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Changes in Sensory Organization Test Scores with Age

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Summary

The goals of this study were to collect normative data on asymptomatic, ambulatory, community-dwelling adults on a standard diagnostic test of vestibular function in balance and to determine if their responses differ significantly from younger adults. Subjects were divided into four age groups, 18–44 years (young), 45–69 years (middle-aged), 70–79 (old), and 80–89 (elderly). Subjects were seen in the neurotologic diagnostic laboratory at a tertiary care facility. Their dynamic balance was tested under a variety of sensory conditions using the EquiTest (NeuroCom), a standard diagnostic test. The data from one subtest, the Sensory Organization Test (SOT) were evaluated. These data showed significant age-associated declines in overall score and changes in movement strategy. These results suggest that those parts of the vestibular system involved with balance have age-related declines through the end of the life span, even in asymptomatic people, and that these changes do not level off but continue into the ninth decade. Therefore, when elderly people are evaluated for balance disorders age-appropriate norms should be used. These results also suggest that declines in motor performance on laboratory tests are not directly related to reduced independence in essential activities of daily living in elderly people.

Introduction

Falling by elderly people is a significant public health problem. Thirty to forty per cent of community-dwelling elderly people fall each year [1, 2] and falling is associated with high rates of morbidity and mortality [3–6]. Of elderly people who fall, approximately two-thirds have balance problems [2] and approximately half of these have vestibular disorders [5]. Thus falling may indicate one or more serious health conditions, among which may be vestibular impairments.

Adequate diagnosis and treatment of problems that cause falling require accurate information on balance in the elderly population but few data have been available. On a simple mechanical apparatus, Overstall *et al.* showed age-associated differences in the angle of sway during quiet stance [5]. More sophisticated tests of dynamic postural control in a population sample aged 7–81 years indicated a significant association of age with the magnitude of postural sway and the number of falls in response to sensory disturbances [7, 8]. Recent studies with behavioural tests and stabilometry have shown age-associated changes in static balance and in vertical spatial orientation skills that are related to vestibular function [9, 10]. Possibly as a consequence of decreased proprioceptive function in older people [10], differences in the kinematics of movement have been found between young adults and older adults under 80 years of age [11] and between young and middle-aged adults [12]. Differences in sway velocity between young and elderly adults have also been reported [13]. There has been a recent review of the relevant literature [14].

Few studies have addressed dynamic balance in subjects over 80 years of age as indicated by their performance on the standard diagnostic tests for vestibular and balance disorders. In the past 20 years several standardized, computerized balance tests have become commercially available. These 'posturography' tests are now considered part of the complete test battery to assess vestibular function, since vestibulo-spinal pathways contribute to postural control [15, 16].

To maintain balance when the feet are stabilized, people use stereotyped synergies or movement patterns known as strategies [17, 18]. Normal subjects typically use combinations of two strategies: (1) the 'ankle strategy', with most active anteroposterior sway about the ankles and little active hip flexion–extension; and (2) the 'hip strategy', with most anteroposterior sway about the hip [17, 18]. Somatosensory or vestibular impairments cause changes in the use of these strategies under some circumstances [18].

Many elderly people complain of the symptoms of vestibular disorders [5, 19, 20], but little normative data are available on this population, especially at the upper end of the age range. We evaluated dynamic postural

Table I. Means and standard deviations of subjects' ages, sex distribution and number of subjects per group

Age group	Age (years)	Sex	No.
Young	30.0 ± 7.7	17 M 15 F	32
Middle-aged	58.1 ± 6.9	10 M 20 F	30
Old	76.7 ± 2.5	11 M 8 F	19
Elderly	83.5 ± 2.9	3 M 10 F	13

control in well elderly people using a standard posturography battery. This battery, the EquiTest (NeuroCom) has two subtests, Motor Coordination and Sensory Organization Test (SOT), each of which generates several measures. Recent evidence suggests that the SOT is more useful for detecting abnormalities than either the motor coordination subtest or the scores on centre of gravity alignment [21]. Therefore, this report is limited to SOT scores.

Methods

Subjects: The sample comprised 94 asymptomatic, ambulatory, community-dwelling adults, divided into four age groups: 18–44 years old (young), 45–69 years old (middle-aged), 70–79 years old (old), and 80 to 89 years old (elderly). The age divisions were suggested by Paige's work on age-related changes in the vestibulo-ocular reflex [22]. Table I gives the sample sizes and the age and sex distributions of the groups. All subjects were independent in activities of daily living [23] and had normal hearing. Old and elderly subjects were screened with pure tone audiometry (Grason–Stadler, Model GSI 17) at 40 dB from 500 to 4000 Hz. No subject had a history of otologic or neurological disorder, or significant orthopaedic disorder. No subjects took medications known to affect vestibular function. Table II lists the various medical problems subjects reported having, including old or mild orthopaedic problems. All subjects, including those with histories of orthopaedic problems, had range of motion in the lower extremities and neck within functional limits. Subjects were recruited from the faculty, staff, and students of Baylor College of Medicine, their friends and families, community groups, and volunteers at this medical centre.

Table II. Subjects' orthopaedic and other medical problems as a percentage of the total sample

Orthopaedic problems	%	Other medical problems	%
Knee replacement	4	Hypertension	13
Foot injury	4	Other cardiac problems	10
Arthritis	4	Hysterectomy	8
Back pain	3	Thyroid problems	7
Fracture of leg	2	Prostate cancer	5
Fracture of ankle	2	Mild idiopathic tremor	2
Hip replacement	1	Head trauma > 25 years ago	4
Old knee injury	1	Diabetes	2
		Breast cancer	2
		Gall bladder removal	2
		Appendicectomy	2
		Colon cancer	1
		Hepatitis	1
		Skin cancer	1

Apparatus: Posturography was administered using the EquiTest (NeuroCom International) computerized dynamic postural test system. This apparatus includes dual-force plates, which can be pitched up and down or translated in the anterior–posterior direction; either motion provokes dorsiflexion/plantar flexion rotations about the ankle. During the test the subject wears a safety harness and stands upright, centred on the force plates with the medial malleoli of the ankles centred over the centres of rotation of the force plates. The subject faces a screen with a coloured visual scene that surrounds the subject on three sides.

The Sensory Organization Test has been described in detail elsewhere [7, 11, 15, 24] and will be described only briefly here. Visual and kinaesthetic stimuli are manipulated in the six conditions of the test, each of which has three 20-second trials. In condition 1, the control condition, all sensory information is available for use. The subject stands still and looks straight ahead. In condition 2, the subject's eyes are closed. In condition 3 the subject watches the visual scene, which moves in phase with the subject's postural sway (sway-referenced vision), providing visual/vestibular conflict and making visual information unreliable. In conditions 4, 5 and 6, the visual manipulations of conditions 1, 2 and 3, respectively, are repeated but the force plates are pitched in phase with the subject's postural sway, making available kinaesthetic information unreliable. Figure 1 summarizes the test conditions.

Results

Equilibrium scores: Data were collected and analysed using software supplied by the manufacturer (NeuroCom International, versions 3 and 4), which continuously records the position of the centre of pressure over the force plates during each trial. A difference score is computed from the theoretical range of normal antero-posterior sway (12.5°) and the maximum range of sway of the subject on each trial; that score is expressed as a percentage. The higher the score, the less the subject swayed. A trial ended by a fall (injury being prevented by the safety harness) is scored at zero.

For each subject the mean data from the three trials per condition were used. Repeated-measures analysis of variance (ANOVA) on the SOT equilibrium score showed significant main effects of age: $F(3,90) = 23.24$, $p < 0.0001$, and test condition: $F(5,90) = 355.91$, $p < 0.0001$, and a significant age by test condition interaction: $F(3,5,15) = 8.1$, $p < 0.0001$. *Post hoc* Bonferroni tests at the 1% level of significance (corresponding to $p < 0.0017$) showed no significant differences among the groups on condition 1. On conditions 2, 4 and 5 young subjects had significantly higher scores than old subjects; on conditions 2 through 6 young subjects had significantly higher scores than elderly subjects; on conditions 4 through 6 middle-aged subjects had significantly higher scores than elderly subjects. Also, on Bonferroni tests at the 5% level of significance (corresponding to $p < 0.0083$), young subjects had significantly higher scores than old subjects on condition 3; middle-aged subjects had significantly higher

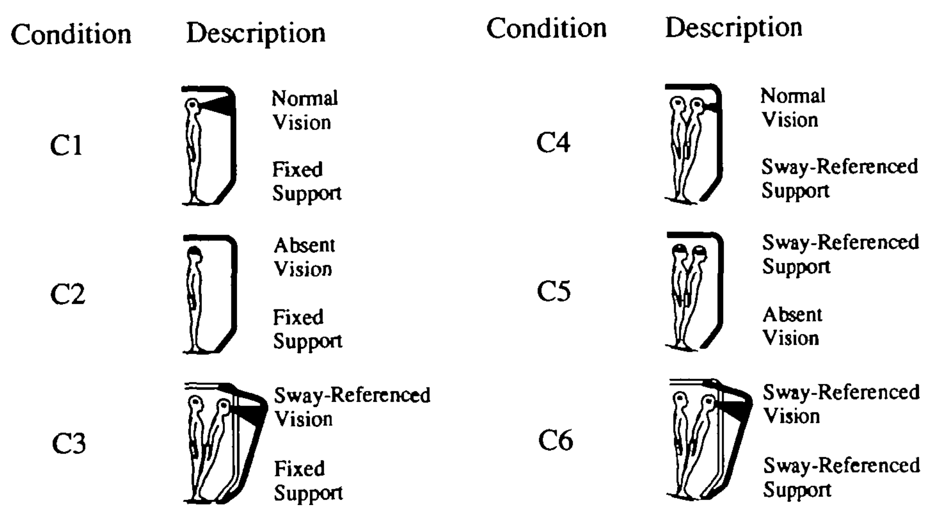

Figure 1. Conditions of the Sensory Organization Test, adapted from Nashner [32], and used with permission.

scores than elderly subjects on condition 3; old subjects had significantly higher scores than elderly subjects on conditions 5 and 6. No other significant differences were found. Figure 2 illustrates these data.

Tests of homogeneity of variance were performed to examine differences in the magnitudes of the variances of the different age groups. In general, except for condition 1, older subjects had more variable responses than younger subjects, as Figure 2 illustrates. On condition 1, young and old subjects were more variable than middle-aged and elderly subjects. On conditions 2 through 6, old and elderly subjects did not differ significantly on the amount of variability of their responses. Table III lists the *post hoc* Bonferroni levels of significance. As the table indicates, the exact levels of significance varied pairwise, but, in general, young and middle-aged subjects differed from old and elderly subjects.

Number of falls: Repeated measures ANOVA on the number of falls per condition showed significant main effects of age: $F(3,90) = 11.0$, $p < 0.0001$, and test condition: $F(5,90) = 12.5$, $p < 0.0001$ and a significant age by test condition interaction: $F(3,5,15) = 7.1$, $p < 0.0001$. *Post hoc* Bonferroni tests at the 1% level of significance showed that young and middle-aged subjects had significantly fewer falls on conditions 5 and 6 than elderly subjects and on condition 6 old subjects had significantly fewer falls than elderly subjects. No other significant differences were found. No subjects fell on conditions 1, 2, and 3; on condition 4 one elderly subject fell once. Table IV shows these data.

Tests of homogeneity of variance showed that on condition 5 and 6, in general, younger subjects had less variability than older subjects. On condition 5, middle-aged subjects differed significantly from old and elderly subjects at less than the 1% level and old subjects differed from elderly subjects at the 2% level of significance. On condition 6, young subjects differed from the other groups at less than the 1% level and middle-aged subjects differed from old and elderly subjects at less than the 1% level of significance. No other significant differences were found. Old and elderly subjects did not differ on the amount of variability in their scores on condition 6.

Strategy scores: The strategy score is also a difference score expressed as a percentage. This score includes the difference between the maximum and minimum sheer forces generated by the subject, divided by a constant representing the theoretical sheer force difference in normals and normalized. The higher the score the greater the use of an ankle strategy rather than a hip strategy.

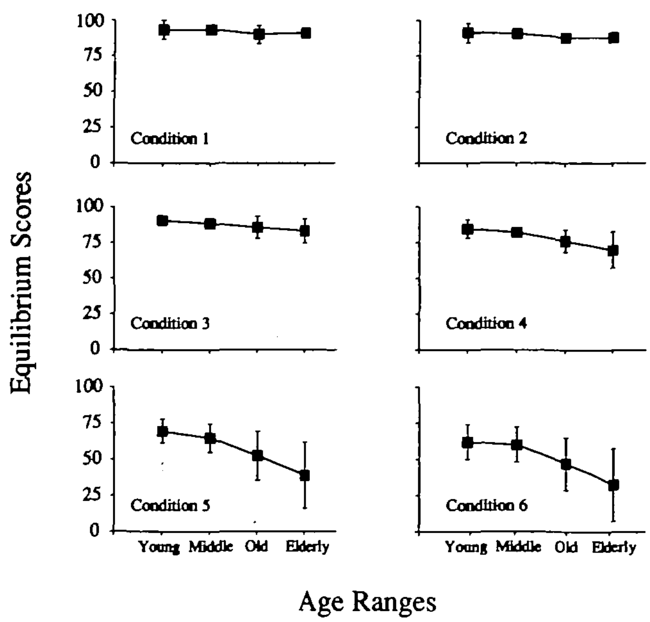

Figure 2. Sensory Organization Test equilibrium scores by condition and age group. Error bars represent standard deviations.

Table III. Variability of standard deviations

Age pairs	Conditions 1	2	3	4	5	6
Y/M	0.01	—	—	—	—	—
Y/O	—	0.05	*0.01	—	*0.01	0.02
Y/E	0.01	*0.01	*0.01	*0.01	*0.01	*0.01
M/O	0.01	0.04	0.01	—	—	0.01
M/E	—	0.02	*0.01	*0.01	*0.01	*0.01
O/E	0.01	—	—	—	—	—

Y, young (18–44); M, middle-aged (45–69); O, old (70–79); E, elderly (80–89 years).
For each combination of age pair and condition for which a significant difference was found, the p value for the *post hoc* test is given: *0.01 indicates that the probability of a type I error was 0.001 or smaller. Where no value is given the groups did not differ significantly.

On these scores, repeated measures ANOVA showed significant main effects of age: $F(3,90) = 17.5$, $p < 0.0001$, and test condition: $F(5,90) = 19.8$, $p < 0.0001$ and a significant age by test condition interaction: $F(3,5,15) = 6.1$, $p < 0.0001$. *Post hoc* Bonferroni tests were performed at the 1% level of significance. On conditions 1 through 6 young subjects had significantly higher scores than old subjects and elderly subjects. On conditions 2, 3, 4 and 6 middle-aged subjects had significantly higher scores than elderly subjects. No other significant differences were found. These data are shown in Figure 3.

Tests of homogeneity of variance were also performed on these data, at the 1% level of significance. In general, the responses of younger subjects were less variable than the responses of older subjects. On conditions 1 and 4, young subjects had significantly less variability than middle-aged subjects. On conditions 2 through 6, young subjects had significantly less variability than old subjects. On conditions 2, 3 and 6 young subjects had significantly less variability than elderly subjects. On conditions 3 and 6 middle-aged subjects had significantly less variability than old subjects. On conditions 2 and 3 middle-aged subjects had significantly less variability than elderly subjects. No other significant differences were found.

Table IV. Means and standard deviations of the number of falls on each SOT condition in each age group

SOT condition	Age group Young	Middle	Old	Elderly
1	0.03 (0.2)	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0.1 (3)
5	0	0.7 (0.3)	0.3 (0.6)	0.7 (1.2)
6	0.3 (0.2)	0.1 (0.3)	0.3 (0.7)	1.1 (1.3)

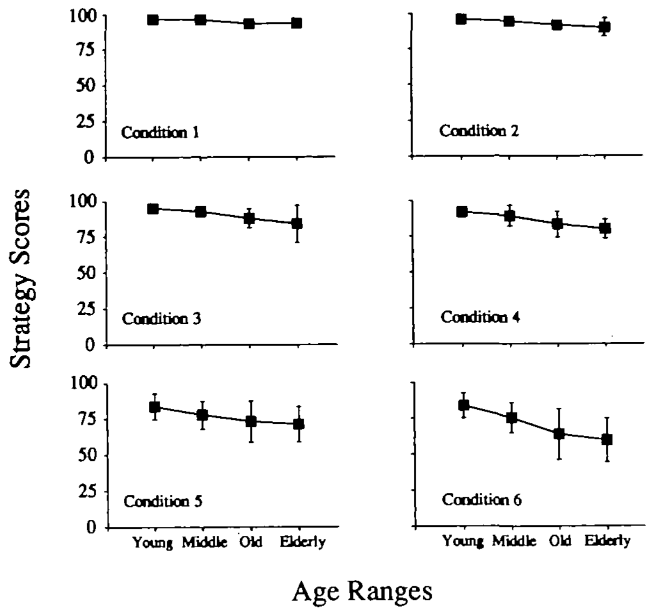

Figure 3. Sensory Organization Test strategy scores by condition and age group. Error bars represent standard deviations.

Discussion

These data indicate age-associated changes in the ability to maintain dynamic balance and may reflect age-related changes in the vestibular system, such as the known anatomical changes (25–29). The range of scores suggests that these changes begin in mid-life and become more pronounced with increasing age, but are not uniform within each age range.

The differences in the scores among age groups on conditions 1 and 2 suggest underlying differences in the ways in which young adults maintain an upright stance. This idea is supported by the low variability of young subjects' scores. Although the strategy scores are inexact descriptors, recent work [24] indicates that these scores reflect subjects' kinematics accurately. Thus, these data suggest that young adults typically combine ankle and hip strategies to maintain their balance, using active ankle and hip flexion. The more variable scores in the older subjects, confirming previous work [11], suggest that older adults use a wider range of strategies. Differences in motor planning would be attributed to age-related changes in musculoskeletal status or differences in motor planning skill.

This finding has some implications for therapy. If older and younger adults use different strategies to maintain their balance successfully, then training paradigms for balance-impaired adults would vary by age group. Standard training paradigms may benefit younger subjects, many of whom use similar movement strategies, but these paradigms may not benefit as many older adults, whose preferred movement patterns may vary more as their individual physical capabilities vary.

All subjects in this study lived independently in the community. Despite obvious differences in their physical capabilities and the differences detected in their vestibular and oculomotor systems described in this paper and elsewhere [30, 31], even the oldest subjects were independently ambulatory and able to perform essential self-care tasks without assistance, although their endurance and speed of task performance may have decreased. Thus, motor performance on such laboratory tests can decline substantially before exceeding the threshold for clinical pathology. This behavioural plasticity allows people to be functionally independent within a wide range of ability and postural skill across the life span.

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