J. Human Ergol., **34**: 35-40, 2005

Communications

CHARACTERISTICS OF POSTURAL SWAY IN OLDER ADULTS STANDING ON A SOFT SURFACE

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Postural responses to challenging situations were studied in older adults as they stood on a foam surface. The experiment was designed to assess the relative contributions made by visual and somatosensory information to the correction of postural sway. Twenty-four subjects, aged 56-83, stood for 20 s on a 1) firm or 2) foam surface with 1) the eyes open or 2) the eyes closed. Centre-of-pressure trajectories under the subjects' feet were measured by using a force platform. A repeated-measure two-way MANCOVA (two surfaces vs. two vision conditions) showed a significant main effect for the surface, but not for the vision. No covariate effect for age was found. Anterior-posterior sway increased in the subjects who were merely standing on the foam surface independent of the vision condition. Medial-lateral sway dramatically increased if the subjects stood on the foam surface with their eyes closed, but not if they stood with their eyes open. These results indicate that older adults rely more on visual information to correct mediolateral postural sway. It appears that the deterioration in visual acuity that occurs with aging may increase the risk of sideway falls, particularly in challenging situations, e.g., when standing on irregular or soft surfaces.
Key words: standing posture, centre-of-pressure, foam surface, the elderly, postural sway

INTRODUCTION

The ability to maintain standing balance is essential for many activities in daily living. Postural control is accomplished by the central nervous system that fuses the afferent information from the visual, vestibular, and somatosensory systems. A progressive deterioration in the functions of these sensory systems occurs with normal aging (Simoneau et al., 1992). In particular, aging results in a deterioration of visual acuity, which increases the risk of falls in older people (Lord et al., 1991; Lord and Dayhew, 2001). Vision is known to be the most dominant modality for postural control. It is therefore assumed that deficits in visual information will necessarily raise the relative contributions of the two remaining sensory systems to maintaining balance.

Both vestibular information and somatosensory information play important roles in the selection of postural movement strategies around the hip and ankle joints in order to maintain balance (Horak et al., 1990). Wu and Chiang (1997) demonstrated that the somatosensory system is the major source of input for correcting postural changes in more challenging stances, e.g., standing on a moving surface. In order to address the problem of the role of somatosensory information in human postural control, various techniques, e.g. cooling (Asai and Fujiwara, 2003; Stal et al., 2003) and ischemia (Horak et al., 1990; Mauritz and Dietz, 1980), have been utilized in past studies in an attempt to alter the function of the somatosensory system. The use of such techniques was limited to a small number of healthy subjects, possibly because of the fact that the subjects suffer pain and feel uncomfortable when undergoing these techniques.

Received for publication December 2, 2005.

More recently, people's postural responses have been examined while standing on foam in a number of studies (Kerr et al., 2001; Lord and Menz, 2000; Vuillerme et al., 2001; Vuillerme and Nougier, 2004). Chiang and Wu (1997) showed that standing on a foam surface would affect the inputs to both the joint receptors and cutaneous mechanoreceptors of the foot. Having subjects stand on foam as an experimental manipulation can provide researchers an opportunity to examine the relationships between the postural corrections performed to maintain an upright stance and somatosensory information. This technique has also been used for preventive purposes such as the assessment of the ability to balance in older adults and the screening for postural instability (Choy et al., 2003). Unfortunately, the available information about the physical properties of the foam used in past studies was not sufficient to allow us to re-examine the previous findings. The thickness of the foam differed from study to study.

We presented a technique for collecting data on the postural sway of subjects standing on a foam block designed primarily for balance exercises. The main goal of the present study is to determine the characteristics of postural responses to challenging situations in older adults.

METHODS

I. Subjects

The experiment was conducted as part of a test battery to measure health-related physical fitness including visual simple reaction time and quadriceps strength (i.e., leg extension). Twenty-four adults (5 men and 19 women) aged 56 to 83 (mean age: 68.7±6.5 years) were pseudo-randomly selected from a group of subjects who took part in the test battery. All subjects reported normal or corrected-to-normal vision, and they could walk independently without walk-aids. Subjects gave consent to participate in the experimental study after receiving information about the study. Subjects who had musculo-skeletal disorders or leg injuries were excluded from the study.

II. Foam material

In the experiment, the subjects were asked to stand on a manufactured foam block (Balance-pad Plus, Alcan Airex AG, Switzerland). The use of this type of product has two major advantages. The AIREX® Balance-pad Plus is available on the market and is widely used to improve balance in physical therapy and rehabilitation and in sports exercises. In addition to this, information about the physical values of the foam can be obtained at http://www.alcanairex.com/. Because the foam and information about it are widely available for other researchers to use, it will be possible to compare different findings from a number of studies.

The Balance-pad Plus is manufactured using the soft foam, AIREX® S34.55 (apparent density, 55 kg/m^3; compression resistance, 18 kPa and 70 kPa for 25% and 50% compression, respectively; tensile strength, 240 kPa). Its dimensions are 50 cm long × 40 cm wide × 5 cm thick.

III. Procedures

Time-varying displacements of centre-of-pressure (COP) sway under each subject's feet during standing were measured by means of an instrumented force platform (ECG-S-1KNSA1, KYOWA Electronic Instruments, Japan). The subjects participated in a set of postural tasks. The first task (i.e., firm surface condition) consisted of standing barefoot in a natural stance on the platform, with the subject's arms hanging relaxed to the sides. In the natural stance, there were no constraints on determining the foot positions other than that the subject's feet were separated mediolaterally by a distance of about 15 cm. The second task (i.e., foam surface condition) was the same as the first one except that the subjects stood on a Balance-pad Plus foam block placed on the force platform. A sheet of rubber was attached to the back of the foam to prevent the foam from sliding out of a determined place on the platform.

The subjects performed these tasks with the eyes open or closed. Under the eyes open condition, the subjects were instructed to focus on a small red square (2.0 × 2.0 cm) placed on a white wall in front of them, approximately at the eye level for each subject, at 1.5 m from the platform.

The medial-lateral (ML) and anterior-posterior (AP) COP coordinates on the platform were collected for a trial duration of 20 s and sampled at 50 Hz. Two trials were conducted for each of the vision conditions and for each of the surface conditions. The order of the four conditions was pseudo-randomly chosen for the subjects.

RESULTS

Conventional COP measurements were calculated from the acquired time series data of COP coordinates: the mean distances of COP displacements in each of the AP and ML directions, and sway velocity. To compute the velocity, the total COP excursion in the two-dimensional plane of the platform was divided by the trial duration. These COP measurements were averaged over the two trials for each condition. Before these three variables were submitted to a MANCOVA, a correlation matrix was calculated to determine the relationships between the variables (Table 1). Ten of the total of 12 combinations (3 combinations for each of the 4 experimental conditions) showed no significant correlation. The mean coefficient values across the conditions can support the assumption that on the whole the three COP measurements were mutually independent.

Table 1. Correlation coefficients between the COP measurements for each of the vision and surface conditions.

	Sway on firm		Sway on foam		
Pairs	Eyes open	Eyes closed	Eyes open	Eyes closed	mean [a]
D-ml vs. D-ap	-0.02	-0.44 *	-0.09	-0.14	-0.18
D-ml vs. Vel	0.31	0.03	0.45 *	0.31	0.28
D-ap vs. Vel	0.03	-0.06	0.08	0.04	0.02

D-ml, the distance in the ML direction; D-ap, the distance in the AP direction; Vel, the sway velocity

* $p<0.05$

[a] Mean values are calculated with z-transformation.

The three variables were then analyzed simultaneously using a repeated-measure two-way MANCOVA (2 surfaces vs. 2 vision conditions) with a covariate of age. The age and visual effects were not significant (Wilk's lambdas=0.78, p=0.16 and 0.95, p=0.79, respectively). The surface effect was statistically significant (Wilk's lambda=0.58, $p<0.05$), allowing for separate ANCOVAs to be carried out to determine which of these independent variables was statistically significant.

There was a significant difference in the AP distance between the firm and foam conditions ($F(1, 22)=5.00$, $p<0.05$, ES=0.57). The mean value of the AP distance during standing on the foam was larger than that during standing on the firm surface. There were no significant interactions, suggesting that the surface effect on the AP sway was independent of the age and vision factors.

For the ML distance, the two-way interaction between the vision and surface conditions was statistically significant ($F(1, 22)=9.29$, $p<0.01$, ES=0.89), even though neither the vision nor surface effects were significant. This interaction was significantly enhanced with age ($F(1, 22)=8.13$, $p<0.01$, ES=0.78). In order to determine which factors increased the ML distance, the two-way design was re-arranged so as to produce four combinations of the vision and surface conditions. A one-way ANOVA showed a significant main effect ($F(3, 69)=4.79$, $p<0.01$, ES=0.89). Figure 1 displays the means and standard deviations of the ML distance for each of the experimental conditions. Follow-up Tukey-HSD tests for multiple comparisons indicated that the ML sway significantly increased as the subjects stood on the foam without vision.

There was a significant interaction between the age and surface factors for the sway velocity ($F(1, 22)=10.94$, $p<0.01$, ES=0.89). Neither the vision nor surface effects were significant. The velocity considerably increased during standing on the foam as compared to standing on the firm surface. This tendency was enhanced with age.

The relationships between the sensorimotor variables (i.e., quadriceps strength and visual simple reaction time) and the COP measurements were determined by computing partial correlation coefficients and controlling for age (Table 2). The quadriceps strength was standardized according to the subject's body weight. No significant correlations were found under any of the experimental conditions. The COP measurements for the subjects standing on the foam surface showed much weaker relationships with the standardized quadriceps strength and reaction time, as compared to those for the subjects standing on the firm surface. These findings suggest that postural sway on the foam may be less predictable using sensory and motor functions, at least functions such as the knee extension muscular strength, the detection of visual stimuli, and the agility of simple motor responses.

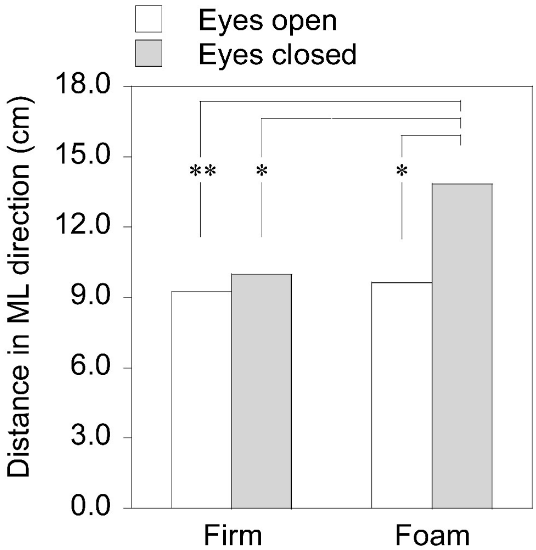

Fig. 1. Mean and standard deviation for the distance in the ML direction. Symbols indicate significant differences determined by Tukey-HSD tests for multiple comparisons among the four combinations of the surface and vision conditions (* $p<0.05$, ** $p<0.01$).

Table 2. Partial correlation coefficients between the sensorimotor variables and the COP measurements controlling for age.

	Sway on firm			Sway on foam		
	D-ml	D-ap	Vel	D-ml	D-ap	Vel
Quadriceps strength	-0.32	0.40	0.03	0.12	-0.14	-0.01
	-0.31	0.26	0.22	0.07	-0.08	0.23
Reaction time	0.20	0.19	-0.23	-0.16	0.30	0.16
	0.29	0.13	-0.03	-0.10	0.22	-0.05

D-ml, the distance in the ML direction; D-ap, the distance in the AP direction; Vel, sway velocity

Upper and lower values in each pair of the variables are for the eyes open and eyes closed conditions, respectively.

DISCUSSION

In the present study, the postural sway was not associated with the strength of representative muscles supporting upright bipedal posture, nor with the functions related to visual stimulus detection and motor response, as the age factor was controlled. This finding is consistent with the previous studies (Kinugasa et al., 1994; Lord and Menz, 2000) that conducted measurements for large numbers of adult subjects. As pointed out by Load and Menz (2000), additional or more direct measures of sensory and motor function, e.g., ankle strength and neuromuscular reflex, may be needed to further explain behaviours of postural sway in elderly people.

Regarding the effects of the foam, the results indicate that the more challenging stance can affect corrective responses to postural sway. Anteroposterior sway increased in the subjects who were merely standing on the foam surface. An absence of vision had no effect on anteroposterior sway, even if the subject was standing on the foam. Elliott et al. (1995) reported similar results (in the case of older adults with normal, healthy eyes) in their experiment. In contrast, mediolateral sway considerably increased in the subjects standing on the foam surface without vision. These findings imply that older adults perform different postural corrections between sway directions in more challenging situations.

One possible explanation that may account for the different postural correction behaviours concerns the difference between sway directions in the reliance on sensory information. When standing on an unstable base of support, subjects are required to control the torque more dynamically, particularly around the ankle joint. Such unstable stances necessarily increase the importance of proprioceptive cues from the muscle, tendon, and joint receptors for maintaining balance. It has been hypothesized that visual input affects the operational characteristics of the somatosensory and vestibular systems, and principally decreases the sensitivity to sensory information from the two remaining systems (Collins and De Luca, 1995; Tanaka et al., 2000). The lack of vision may amplify the sensitivity to the somatosensory information in the feedback systems that function to correct postural sway. In this scenario, the present findings reflect a relatively lower reliance on somatosensory information for postural corrections in the mediolateral direction than in the anteroposterior direction in older adults. If this is the case, it is plausible that significant decline occurs with aging in the ability to balance in the mediolateral direction (Nitz et al., 2003).

Another explanation for the different postural correction behaviours relates to the influence of the musculo-skeletal structure on postural sway. It is likely that in an upright stance, an individual can more easily control posture in the sagittal plane than in the transversal plane using simple movements, e.g., extension-flexion in the knee and ankle joints. Such functional structure may cause the difference in the postural responses to more challenging situations. More biomechanically-oriented studies are needed if we hope to fully understand this issue.

In conclusion, the observed characteristics of postural sway in subjects standing on the foam provide further evidence that older adults rely more on visual information to regulate postural changes in the mediolateral direction. The deterioration in visual acuity with aging may increase the risk of sideway falls in challenging situations, e.g., standing on irregular or soft surfaces.

Acknowledgements

This research was supported by the Department of Lifetime Education, Fuchu City Office, Tokyo and was conducted as part of the regional contribution activities of Tokyo University of Agriculture and Technology. The authors would like to thank Dr. Syu-ichi Ohbuchi and Dr. Satoshi Nishizawa, Department for Prevention of Dependence on Long-term Care, Tokyo Metropolitan Institute of Gerontology, who made available a Balance-pad Plus.

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