Abstract The present study sought to determine if the postural sway of a subject required to grasp a tray (motor task) holding a cup filled with water and prevent spilling (mental task), would be reduced by consciously redirecting attention to maintain the tray in a horizontal position. We hypothesized the mental task would increase the stabilization of standing postural balance. Postural sway was measured in 17 normal subjects under the following conditions: 1) holding a 100 g weight in each hand (total 200 g; no mental task), 2) holding with both hands a tray on which 200 g was placed (tray-holding task), and 3) holding with both hands a tray on which a cup filled with water weighing 200 g was placed in the center (mental task). Postural sway was significantly reduced during the mental task versus other tasks. Standing posture balance was stabilized when a mental task was added. Thus, we concluded that higher brain functions such as attention and consciousness exerted a significant influence over the control of standing posture.

Introduction

Sensory information from the visual, vestibular and somatosensory systems plays an important role in postural control in humans. Posture is maintained by the continuous and coordinated control of muscle contractions in various parts of the body made possible by the integration of such sensory information in the central nervous system (Shumway-Cook and Woollacott, 2000a; Morioka et al., 2000).

Until recently, it was believed that postural control is achieved through unconscious, automatic mechanisms and does not involve higher brain functions such as attention and consciousness. However, previous experiments utilizing dual task methodology revealed that higher brain functions such as attention and consciousness influence postural control during standing (Kerr et al., 1985; Yardley et al., 1999). In the evolutionary process of mankind, the acquisition of a standing posture on own's feet created a freedom for both hands, triggering development of dexterity of hands and fingers including the use of tools. Subsequently, the use of tools accelerated development of the cerebral cortex of humans. The cerebral cortex of humans controls cerebral functions of a high order including attention and mental functions. Therefore, finding the correlation between control of the standing posture and attention and mental functions is an important study theme from the standpoint of the process of human evolution.

Fearing (1925) published the first article demonstrating that static equilibrium is influenced by attention. Kerr et al. (1985) indicated that postural control of stance in young adults is significantly affected by attention demands. Also Yardly et al. (1999) reported that postural sway was increased by a secondary spoken mental task, thus concluding that changes in attention affect standing postural control. Ordinarily, the mechanism of attention is roughly divided into two processing systems, automatic and controlled (Shiffrin and Schnelder, 1984). Automatic processing is carried out even if attention is not directed to the information processing system, since performance is unconsciously accomplished through a set of ideas for a series of actions. On the other hand, controlled processing cannot take place if attention is not directed to the information processing system. Attention is directed to the detection of errors and modification of ensuing action provided by processing of the feedback information, and the activity is consciously controlled. The main components of attentional resources are search, concentration and flexibility. Dual task methodology is a method for evaluating the flexibility of attention (Guitentag and Madden, 1987). In this method of evaluation, two tasks are assigned simultaneously and the performance is compared with the performance of each task assigned separately. The dual task commonly used in postural control studies involves the addition of a mental task, not a motor task (Shumway-Cook et al., 1997; Andersson et al., 1998; Andersson et al., 2002; Redfear et al., 2001; Shumway-Cook and Woollacott, 2000b). To summarize these preceding studies, the predominant opinion is that postural balance in
standing is destabilized by the addition of a mental task in the elderly. In the meantime, Pozzo et al. (1995) clarified that the movement of the trunk increased in the dynamic equilibrium task, in young adults when the mental task of holding a tray with water was added.

In the current study we investigated the stability of standing balance during the addition of a motor task using the arms that also included a mental task. We hypothesized that during postural control, if a subject is required to grasp a tray (motor task) holding a cup filled with water and prevent spilling (mental task), lateral postural sway would be reduced by consciously redirecting attention to maintain the tray in a horizontal position. This would then result in the stabilization of standing postural balance.

**Materials and Methods**

**Subjects**

Subjects included 17 healthy women 19–32 years of age without orthopedic or neurological diseases, who gave informed consent prior to testing. The mean age of the subjects was 21.1 ± 3.8 years, with a mean height of 157.6 ± 3.2 cm, and a mean body weight of 53.4 ± 2.0 kg.

**Task procedures**

Subjects were required to stand on a force plate, with the shoulder thrust forward and elevated 90 degrees, elbow extended at 0 degrees, and the forearm in mid-position. In this position, subjects 1) grasped a 100 g weight in each hand (total 200 g) (no mental task), 2) held with both hands a tray 15 cm in radius on which the same weight (200 g) was placed (tray-holding task), or 3) held with both hands a tray on which a cup filled with water weighing 200 g was placed in the center (mental task). At the beginning of this measurement, the subject was given the spoken task “Don’t spill a drop.” Postural sway was then measured while the subject performed the task. These tasks were carried out in randomized order for 30 seconds with a 5-minute interval between tasks.

Two foot positions were used during the tasks: legs closed with the medial margins of the feet in contact with each other, and legs in a tandem position with the dominant foot forward and the non-dominant foot immediately behind the forward foot in a heel-to-toe fashion. The foot on the same side as the dominant hand was regarded as the dominant foot. Measurements were carried out during two visual conditions: eyes open and eyes closed. The measurement of the eyes-closed condition was carried out after the eyes-open condition. During all tasks, subjects were asked to “Please stand while swaying as little as possible”.

**Postural Sway Measurement and Data Analysis**

For the measurement of postural sway, a pressure distribution platform (force platform) by Zebris Co. (Tuebingen, Germany) was used. This force platform operates with 1504 capacitive force sensors arranged in a 32*47 cm matrix. Measurement lasted 30 s, with a 50 ms sampling rate. The Foot Print and Balance Test, using the center of foot pressure analysis software by Zebris Co., synchronized to a Dell personal computer linked to the force platform was used to analyze the following sway parameters: sway path length (SPL), standard deviation of the y-axis (SDy), standard deviation of the x-axis (SDx), width of ellipse (WoE), height of ellipse (HoE) and area of ellipse (AoE). The SPL is the total length of track in recorded movement of the center of foot pressure within the measurement time. The SDx is the standard deviation of the total length of track in a lateral direction within the measurement time. The SDy is the standard
deviation of the length of track in an anterior-posterior direction within the measurement time. 95% of the measurement data regarding the location of the center of foot pressure is contained within the inside of the calculated ellipse. WoE indicates the amplitude; HoE the height and AoE the area of the ellipse. AoE indicates the orientation of the direction of the longitudinal axis of the ellipse compared to the longitudinal axis of the platform (indicating clockwise rotation).

One-way analysis of variance, with Fisher’s PLSD test, was used to compare the mean postural sways in measurements with no mental task, the tray-holding task and the mental task. All statistical tests were completed at the \( p < 0.05 \) alpha level.

**Results**

*Comparison of postural sway with eyes open (Table 1)*

In comparison of postural sway with legs closed, the mean value of SPL was significantly reduced during the mental task relative to postural sway with no mental task or during the tray-holding task \( (F(2, 48) = 3.61, p < 0.05) \). Fisher’s PLSD analysis revealed a significant difference between the mental task and no mental task or tray-holding task \( (p < 0.05) \). No significant differences were detected with respect to other parameters.

In comparison of postural sways with the legs in the tandem position, the mean values of SDx \( (F(2, 48) = 5.00, p < 0.05) \), WoE \( (F(2, 48) = 3.90, p < 0.05) \) and AoE \( (F(2, 48) = 3.28, p < 0.05) \) were significantly reduced during the mental task relative to postural sway with no mental task or during the tray-holding task. Fisher’s PLSD analysis revealed significant differences in SPL, SDx, WoE and AoE between no mental task and the mental task \( (p < 0.05) \), with postural sway significantly reduced when the mental task was added.

*Comparison of postural sway with eyes closed (Table 2)*

In comparison of postural sway with the legs closed, Fisher’s PLSD analysis indicated a significant difference between the mental task and no mental task in SPL \( (p < 0.05) \). No significant differences were detected with respect to other parameters, but mental task values decreased.

In comparison of postural sway with the legs in the tandem position, the mean value of AoE was significantly reduced during the mental task relative to postural sway with no mental task or during the tray-holding task \( (F(2, 48) = 3.24, p < 0.05) \). Fisher’s PLSD analysis revealed significant differences in SPL, SDx and AoE between no mental task and the mental task \( (p < 0.05) \), with postural sway significantly reduced when the mental task was added.

**Discussion**

Recently, several studies related to postural control during standing have been conducted using dual task methodology. Dual tasks thus far employed include repeating a memorized
digit sequence (Maylor and Wing, 1996), completing sentences silently (Shumway-Cook et al., 1997), reciting names (Camicioli et al., 1997), holding a conversation (Lundin-Olsson et al., 1997), identifying spatial locations mentally (Andersson et al., 1998) and silently counting backwards (Redfern et al., 2001). The effects of the addition of these mental tasks on the maintenance of posture have been studied. Redfern et al. (2001) gave a high-level sensory information-processing task as a dual task in the elderly, and reported that this destabilized the standing postural balance. Shumway-Cook et al. (2000) added an auditory memory task to the maintenance of standing posture, and found that, while the dual task produced no effect on young adults, the addition of a dual task elicited an increase in the postural sway in the elderly. Melzer et al. (2001) added the Stroop test, a visual stimulation task, and confirmed that it increased postural sway more markedly in the elderly than in young adults. Stelmach et al. (1999) and Teasdale et al. (1993, 2001) assigned an arithmetic task by auditory stimulation to the elderly, and found that this elicited a delay in the speed of postural response. Lajoie et al. (1996) also investigated age-related differences in the attention demands associated with maintenance of a static posture and walking. The results of this study suggest that normal aging requires a greater proportion of resources must be allocated to balance demands during a postural task. As the above reports show, the effect of a dual task on postural sway has been negative in the elderly, with the standing postural balance destabilized.

In the present study, the standing posture maintenance task of “standing with as little sway as possible” was combined with the mental task of “not spilling a drop” while holding a tray on which a cup filled with water was placed. The effect of the mental task on the primary standing posture maintenance task was evaluated. Results indicate that postural sway was significantly decreased during a mental task as compared to no mental task. Most likely the addition of a mental task “try not to spill the water” forced the subject to consciously concentrate attention on maintaining the tray in a horizontal position, thus reducing postural sway. This finding is corroborated by the fact that indicators of lateral sway such as SPL, SDx, WoE and AoE also marked this difference. Therefore, this mental task significantly reduced right and left sway. These findings suggest that cognitive function, specifically conscious attention, has a significant effect on postural control.

Welford (1974) pointed out the existence of a 3-stage hierarchical system in information processing by humans. In the first stage, the sensory system operates to provide input. In the second stage, the input accumulated in the first stage and the response are allowed to correspond to each other, known as the coding stage. The third stage is an execution stage in which the coded response is automatically executed. In the present study, in healthy subjects it was inferred that the coded motor strategy for maintaining standing posture was automatically selected in accordance with the circumstances, and subconscious postural control was activated by attention. Maylor et al. (1996) reported that postural sway was reduced by a task of repeating a memorized digit sequence. However, Yardley et al. (1999) stated that postural sway was increased by execution of the task of calculating aloud. This was considered not attributable to the mental task, but counting numbers aloud seemed to have precipitated an increase in postural sway. As the above examples show, the use of a dual task may produce exactly opposite effects. The secondary task added to the maintenance of standing posture may be considered a mental load added to the motor task of holding an object, so that its effect on performance such as standing postural control was more direct. In advance studies using the dual task methodology, issues that are not directly related to maintaining standing, which is a primary task, are used as a mental task such as silent counting backwards and the Stroop test. On the other hand, a mental task that may potentially affect maintenance of standing is added to this study. For this reason, the impact of a mental load on the primary task (maintenance of standing) can be evaluated directly. However, it is possible that this increased selective attention to the primary task with the result that the brain might have processed it as a single task, instead of as a dual task. Regarding this, an experimental technique to directly measure brain activity will be needed.

The fact that essentially unconscious postural control was converted by the addition of the present task to conscious control suggests that humans have a certain reserve in the ability to control standing posture. If postural control is analyzed from the viewpoint of motor learning, the possibility emerges that standing postural balance could be further improved by seeking such a conscious control. In addition, a significant decrease in postural sway was detected in the measurement with eyes closed, which suggests that the maintenance of the tray in a horizontal position involved not only visually based information, but the maintenance of horizontal position based on sensory information from the somatosensory or vestibular system as well. It is also possible that, because the eyes-closed measurement was given after the eyes-open measurement according to the present protocol, the precedent visual or motion image was recalled. In that case, the activity in the frontal lobe that is not detected during eyes-open testing may have been activated during eyes-closed testing (Ouchi et al., 1999).

In the present study, a significant difference was detected under both eyes-open and eyes-closed conditions. However, individual differences with regard to cognitive functions such as concentration or attention cannot be ruled out. There may also be individual differences in brain activity at the time of mental loading. Accordingly, unless spatial or temporal brain activity is detected during performance, it cannot be concluded definitively that the present task was clearly an effective means of reducing postural sway. Moreover, since the subjects were healthy and in their late teens to early 30’s, it was not possible to compare our results with those in the elderly as done in the preceding studies (Redfern et al., 2001; Shumway-Cook and Woolacott, 2000; Melzer et al., 2001; Stelmach et al., 1999).
Thus, the possibility that a negative result may be obtained in the elderly cannot be ruled out. It is therefore necessary to carry out further experiments in the elderly using the present methodology.

**Conclusion**

It was clarified by the present study that, in healthy subjects, postural sway while standing was reduced by conscious control provided by holding a tray on which a cup filled with water stood as the subjects tried not to spill a drop. This suggests the possibility that standing postural control may be altered by a change in consciousness produced by an attentional demands task. Data indicate that the effect on postural sway may be greater if a mental load synchronized with the motion task produced by constant feedback is given as a dual task, rather than if a mental load provided by mere mental practice in the brain is used as a dual task.

**References**


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