [9]. Miyoshi et al. [9] demonstrated that the greater sway in the elderly subjects continued for four sec. immediately after sit-to-stand movement from a chair. Before each force contact trial, each subject was given verbal feedback about the level of applied fingertip force until it was close to 1N or 10N. The subject was instructed to maintain this force level throughout the trial and the applied force level was monitored by one experimenter during the trials. If at any moment in time, more than 1N (light touch) or less than 5N and more than 10N (forceful touch) was applied, the trial was rejected and stopped. The rest period between conditions was about 1 min.

2.3. Measurement of EMG activities (Figs. 1&2)

After thorough skin preparation, which involved cleansing with alcohol and the use of a skin abrasion technique, disposable surface electrodes were placed over the right rectus femoris, biceps femoris, tibialis anterior, gastrocnemius, and soleus muscles to measure the EMG activities associated with sway. Although many muscles are involved in maintaining an upright standing position, these muscles mainly serve to control standing posture. Disposable silver/silver chloride surface electrodes with a recording diameter of 1 cm (Blue Sensor N-00S, Medicotest A/S, Denmark) were used. Bipolar electrode pairs were placed longitudinally over the muscle belly at an inter-electrode distance of 3 cm. The grounded electrode was placed over the head of the fibula. EMG signals were recorded during all postural sway tasks. Signals were amplified, band-pass filtered (10-500 Hz), digitized and stored by a data acquisition system (VitalRecorder2, Kissei Comtec, Co., Ltd., Japan) at a sample frequency of 1000 Hz. The average EMG activity values for each task were normalized to maximal voluntary contractions (MVC), which were obtained in isometric maximal exertion tasks, using a standard manual muscle test described by Hislop et al. [10] (%MVC). %MVC was obtained by dividing the average EMG values for each task by EMG values of MVC. Each MVC was held for five seconds and the average of EMG activity was used to determine the MVC. All the experiments were carried out in an air-conditioned laboratory maintained at about 24 °C.

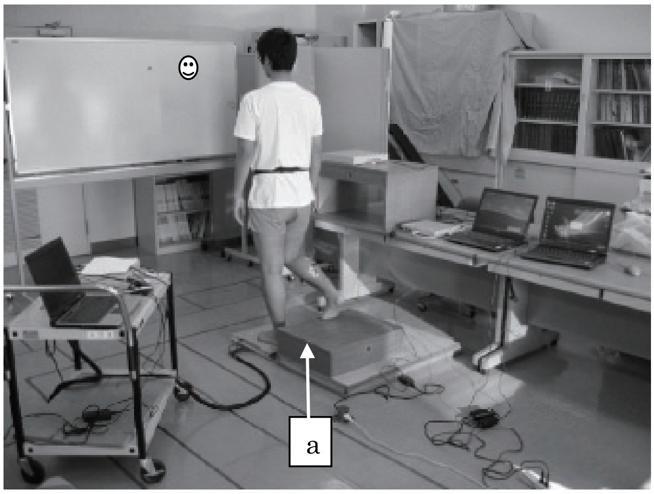

Fig. 1 Each subject was asked to descend a step (a).

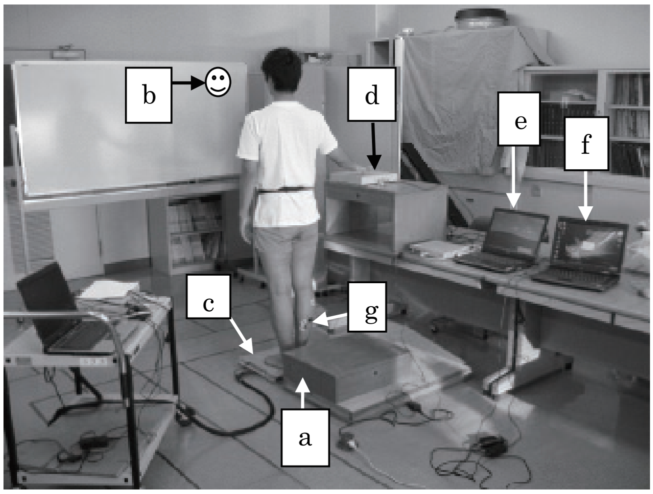

Fig. 2 Immediately after descending a step, each subject was asked to keep standing upright quietly watching a mark (b) in the standard Romberg position on a gravicorder (c) under three conditions: standing without touching a force plate (a stable surface) (d) simulating touching it, and standing with a right fingertip lightly (<1N) or forcefully (5~10N) touching a force plate (d). The level of applied fingertip force was monitored using a force plate system (e). EMG signals at the right rectus femoris, the biceps femoris, the tibialis anterior, gastrocnemius, and soleus muscles were recorded while standing (f, g).

2.4. Statistical analysis

One-way analysis of variance (ANOVA) was used to validate statistical differences among three experimental conditions. Multiple comparison by the Bonferroni method was used to compare differences in group means using the SPSS statistical package 16.0 for Windows. A high level of $p<0.05$ was considered significant for these comparisons.

3. Results

Comparisons of the parameters of postural sway under each condition are shown in Table 1. No significant COP length was observed among the three conditions. A more significant rectangular area was measured while standing without touching a stable surface than while standing with a light or forceful touch, but there was no significant difference between the two touch conditions. A more significant environmental area was measured while standing without touching a stable surface than while standing with light or forceful touch, but there was no significant difference between the two touch conditions. The %MVC results from each condition are shown in Table 2. No significant differences were observed among the three conditions.

4. Discussion

In this study, rectangular and environmental areas while standing without touching a stable surface were greater than those while standing with a light or forceful touch immediately after descending a step, but there was no significant difference between the two touch conditions. These results were almost the same as those in the studies of Holden et al. [11] and Jeka et al. [5]. They asked a subject to touch his or her index fingertip to a horizontal bar. Holden et al. [11] found that when a standing subject applied 5-8N of force to the bar with his or her index fingertip, postural sway was reduced by over 60% from the control condition; in which subjects stood with arms hanging passively by their sides. When the subjects were limited to applying a very small contact force level (<1N), postural sway was also attenuated by over 60% from the control condition. Holden et al. [11] have provided a systematic physical analysis of the amounts of passive and dynamic stabilization of posture that can be achieved with different fingertip contact force levels. In a condition involving less than 1N (<1N) of applied fingertip force, neither passive stability nor direct active stabilization is possible. The maximum sway reduction attributable to actively applied contact force is 2.3%. However, in conditions involving 5-8N of applied contact force, attenuation of sway through passive and dynamic stability is estimated to be 20-40%, indicating that biomechanical factors are playing

Table 1 Comparisons of parameters of postural sway under each condition

	NT	LT	FT
LNG (cm)	134.4±15.7	123.2±12.1	122.8±12.1
REC (cm^2)	177.7±117.6	55.7±17.9*	67.1±22.2*
ENV (cm^2)	58.3±25.1	28.6±6.6*	32.1±10.6*

Values are means ± SD (standard deviation).

*; $p<0.05$ (compared with NT)

NT: No Touch

LT: Light Touch

FT: Forceful Touch

LNG: Length of COP (Center of Pressure)

REC: Rectangular area of COP (Center of Pressure)

ENV: Environmental area of COP (Center of Pressure)

Table 2 Electromyographic activities normalized as a percentage of maximal voluntary contraction (%MVC) for the five lower extremity muscles under each condition

	NT	LT	FT
RF	7.0±7.5	6.8±7.6	6.7±6.0
BF	4.3±3.1	4.0±2.6	4.4±4.2
TA	1.9±0.9	2.8±2.0	2.0±0.6
GA	12.8±10.6	12.1±8.5	12.4±11.0
SO	20.0±8.8	19.5±7.5	19.1±7.3

Values are means ± SD (standard deviation).

NT: No Touch

LT: Light Touch

FT: Forceful Touch

RF: Rectus femoris muscle

BF: Biceps femoris muscle

TA: Tibials anterior muscle

GA: Gastrocnemius muscle

SO: Soleus muscle

a significant role [11]. Jeka et al .[5] reported that sensory input to the hand and arm through contact cues at the fingertip or through a cane can reduce postural sway in individuals who have no impairments and in patients without a functioning vestibular system, even when the contact force levels are inadequate to provide physical support of the body.

Maeda et al. [7] reported that for the visually impaired elderly, the greatest degree of sway occurred when subjects stood unsupported, the second largest was recorded while standing with a cane, and the smallest sway occurred when they stood touching a wall. Although they did not record the force touch level, the results were similar to ours. They considered that, as in the case of body support using a cane, the increase in somatosensory inputs achieved by touching a wall was adequate to compensate for the lack of visual information [7]. They hypothesized that touching a wall for body support is more effective for visually impaired persons than holding a cane because the wall's fixed plane effectively suppresses body sway [7]. They did not measure the contact force level, but the authors measured the force level. After that, we showed that an active light or forceful touch to a vertical surface, such as a wall, led to a decrease in body sway as the touch to a horizontal surface, such as a desk [8]. We also considered that the increase in somatosensory input achieved by actively touching a wall was enough to decrease the body sway.

Although rectangular and environmental areas while standing without touching a stable surface were greater than those while standing with a light or forceful touch immediately after descending a step, no significant COP length was observed among the three conditions. The results suggest that COP swayed more finely in the smaller areas in the two touch conditions than in the no touch condition. The authors considered that postural sway was controlled more finely by the touch cue even after descending a step.

We were concerned about how the sensory input from a fingertip to a stable surface is interrelated with proprioceptive information about the configuration of the arm and the body to stabilize standing balance. When the contact force is too small to counteract postural sway biomechanically, the fingertip stimulation must be providing cues about torso motion that can be used to activate the lower extremity muscles to attenuate the sway. Jeka et al. [5] reported that both light and forceful touch contacts led to decreased levels of EMG activity in the peroneal muscles relative to a no contact condition in the tandem Romberg stance, and the EMG activity was significantly lower under the forceful touch condition than under the light touch condition. They considered that the level of EMG activity in the peroneal muscles and timing relationships between fingertip forces and the body sway suggested that "long-loop reflexes" involving postural muscles were stabilizing sway [5]. In the previous study, the authors observed no significant change in the EMG activity level at the soleus muscle while standing under the three conditions [8]. The authors considered that both light and forceful fingertip touch contact led to a decrease in the sway but did not influence the EMG activity level of the soleus muscle, because it contracts continuously at a constant level to maintain static standing balance. In the present study, we investigated how EMG activity in the lower extremity muscles changed with different levels of fingertip contact force compared with no touch contact. No significant differences in the %MVC were observed under the three conditions. The results suggest that lower extremity muscles were activated more finely to control sway in the smaller area under the two touch conditions and activated roughly to control sway in the large area under the no touch condition. The authors considered that the active contact cue from the fingertip on the stable surface decreased postural sway and controlled it more finely even immediately after descending a step.

5. Conclusion

The results of this study suggested that active fingertip contact with a stable surface decreased sway and controlled it more finely even immediately after descending a step. The touch paradigm can be used to stabilize balance immediately after dynamic activities of daily living in individuals with poor balance including the elderly.

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