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Age-Related Changes of Postural Control: Effect of Cognitive Tasks

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Key Words
Postural control · Cognitive tasks · Force platform · Center of pressure · Surface electromyography

Abstract
Background: Postural control and falls in the elderly constitute a major health problem. The interest in balance deficits is growing, as concern about the rising costs of health care increases. This issue is particularly relevant to the elderly population in which falls occur most frequently. Postural control in the elderly was studied using a cognitive approach. ***Objective:*** The purpose of this study was to study the characteristics of central processing of postural control while performing cognitive tasks. ***Methods:*** A dual-task procedure was developed to estimate the level of automaticity of a quiet upright standing task. The effect of a concurrent attention-demanding task (modified Stroop test) on the efficiency of balance control in the elderly was determined using force platform and electromyography measurements. ***Results:*** It was found that there is an increase in postural sway in old subjects compared with young subjects when performing single tasks and dual-task tests. The results of the study demonstrate that postural adjustments require cognitive processing; young and old subjects showed similar interference effects on postural steadiness (postural sway) caused by the concurrent attention-demanding task. The results are corroborated by the hypothesis that a dual task gives information on the restoration of automaticity of postural control in old age by a central reorganization process. When performing a dual task tested on a narrow base of support, the old subjects decreased their body sway, while the younger did not. According to electromyography measurements, the older subjects increased their muscle activity in the tibialis anterior and soleus muscles, using slow-twitch motor units compared with the younger subjects. ***Conclusions:*** Both alterations (cognitive and base of support) have a substantially greater effect on the elderly than on the young. The older subjects decreased their body sway by activating a cocontraction strategy of postural control around the ankle joint, probably because of the danger to their postural stability.

Introduction

The control of the posture is maintained by a complex central sensorimotor system which integrates information from the vestibular, visual, and somatosensory systems. This coordinates posture mechanisms in such a way than neural command to the posture-stabilizing muscles of leg and trunk can be corrected almost instantaneously for deviation in balance. Because these corrections occur rapidly, there must be central system programs, like computer programs, which organize balance information from

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different systems subconsciously, and these corrections automatically activate the appropriate correction strategy. There are peripheral and central disorders in the elderly that increase the inability to control body sway and may result in falls.

A central reorganization within the central system must take place as a reaction to these disorders. The body compensates for this loss through less affected systems by shifting towards less efficient strategies. The body must adapt and reforms its internal representation and learn to reduce the effects of the peripheral and central disorders. A central reorganization within the sensomotor system must take place as a reaction to the altered peripheral and central controls.

From a cognitive point of view, the restoration of motor control is regarded as a learning process requiring substantial central information processing [1, 2]. Because the processing demands are directly related to the novelty and difficulty of the motor task, the induced attention load indicates the lack of task automaticity. Most of the cognitive theories claim that the available processing resources are assumed to be limited. As a result, resource competition may occur during the performance of more than one attention-demanding task, leading to task interference, a difficulty of motor task, and lack of task automaticity [3, 4]. Balance control in the elderly may well depend on central reorganization that should be accompanied by less interference of concurrent cognitive tasks in balance control.

A dual-task procedure was developed to estimate the level of automaticity of a quiet upright standing task [3]. The modified Stroop test [5, 6] was used because the test demands a considerable amount of focused attention, few instructions, and shows relatively small long-term learning effects. It does not address memory which is often impaired in the elderly, it requires only verbal responses. Simultaneous performance of modified Stroop test and balace task would provide information that is different from that obtained from a simple upright standing. This information could be interpreted in terms of automaticity of the acquired balance behavior as an essential characteristic of the central reorganization process. It was, therefore, predicted that interference effects would be reduced, or completely absent, in the elderly who have a successful reorganization process.

The aim of this study was first to estimate the level of the central reorganization process by investigating the automaticity in upright standing in the elderly by simultaneous performance of a modified Stroop test and a balance task. Secondly, to show whether an important characteristic of the central reorganization process of postural control after the gradual decrease in the somatosensory system in the older population is present. Thirdly, an attempt has been made to integrate rehabilitation practices with aspects of neuroscience.

Subjects and Methods

Our sample consisted of 20 young subjects aged 20–34 (mean ± SEM 26.6 ± 3.2) years and 20 old subjects aged 75–84 (77.8 ± 2.1) years, volunteers who did not have any neurological or psychiatric disorders and did not show signs of serious cognitive dysfunction.

Balance measurements were made with a firmly secured force platform (AMTI) consisting of one aluminum plate placed on three force transducers (hysteresis and nonlinearity <0.1%), recording the vertical ground reaction forces. Signals were processed by six DC amplifiers (nonlinearity <0.1%) and first-order low-pass filters (cut-off frequency 100 Hz), then they were stored in a microprocessor after AD conversion at a sampling rate of 200 Hz.

Calculations were made by means of digital movement of force. The virtual center of the ground reaction forces, in a two-dimensional transverse plane, was determined for each sample with a maximum error of ± 1 mm in both directions. The coordinates of the center of pressure (COP) were passed through a digital low-pass 5-Hz filter, and the smoothed fluctuations of the COP were further processed by a first-order differentiation of the displacements.

Surface electromyographic signals were recorded from the tibialis anterior and soleus muscles of the dominant leg [1]. The skin above the motor points was shaved and cleaned with 95% isopropyl alcohol [2]. Two silver/silver chloride monopolar surface electrodes (N-00-S, 30 × 22 mm; Medicotest, Ølstykke, Denmark) were positioned center-to-center at a distance of 3 cm, over the muscle bellies, and a third electrode was placed between the two electrodes as a grounding contact. The EMG was recorded continuously on a portable data logger (ME 3000; Mega Electronics, Kuopio, Finland). The raw EMG signals were treated first by the preamplifiers located on the electrode leads and then filtered (at 15–500 Hz, CMMR 110 dB, with a gain of 412) and digitized at 12 bits, with a sampling rate of 1,000 Hz.

The force platform was placed 1.2 m in front of a white projection screen (120 × 200 cm). A remote slide projector was used to project the sample of the modified Stroop test onto the screen.

Protocol

Balance was registered for a period of 20 s. The subjects stood erect on the force platform with the feet positioned 17 cm between the heel centers and with each foot toeing out at a 14-degree angle from the sagittal midline [7]. The subjects were instructed to stand still, and as symmetrically as possible, with their hands folded on their back. No further instructions were given concerning visual attention.

Four different conditions were measured: (1) single task, standing upright with wide base, the eyes open; (2) single task, standing upright with narrow base, the eyes open; (3) dual task, standing upright while performing cognitive task (modified Stroop test), with wide base, the eyes open, and (4) dual task, standing upright while performing cognitive task (modified Stroop test), with narrow base, the eyes open. The subjects were instructed to start the modified Stroop test as soon as possible.

Table 1. COP-based measures of postural stability with wide and narrow base of support (mean ± SEM)

	Young		Old	
	single task	dual task	single task	dual task
Postural stability standing with wide base				
COP path, cm	13.21 ± 0.65	19.3 ± 1.39[b]	23.4 ± 2.49[a]	33.7 ± 4.03[a, b]
Elliptical area, cm^2	0.79 ± 0.1	1.38 ± 0.19[b]	1.32 ± 0.16[a]	4.6 ± 1.43[a, b]
Anteroposterior sway, cm	1,53 ± 0.12	1.8 ± 0.16	1.69 ± 0.11[a]	1.87 ± 0.16[a, b]
Mediolateral sway, cm	0.71 ± 0.07	1.1 ± 0.13[b]	0.97 ± 0.21[a]	2.43 ± 0.54[a, b]
Mean velocity, cm/s	0.66 ± 0.06	0.96 ± 0.1[b]	1.17 ± 0.12[a]	1.68 ± 0.2[a, b]
Postural stability standing with narrow base				
COP path, cm	23.7 ± 1.23	26.35 ± 1.10[b]	45.2 ± 3.29[a]	40.7 ± 2.68[a]
Elliptical area, cm^2	3.1 ± 0.30	3.4 ± 0.47	6.2 ± 0.74[a]	4.8 ± 0.61[a, c]
Anteroposterior sway, cm	1.84 ± 0.11	2.04 ± 0.17	2.47 ± 0.17[a]	2.2 ± 0.13[a]
Mediolateral sway, cm	2.01 ± 0.12	2.01 ± 0.15	3.39 ± 0.24[a]	2.9 ± 0.23[a, c]
Mean velocity, cm/s	1.18 ± 0.09	1.43 ± 0.12[b]	2.26 ± 0.16[a]	2.26 ± 0.19[a]

[a] $p < 0.05$: significant difference old versus young.
[b] $p < 0.05$: significant increase in dual task versus single task in the same age group.
[c] $p < 0.05$: significant decrease in dual task versus single task in the same age group.

The modified Stroop test was projected onto a screen approximately 100 cm width × 50 cm high, at eye level. It consisted of a presentation of 25 colored words (five lines of five words, word size approximately 5 cm wide × 10 cm high), representing color names that were always different from the printed colors. For example, the word yellow was printed in red. The subjects were instructed to name the colors as quickly as possible until the end of the procedure (20 s). At the same time they had to suppress the strong tendency to read the words [8]. Before performing the balance test, the cognitive task was practiced once while in the sitting position.

Data Analysis

The biomechanical parameters of the balance performance were expressed as the length of the COP path, sway in anteroposterior and mediolateral directions, COP velocities, and elliptical area of 95% of the COP points. The electromyographic parameters of balance performance were expressed as the mean median frequency, and the average electromyography recordings were processed and analyzed off-line by means of ME3000P Multisignal software.

Results are presented as mean values ± SEM. Statistical evaluation was carried out using factorial analysis (Anova) and a two-tailed Student's t test.

Results

Postural Stability in Old and Young Subjects

As shown in table 1, in the performance of single and dual tasks, older subjects increased significantly ($p < 0.05$) their COP path, elliptical area, mean velocity, and mediolateral sway compared with the younger group. The older subjects increased their COP path by 77.2% compared with young subjects in single-task performance and by 73% in dual-task performance under wide-base conditions. Under narrow-base conditions older subjects increased their COP path by 75% compared with young subjects while performing a single-task test and by 54% while performing a dual-task test.

Dual Task Compared with Single Task in Old and Young Subjects while Standing on a Wide Base

COP path, elliptical area, mean velocity, and mediolateral sway increased significantly ($p < 0.05$) in dual-task performance in both age groups compared with a single-task performance (table 1). There was a significant increase in anteroposterior sway only in older subjects. For example, the increase in the COP path in the younger subjects was 46.1% and 44.2% in the older subjects.

Dual Task Compared with Single Task in Old and Young Subjects while Standing on a Narrow Base

There were significant increases in COP path (13%) and mean velocity (21%) in the younger subjects while performing a dual-task test compared with a single-task test. By contrast, there was no significant difference in COP path and mean velocity in older subjects and significant decrease ($p < 0.05$) in their elliptical area (29%) and mediolateral sway (16%) in a dual-task test (table 1).

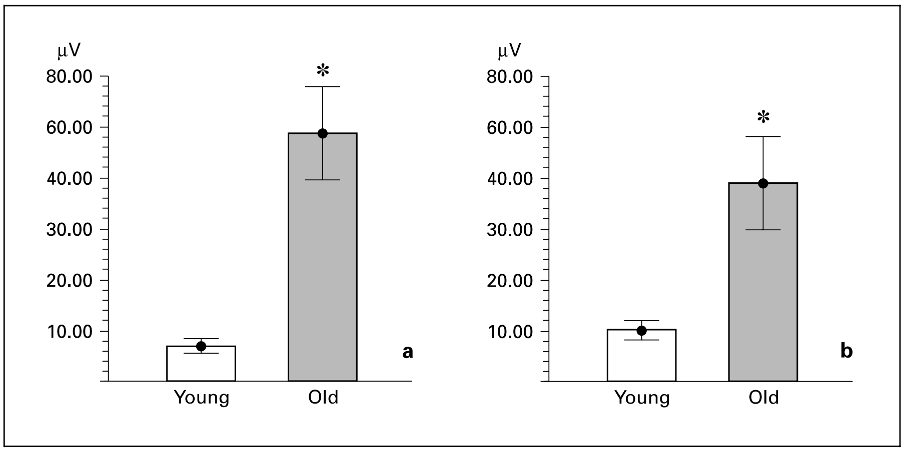

Fig. 1. Average electromyographic activity of tibialis anterior (**a**) and soleus (**b**) muscles in the young and old groups. * $p < 0.005$.

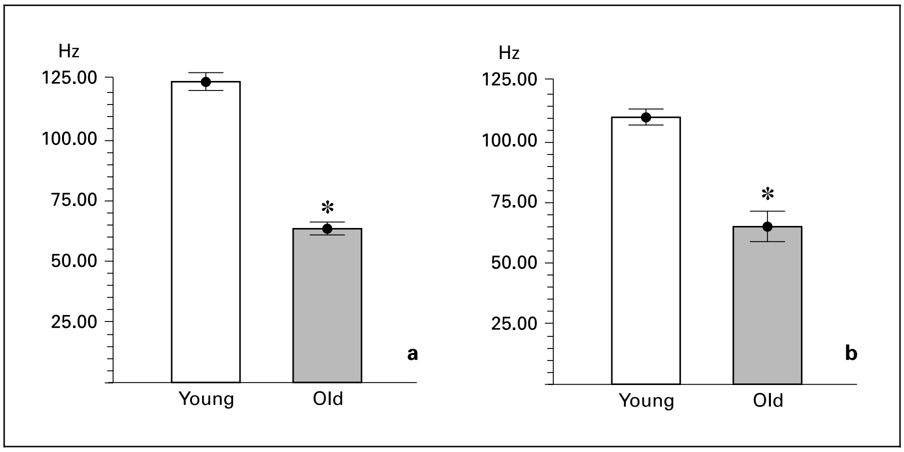

Fig. 2. Mean median frequency of tibialis anterior (**a**) and soleus (**b**) muscles in the young and old groups. * $p < 0.005$.

Electromyographic Data

Standing on a narrow base while performing a dual-task test, the average EMG activities of tibialis anterior and soleus muscles, were significantly higher (586 and 290%, respectively) in older subjects compared with younger ones (fig. 1). The mean median frequency in tibialis anterior and soleus muscles likewise was significantly lower in the older subjects that in the younger ones (98 and 66.9%, respectively) (fig. 2).

Discussion

The results of this study show a significant increase in postural sway under single-task conditions in older subjects compared with younger ones. There is also a significant increase in postural sway in both age groups while performing dual-task tests. The study showed that postural adjustments require cognitive processing and more attention. The cognitive task interfered with the ability to maintain postural stability due to resource competition [9]. Teasdale et al. [10] showed that as the sensory information decreased, the postural task became increasingly difficult for older subjects and required more of their attention capacity. These findings suggest that balance control is not only a motor output as a discrete entity, but also concerned with a motor behavior as an integrative outcome of perceptual, cognitive, motor, and sensory processes. The notion that the restoration of postural control is partly based on cognitive processes that are not directly accessible for a motor assessment procedure using simple tasks has clear clinical implications.

During the simultaneous performance of cognitive and attention-demanding postural tasks, young and old subjects showed a similar level of postural efficiency and similar interference levels. The level of interference is expressed as the absolute difference between the COP paths in the dual-task and single-task conditions. Shumway-Cook et al. [11] found the same decrement in performance of postural stability between young and old healthy adults. A more challenging postural condition such as standing on a compliant surface or the performance of a secondary cognitive task in postural stability varies between the two groups. These authors found that in contrast to the young and healthy, the older adults with a history of falls and postural stability problems were significantly affected by a simple cognitive task. The same trends of results were found in two other studies [12, 13]. These findings suggest that the central reorganization process accompanies a decrease in the somatosensory system in old subjects. Our study suggests that there is a successful central reorganization process at the same level of interference in both age groups.

Postural stability performance was found to be dependent on the base of support. While both age groups were affected by the dual task, the old subjects showed less postural sway while performing a cognitive task with narrow base of support. This study claims that both alterations (cognitive and narrow base of support) had a substantially greater effect upon the older subjects. Anderson et al. [12] found similar results: patients who had failed in a postural test swayed less when performing the mental test. Subjects that did not fail swayed more when performing a mental test.

Adaptation of postural control to a varying base of support diminishes the proprioceptive information from the ankle musculature. It has been suggested that postural stability is dependent on vestibular and cervical receptor input to the general sensory system which regulates the movement of the body [14]. However, the present findings indicate that, unlike young subjects, old subjects naturally put more emphasis on postural control rather than the cognitive task demands, especially when the narrow base of support was imposed during the dual-task condition.

There are clear differences in the mode of postural control between these two age groups associated with changes in the activity of postural msucles. It seems that old subjects generate anticipatory postural adjustment reactions that would try to minimize postural sway. There are several mechanisms of defense against unexpected postural changes. The first is the peripheral elasticity of muscle tendons and other connective tissues. The second is the stretch reflex defense mechanism which contributes to the damping of perturbations even though this occurs at a certain reflex delay. However, these two mechanisms cannot provide an explanation for body equilibrium in dual-task procedures. The mechanism is probably the preprogrammed reactions activated when the brain increases the level of muscle activity. The surface electromyographic findings suggest that old subjects decrease their postural sway by utilizing the co-contraction of the agonist-antagonist muscles, stabilizing the ankle joint. Significant decreases of elliptical area and mediolateral sway and increased EMG activity of ankle musculature in dual-task performance emphasizes this change in the postural control strategy. Thus, the ankle co-contraction strategy seems to be more effective and safer for postural control for the elderly, due to lack of confidence in their ability to respond quickly enough to postural demands in dual-task performance. A greater amount of co-contraction of antagonists stiffens the ankle joint which reduces the amount of movement they have for controlling and maintaining posture. We strongly believe that a fear of falling and lack of confidence about their balance probably partially accounts for this co-contraction pattern.

Some authors [15–17] found that aging slows monosynaptic ankle reflexes in old people. These findings of age decrements in monosynaptic reflexes seem reasonable, because the speed with which neural impulses travel along peripheral nerves is slowed with age. Vandervoort and Hayes [18] found that the postural response was slower in older people than in younger subjects. These authors found that there is a relatively high amplitude of muscle activation in older people performing stability tests. Old people tend to produce more global muscular contraction.

The elderly recruit predominantly slow twitch motor units compared with the young. This might be due to selective atrophy of fast-twitch motor units within the muscles, due to disuse. However, it might be due to a part of a central reorganization process that in response to postural tasks slow-twitch (slow fatigue) motor units are preferred for long-lasting performance.

From the results of this study we recommend that any postural stability tests in the future should include dual-task procedures; in this way, we can discover the changes in the central reorganization process. It is a functional assessment of postural control that is revealed through 'real-life' motor and cognitive functions. The estimation of gross motor behavior like postural control by means of a dual-task procedure can be useful and show essential characteristics of well-developed locomotor skills. This procedure can be used as an important diagnostic tool for assessing the quality of postural stability. It has a general implication for the monitoring of rehabilitation processes and for the assessment of therapy and exercise outcome, not only with regard to standing, but also concerning other forms of motor behavior.

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