Original Article

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Sequential Analysis of Postural Control Resource Allocation During a Dual Task Test

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Objective To investigate the postural control factors influencing the automatic (reflex-controlled) and attentional (high cortical) factors on dual task.

Methods We used a dual task model to examine the attentional factors affecting the control of posture, subjecting test subjects to vibration stimulation, one-leg standing and verbal or nonverbal task trials. Twenty-three young, healthy participants were asked to stand on force plates and their centers of pressure were measured during dual task trials. We acquired 15 seconds of data for each volunteer during six dual task trials involving varying task combinations.

Results We observed significantly different sway patterns between the early and late phases of dual task trials, which probably reflect the attentional demands. Vibration stimulation perturbed sway more during the early than the late phases; with or without vibration stimulation, the addition of secondary tasks decreased sway in all phases, and greater decreases in sway were observed in the late phases, when subjects were assigned nonverbal tasks. Less sway was observed during the nonverbal task in a sequential study.

Conclusion The attentional and automatic factors were analyzed during a sequential study. By controlling the postural control factors, optimal parameters and training methods might be used in clinical applications.

Keywords Task performance, Analysis, Postural balance, Attention

INTRODUCTION

Sensory perturbations of visual, somatosensory, and vestibular systems disrupt the postural stability. Postural control can be influenced by the automatic (reflex-controlled) and attentional (high cortical) factors, and previous studies have suggested that the postural control systems require varying degrees of attention, depending on the postural tasks involved and the age of the subjects [1-5]. The attentional factors are thought to arise from the central nervous system, while the automatic factors are reflex-controlled by somatosensory (muscle, skin, and

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pressure receptors) visual and vestibular inputs [6,7].

Dual task paradigms are important tools for understanding the balance control. The primary task is usually postural control, which involves standing on a force plate with different levels of difficulty; for example, on an uneven surface or standing on one leg. Teasdale et al. [8] showed that adults of all ages exhibit delays in reaction time as postural task complexity increases. When vibrations are applied during primary postural tasks, they typically cause directional shifts in subjects, due to increasing primary afferents that are discharged during vibration and interpreted as lengthening of the vibrated muscles [7]. In previous studies, tendon vibration stimulation was shown to increase the postural sway, and subjects frequently experience vibration-induced compensatory losses of balance, falling in the same direction as the applied vibration [9,10]. However, in several studies directional shifts were either increased or decreased according to the stimulation intensity and type [11-15].

The secondary task in dual task paradigms is usually attention demanding, and task intensity and difficulty influence postural control in various ways [5,16,17]. Both verbal and nonverbal tasks have been applied as secondary tasks in dual task paradigms [18,19]. Verbal tasks are considered relatively easy for participants to complete, while nonverbal tasks are more difficult due to their attention demanding characteristics. Verbal and nonverbal working memories are thought to be associated with different regions of the brain [20-22].

Several studies have explored the effects of tendon vibration on the postural control and the ability to complete tasks. However, the relationships between these parameters and postural sway have not been investigated in a dual task study design. Furthermore, the sequential relationship between automatic control and attention factors during in dual task contexts is still unclear.

We examine the sequential relationships of dual task on the postural control. When subjects were subjected to dual task trials, we were able to sequentially observe the demands of attention factors, how they differed depending on the combinations of tasks that were presented, and the effects of attentional factors on the balance control. The clinical implications of postural control can be understood through dual task performance and resource allocation analysis.

Table 1. The demographic data of the participants

	Verbal task	Nonverbal task
Sex (male:female)	11:9	
Age (yr)	28.36±4.03	
Height (cm)	169.05±7.26	
Weight (kg)	59.94±12.16	
Accuracy of correction (%)		
Vibration off	0.84±0.09	0.78±0.14
Vibration on	0.83±0.09	0.80±0.12
Reaction time (ms)		
Vibration off	531.24±74.43	508.50±77.35
Vibration on	512.53±94.54	516.31±82.72

Values are presented as mean±standard deviation.

MATERIALS AND METHODS

Subjects

There were twenty-three young, healthy participants in this study. No participants reported neurological or orthopedic disorders, and none were receiving medications known to affect the postural control. All participants provided informed consent prior to testing.

Methods

A total of 23 subjects participated in the study. Detailed demographic data are shown in Table 1. All participants

Table 2. Six trials of dual task

Name	Abbreviation	Condition	Sequence
Trial I	S	One leg standing	Randomized
Trial II	Sv	One leg standing+verbal task	Randomized
Trial III	Snv	One leg standing+nonverbal task	Randomized
Trial I-1	viS	One leg standing+vibration on foot	Randomized
Trial II-2	viSv	One leg standing+vibration on foot+verbal task	Randomized
Trial III-3	viSnv	One leg standing+vibration on foot+nonverbal task	Randomized

were randomly assigned to six trials (Table 2). Three participants were excluded due to poor compliance and the other 20 participants were included in the experiments.

Each participant stood on his or her dominant leg on a force plate, while watching a computer display monitor. While standing on the force plate, each participant was subjected to six successive dual task trials in random order (Table 2). Secondary tasks were given to participants via the computer display and center of pressure (COP) values were recorded during each experiment.

Subjects were asked to stand with arms folded and a button in one hand, and to press the button to indicate correct answers to task questions, in order to reduce any confounding effects of articulation [23]. All participants were allowed two practice trials, and each trial began with the 'ready' cue, followed by a 'set' cue three seconds later. When the participants were told to be 'ready', they stood on one leg and held that position for 15 seconds. Participants rested for one minute between the trials.

A primary task involving proprioceptive vibration stimulation was given to subjects as they stood on one leg for 15 seconds. A vibratory motor (consisting of two vibratory plates, 10 g and 10 mm) was applied to the skin overlying the Achilles tendon and tibialis anterior on the inferior third of the dominant leg. The vibratory motor (Jahwa Electronics Co. Ltd., Seoul, Korea) produced a stimulus at 8,000 rpm and 10 mm of the motor diameter. The amplitude and intensity of vibration were controlled by LabVIEW 8.0 (National Instruments, Austin, TX, USA). As soon as participants could feel the vibratory stimulation, we determined and set it at the supra-threshold intensity.

Leg dominance was determined by ball kick tests. During the one-leg stand, the COP was measured and recorded by the Bertec force plate system (Bertec Co., Columbus, OH, USA), which consists of four road cells and Acquire software ver. 5.1.

A cognitive task was presented to subjects either as a series of random characters (verbal) or shapes (nonverbal) displayed on a computer screen. If the presented character or shape was identical to the one that had been displayed two steps before (two back task), participants were asked to respond by pressing the button [24,25]. Cognitive performance was calculated by the number of correct responses and the response time.

Sway was measured by the force plates and amplified, and the summation of the sway distance during each trial was recorded as the distance from the center of pressure (DCP). Three trials of DCP data were acquired per each test (trial I–VI), and the mean values were calculated for use in analyses. The recorded force information was used to derive the position time function of the COP for each trial.

Statistical analysis

Data were collected during three sessions performed on three different days, no more than a week apart. Acquire software was used to receive the signals from the force plate, and MATLAB (MathWorks Inc., Natick, MA, USA) was used to analyze the data after filtering with the Butterworth method [26,27].

Experimental parameters included vibration (on, off) and task context (no task, verbal task, nonverbal task). The total summations of sway distances of 15 seconds from six different trials each were compared using paired t-tests. Participant performance under different test conditions (no secondary task, verbal/nonverbal tasks without vibration and without secondary task, and nonverbal/verbal tasks with vibration) were compared using one-way ANOVA with a Bonferroni correction. The amount of sway in time sequence was analyzed using a one-way repeated ANOVA. After first one second for one leg standing adjustment, the summation of sway distance in the first phase (2–8 seconds) and the late phase (9–15 seconds) were compared using a paired t-test. To analyze the sway difference in time sequence, the sway differences in each second were acquired and compared with the first one second sway difference (2–3 seconds) using a paired t-test.

RESULTS

The total summation of the DCPs is shown in Fig. 1. Participants exhibited more sway when subjected to vibration (434.99±86.73 mm) than in trials with no vibration (416.54±70.97 mm). The addition of verbal and nonverbal secondary tasks decreased sway compared to the trials in which the participants were not given secondary tasks. We did not observe any significant differences between the trials when secondary tasks were provided with or without vibration stimulation.

However, during trials in which participants are asked

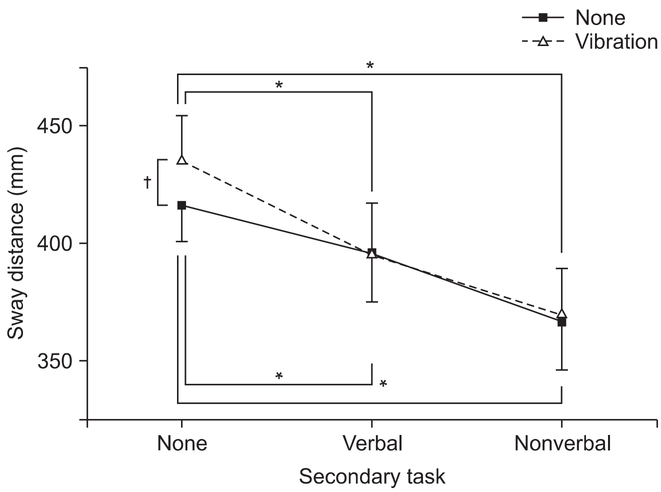

Fig. 1. Comparison among the total summation of distance of center of pressure during 6 trials. *Denotes significant differences between different secondary tasks (none and verbal, none and nonverbal). †Denotes significant differences between none and Vibration.

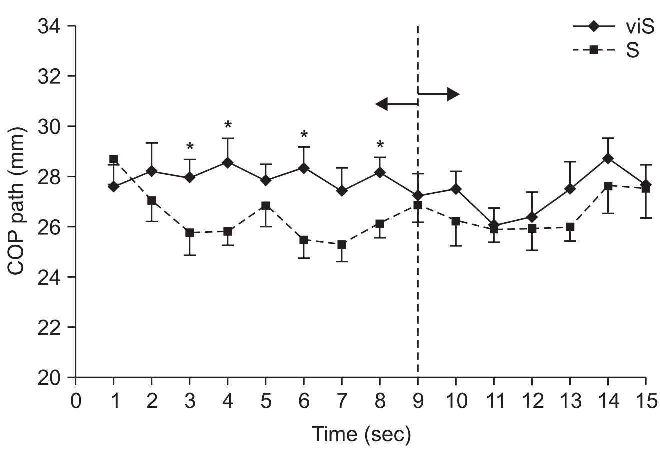

Fig. 2. The amount of sway per second with or without vibration during one-leg standing trials. viS, stands for vibration and one-leg standing as the dual task; S, stands for one-leg standing only as the primary task; COP, stands for the center of pressure distance. *Denotes significant differences between viS and S.

to maintain one-leg stands, greater postural control is needed as time goes by to maintain the balance, and eventually, the participants were forced to break posture. In our study, we observed that after 8–10 seconds, sway began to increase in such trials. In addition, when secondary tasks were given to standing participants, noticeable changes of sway were observed after 8–10 seconds (Fig. 2). Therefore, we split the trials into early and late

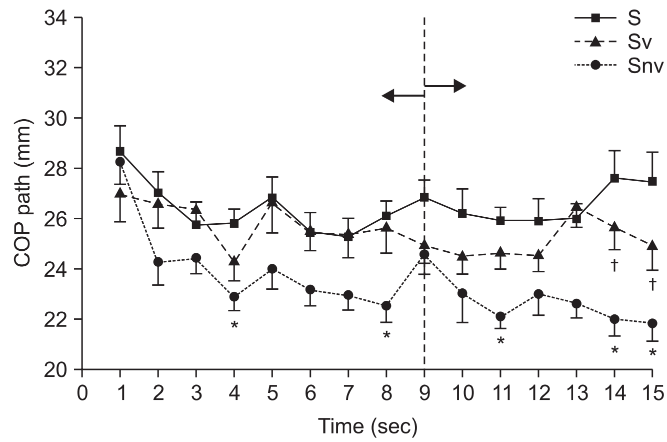

Fig. 3. The amount of sway per second with secondary tasks during one-leg standing trials. COP, stands for the center of pressure distance; S, stands for one-leg standing as the primary task; Sv, stands for one-leg standing as the primary task and a verbal task as the secondary task; Snv, stands for one-leg standing as the primary task and a nonverbal task as the secondary task. *Denotes significant differences between Sv and Snv. †Denotes significant differences between viS and viSv.

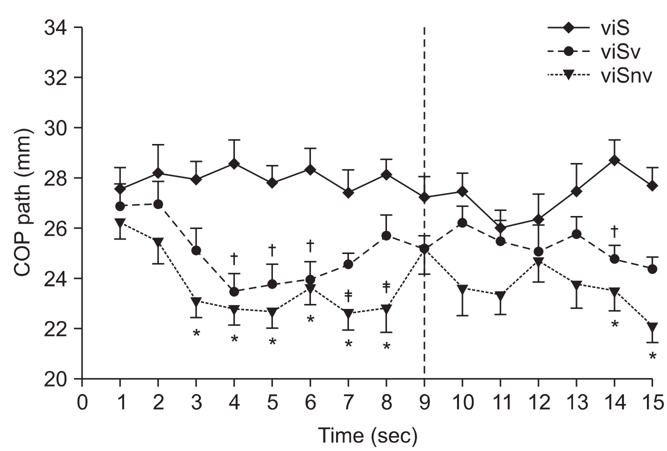

Fig. 4. The amount of sway per second with secondary tasks during one-leg standing trials with vibration. COP, stands for the center of pressure distance; viS, stands for vibration and one-leg standing as the primary task; viSv, stands for vibration and one-leg standing as the primary task and a verbal task as the secondary task; viSnv, stands for vibration and one-leg standing as the primary task and a nonverbal task as the secondary task. *Denotes significant differences between viS and viSnv. †Denotes significant differences between viS and viSv. ‡Denotes significant differences between viSv and viSnv.

phases with the distinction made when we observed the noticeable sway differences (Figs. 3, 4).

Vibration stimulation study

One-leg standing tasks and/or vibration stimulations were given to participants as primary tasks. More sway was noted when supra-threshold intensity vibration stimulations were applied than in trials with one-leg standing alone (Fig. 2). Significant increases in sway were noted during the early phases, but none were observed in the late phases. After an adjustment period with one leg standing (1—2 seconds), more sway was noted during vibration trials than in trials requiring participants to maintain a one-leg standing alone, up to 9 seconds. However, after 9 seconds, we did not observe any significant differences in the sway between the trials. In one-leg stand trials, after a short adjustment period with one leg standing, more sway was noted during the late phases compared to the early phases. In trials combining the vibration and one-leg standing, more sway was noted in the early phases, but then decreased in the late phases. The greatest amounts of sway were noted at the end of both types of the trials (14—15 seconds).

Secondary tasks given to subjects standing on one leg

Sway decreased when subjects standing on one leg were given each secondary task to complete (Fig. 3). We observed significant decreases in the sway during the late phases of the verbal task trials when compared to the trials in which participants were not given secondary tasks. Compared to trials in which participants were given verbal tasks, decreased sway was noted for all phases during the nonverbal task trials, but this difference was not significant. Significant decreases in the sway were noted for all phases of the nonverbal task trials compared to the trials in which participants were not given secondary tasks.

Vibration stimulation applied to subjects given secondary tasks

For trials in which subjects were given nonverbal tasks, the application of vibration stimulation increased the sway in the late phases, though this increase was not significant (Fig. 5). In trials in which participants were given verbal tasks, the application of vibration stimulation increased the sway in the late phases, but this increase was also not significant. In a general sense, vibration did not increase the sway when secondary tasks were given in any phases (Fig. 6).

Secondary tasks given to subjects standing on one leg standing and exposed to vibration stimulation

The assignment of secondary tasks decreased sway in all phases in subjects standing on one leg and simultaneously exposed to vibration stimulation (Fig. 4). Trials in which subjects were given both verbal and nonverbal tasks resulted in significantly decreased sway in all

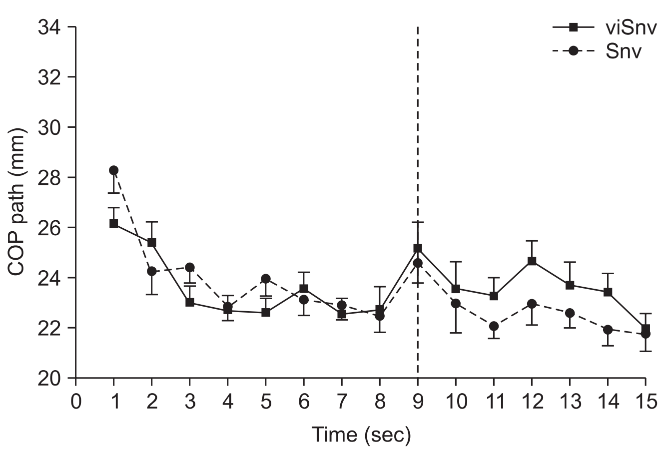

Fig. 5. The amount of sway per second with or without vibration during one-leg standing trials with nonverbal task. COP, stands for the center of pressure distance; viSnv, stands for vibration and one-leg standing as the primary task and a nonverbal task as the secondary task; Snv, stands for one-leg standing as the primary task and a nonverbal task as the secondary task.

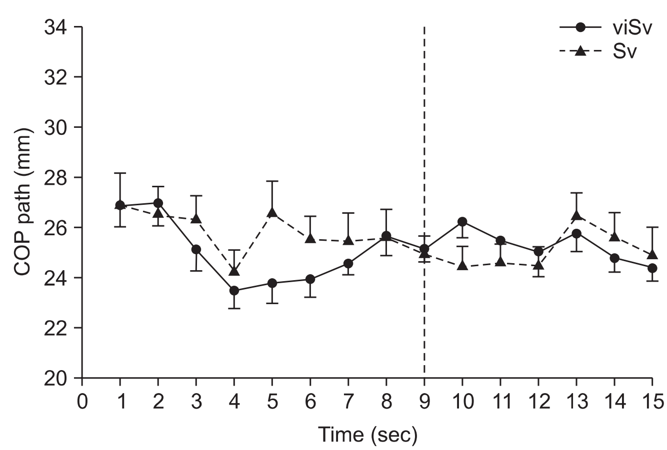

Fig. 6. The amount of sway per second with or without vibration during one-leg standing trials with verbal task. COP, stands for the center of pressure distance; viSv, stands for vibration and one-leg standing as the primary task and a verbal task as the secondary task; Sv, stands for one-leg standing as the primary task and a verbal task as the secondary task.

phases compared to the trials with no secondary tasks. Compared to the trials in which participants were given verbal tasks, nonverbal task trials resulted in significantly decreased sway within an early phase.

DISCUSSION

The present study implemented a difficult, attention-demanding two-step recall memory task. Postural changes were less apparent in subjects given attention-demanding tasks than in subjects given a primary task only. The effects of attention-demanding tasks are similar to those of the external foci. Attention-demanding tasks divert attention away from the postural control, perhaps allowing for more automatic processes and less conscious interference in the control of the balance [28]. Previous studies have suggested that requesting participants to focus on the body sway induced an increase in the sway and hampered neuromuscular efficiency for controlling posture during standing [29,30]. This phenomenon has been explained by either high cortical arousal [5,16] or automatic reflex caused by the total consumption of the attention factors [4,5].

Previous studies suggested that stimuli used to test verbal and nonverbal working memory are received and interpreted by different regions of the brain. Based on neural networks, it has been suggested that the verbal/nonverbal dichotomy reflects ventral/dorsal or left/right domain differences in the brain [20-22]. Prominent activation of the left hemisphere is associated with verbal coding, while right prefrontal activation is associated with nonverbal coding [20]. Therefore, differences in the area of cortical stimulation targeted by different tasks may also be related to the body sway. In our study, in nonverbal task trials, which are presumably related to the right prefrontal activation, directional shifts were less apparent. Perhaps the right prefrontal activation allows for more automatic processes to activate and control the balance without conscious interference. On the other hand, in verbal task trials, which are presumably related to the left hemisphere activation, fewer automatic processes may take place.

We found that the application of vibration stimulation induced sway, especially in the early phases during which more automatic factors are activated. This may reflect an increase in body awareness due to the application of supra-threshold degrees of vibration stimulation. McIlroy et al. [17] hypothesized that the processing requirements for postural control vary during the time course of stability recovery, and therefore, the related attentional demands also vary. The characteristics of the time courses predicted by stability recovery theory are very intriguing, and it is not clear whether the results of McIlroy's study can be generalized to the control of human posture [5]. Furthermore, no studies have evaluated each phase in sequence after several seconds of postural control.

We observed postural control response during a total period of 15 seconds per trial. We hypothesized that the action of attentional factors becomes more important as time goes on and that body awareness increases after an initial adjustment phase. This is similar to the summation of McIlroy's three phases. We divided each trial into the early and late phases. After 8 seconds, the amount of sway in time sequence was significantly increased. From 0 to 8–10 seconds, the early phase includes the characteristic adjustment time for one leg standing and our results implicate the involvement of more automatic reflexes during that phase, as stance does not seem to be disturbed by the attentional factors. The late phase starts after 10 seconds, during which, the attentional factors become more prominent. When participants were given difficult memory tasks to complete, sway greatly decreased compared to the performance of participants who were not given such tasks (Figs. 2–4). From these results, it seems possible that postural response can be divided into an early phase and a more attention-demanding late phase.

We attempted to induce changes in postural control resource allocation by implementing dual task paradigm comprised of the postural task (one leg standing, vibration stimulation with supra-threshold intensity) and a high demand cognitive working memory task (two-word recall). Cognitive resources play a key role in maintaining postural stability in older adults, which may be due to an age-related decline in sensory and motor function [8,31-33]. In previous studies, older adults are characterized as giving greater priority to the task that they perceive to have greater importance [34]. Given a choice between postural control and cognitive task, older adults prioritized the former [35] due to the high prevalence of instability and risk of falling in the elderly [34]. In one study, young adults did not show a decrease in postural sway for either easy or difficult balance tasks [36]. However, Swan et al. [36] demonstrated a decrease in postural sway in older adults during difficult dual task balance conditions, but no sway reduction for relatively easy balance tasks. Since demanding tasks impose greater cognitive loads for older adults than younger adults, older adults may be better subjects, in which to evaluate the changes in postural control resource allocation.

We observed the sequential influence of automatic and attention factors in dual task paradigms in young participants. Our results suggest that optimal training strategies for patients at high risk of injury from falls, such as older adults, should prioritize automatic factors and the maintenance of external focus over postural control.

The shortcomings of our study include a relatively small sample size and broad vibration stimulation levels that were not sensitive enough to assess the differing effects of varying, sub-threshold vibration stimulation intensities. Future studies that include more subjects and more standardized levels of difficulty may demonstrate clearer results. Future research should focus not only on a better understanding of dual task on postural control in time sequence, but also on their detailed applications in various rehabilitation settings.

In conclusion, both the automatic and attentional factors are required for postural control. We observed that the attentional factors were prioritized for postural control and more dominant in the later phase during a sequential study. By controlling the postural control factors, optimal parameters and training methods for postural control can be designed for use in practical applications.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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