Sensory Organization for Balance: Specific Deficits in Alzheimer’s but not in Parkinson’s Disease

Raymond K. Y. Chong, Fay B. Horak, Jim Frank, and Jeffrey Kaye

Background. The cause of frequent falling in patients with dementia of the Alzheimer type (AD) is not well understood. Distraction from incongruent visual stimuli may be an important factor as suggested by their poor performance in tests of shifting visual attention in other studies. The purpose of this study was to determine whether AD patients have difficulty maintaining upright balance under absent and/or incongruent visual and other sensory conditions compared to nondemented healthy elderly persons and individuals with Parkinson’s disease (PD).

Methods. Seventeen healthy older adults, 15 medicated PD subjects, and 11 AD subjects underwent the Sensory Organization Test protocol. The incidence of loss of balance (“falls”), and the peak-to-peak amplitude of body center of mass sway during stance in the six sensory conditions were used to infer the ability to use visual, somatosensory, and vestibular signals when they provided useful information for balance, and to suppress them when they were incongruent as an orientation reference. Vestibular reflex tests were conducted to ensure normal vestibular function in the subjects.

Results. AD subjects had normal vestibular function but had trouble using it in condition 6, where they had to concurrently suppress both incongruent visual and somatosensory inputs. All 11 AD subjects fell in the first trial of this condition. With repeated trials, only three AD subjects were able to stay balanced. AD subjects were able to keep their balance when only somatosensory input was incongruent. In this condition, all AD subjects were able to maintain balance whereas some falls occurred in the other groups. In all conditions, when AD subjects did not fall, they were able to control as large a sway as the healthy controls, except when standing with eyes closed in condition 2: AD subjects did not increase their sway whereas the other groups did. In the PD group, the total fall incidence was similar to the AD group, but the distribution was generalized across more sensory conditions. PD subjects were also able to improve with repeated trials in condition 6.

Conclusion. Patients with dementia of the Alzheimer type have decreased ability to suppress incongruent visual stimuli when trying to maintain balance. However, they did not seem to be dependent on vision for balance because they did not increase their sway when vision was absent. Parkinsonian patients have a more general balance control problem in the sensory organization test, possibly related to difficulty changing set.

One-third to one half of healthy older adults over 65 years old fall each year. In patients with dementia of the Alzheimer type (AD), the occurrence of falls and hip fractures is three times higher than in the healthy older population (1,2). That is, nearly all AD subjects have at least one falling episode per year.

Few attempts have been made to determine the nature and cause of these frequent falls in AD patients. Gait abnormalities and increased body sway in quiet stance were reported in AD patients as potential predictive factors (3). On the other hand, patients with Parkinson’s disease (PD) who have severe balance problems may have decreased, rather than increased, body sway (4). Thus, sway in quiet stance may not fully characterize balance dyscontrol.

One way to clarify the nature of balance control deficits in clinical populations has been to compare sway in stance when the type of sensory information available to subjects is manipulated. Any sensory signal that is incongruent with body sway can destabilize balance and must be suppressed. The Sensory Organization Test is one such protocol that measures sway in stance while visual and/or somatosensory information are made either unavailable or incongruent for stance orientation (5). In this test, the visual surround and/or the surface are rotated in proportion to body sway. These conditions present incongruent visual and/or ankle somatosensory information regarding spatial orientation for posture. Subjects must attend to the sensory system(s) relevant for orientation, while at the same time, suppress or filter out any incongruent or distracting ones.

The requirement to attend to relevant sensory information while concurrently suppressing incongruent or distracting information in some of the sensory organization test conditions bears resemblance to the Stroop test. In this test, subjects respond as quickly as possible, either by reading a given word, or naming its color. The color of the word may be in conflict with the word itself, for example, the word “red” written in blue. Because the visual system takes in both kinds of cues—the meaning of the word and its color—cognitive processes must resolve the conflicting information properly to make a correct predefined response. Thus the Stroop test is somewhat similar to the Sensory Organization Test, in that relevant visual information (name of word) must be processed and acted on, while unwanted or conflicting ones (color incongruent with meaning of word) must be suppressed or filtered out. AD patients are known to...
have difficulty suppressing unwanted visual cues in the Stroop test compared to healthy individuals (6). The Stroop test compels substantial cortical involvement because patients with primary subcortical damage, such as nondemented PD patients, perform similarly to healthy individuals (7). It is not known whether PD patients would also show similar balance performances under incongruent visual conditions, although they did not have difficulty under incongruent somatosensory and/or eyes-closed conditions (4).

Balance control and sensory organization are critical for moving safely in, and adapting to, the environment. Although AD patients are capable of wandering long distances and getting lost, their cortical deficits may be associated with specific impairments in sensory organization such as suppressing visual distraction which might account for their frequent falls. This hypothesis was tested by comparing the balance performance of AD patients in the Sensory Organization Test with healthy age-matched individuals and PD patients.

METHODS

Subjects

Eleven patients (six males and five females, mean age 73 ± 10 years, mean ± SD; range 53–86 years) diagnosed with probable Alzheimer’s disease (AD) as defined by the NINCDS-ADRDA workgroup guidelines (8) were recruited for the study. Brain autopsy that was subsequently performed on one of the subjects showed the classic neuropathology of AD. The Mini-Mental State Examination score from 10 of the AD subjects ranged between 8 and 27 (mean 19 ± 6) (Table 1). One subject’s Mini-Mental State score was not available. All the AD subjects were screened to be free from the presence of extrapyramidal signs associated with basal ganglia dysfunction, such as balance instability, rigidity, resting tremor, bradykinesia, masked face, and abnormal voice.

Fifteen nondemented patients (seven males and eight females; mean age 60 ± 9 years; range 36–65 years) diagnosed with idiopathic Parkinson’s disease (PD) comprised the second group. The subjects were in stages III and IV of the Hoehn and Yahr disease severity scale (9) (Table 1). They maintained their usual dosage of parkinsonian medication during the experiment.

Seventeen healthy adults (nine males and eight females; mean age 65 ± 6 years; range 49–80 years) formed the healthy control group. The mean age of the AD and PD groups did not differ from the healthy controls. All subjects in the three groups did not have musculoskeletal or neurological impairments that could confound the study.

Tests of Vestibular Function

To ensure that any balance disorder observed during experimental testing was not due to impaired peripheral (inner ear) or central vestibular function, all subjects underwent standard clinical tests of the vestibulo-ocular (VOR) and optokinetic (OKR) reflexes in the Clinical Vestibular Laboratory at Legacy Good Samaritan Hospital.

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Briefly, the VOR rotates the eye in the opposite direction to the head so that clear vision can be maintained during head movements. For tests of the VOR, subjects sat in the dark on a moveable chair that rotated from side to side while the eye movements evoked by the VOR were recorded. Eye movements within the normal range on this test indicate normal inner ear function, and abnormal scores can reflect damage to either the inner ear or the brainstem structures that receive sensory information from the inner ear. Tests were repeated with lights on, to determine whether subjects could use visual cues to enhance (VOR light gain: subjects watched a stationary light pattern while being rotated) or suppress (fixed suppression gain: subjects watched light patterns that moved with them) the VOR. In the OKR test, the room rotated around the stationary subject, and eye movements were recorded (OKR gain). Abnormal scores suggest problems related to the central vestibular system. Four AD subjects (Mini-Mental State scores 8, 12, 18, and 19) did not finish the tests due to difficulty in following instructions.

Sensory Organization Test Protocol

The protocol tests a subject’s ability to maintain in-place balance under combinations of normal, absent, and/or incongruent visual, vestibular, and somatosensory conditions. Subjects stood inside a three-sided visual-surround, looking forward, arms at their sides, and with their ankle joints positioned over the rota-

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M-M, Mini-Mental State Examination score; H & Y, Hoehn & Yahr severity scale.
tional axis of two moveable force plates. In some conditions, the visual surround and/or the floor plates were sway-referenced. That is, they rotated toes up or toes down in proportion to the subject’s anterior-posterior hip position that was monitored with a potentiometer. Under these conditions, sway information from visual and/or surface somatosensory inputs were incongruent with body sway. To maintain balance, subjects must suppress the incongruent signals, while using the congruent ones at the same time.

The instruction to the subjects was to stay upright under each of the six different sensory test conditions, and not to take a step unless necessary to prevent a fall. The order of testing followed standard procedures as follows: condition 1: normal vision and support surface; condition 2: eyes closed, normal surface; condition 3: incongruent visual information (visual surround sway-referenced in direct proportion to body sway), normal surface; condition 4: normal vision, incongruent surface information (support surface sway-referenced to keep ankle joint angle relatively unchanged); condition 5: eyes closed, incongruent surface; and condition 6: incongruent vision and surface information (Table 2).

Conditions 1 and 2 were tested once, while three consecutive trials were given in conditions 3 to 6. Each trial lasted 20 seconds, with a pause of 15 to 30 seconds between trials. Subjects were not informed of the test order, nor when each trial was initiated. A harness suspended from the ceiling was worn by the subjects during testing. The harness allowed free body movements, but would have prevented the subjects from contacting the floor in the event of a complete loss of balance. A fall was defined as when a subject fell into the harness or took a step. All other details of the testing procedure have been described previously (5).

Anteroposterior body sway was measured by two potentiometers (50 Hz) attached to the subject’s body at the hip and shoulder levels. The vertical axis and the line extending through the hip and the rotational axis of the visual surround at the height of the ankle joint formed the ankle angle (θa). Hip angle (θh) was derived by subtracting the ankle angle from the angle formed by the vertical axis and the line passing through the hip and the shoulder. Based on the assumption that subjects had average body mass distribution and proportional body segments (12), the calculated ankle and hip angles from trigonometric conversions were then used to derive the subject’s anteroposterior center of mass sway (5,13):

\[ \theta_a = \tan^{-1} \left( \frac{(0.860\sin \theta_a + 0.242\sin(\theta_v + \theta_b))}{(0.860\cos \theta_a + 0.242\cos(\theta_v + \theta_b))} \right) \]

The peak-to-peak sway amplitude of the center of mass on successful trials and the number of falls were used as measures of stability under the six SOT conditions.

All the procedures described were approved by the Institutional Review Board. For the AD group, consent to participate was obtained from their caregivers. Informed permission was obtained directly from the healthy control and PD subjects.

**Data and Statistical Analyses**

No difference in sway or incidence of falls was observed between the male and female subjects in each group. All data were thus collapsed for group comparison. Successful and falling trials were analyzed separately so any difference in the ability of subjects to control their sway, when they did not fall, could be distinguished among the groups. For peak-to-peak sway, group mean was obtained from each subject’s mean successful trials under each condition. Dunnett’s tests (p < .05) were then used to compare the AD and PD groups to the healthy control group. When necessary, data were transformed to natural logarithm values prior to analyses to obtain comparable between-group variance. The number of falls recorded in conditions 3 to 6 were compared among the groups using chi-square statistics (p < .05). Data are expressed as mean ± standard error.

**RESULTS**

**Vestibular Screening Tests**

The AD subjects as a group did not differ from the healthy controls in tests of vestibular and visual-vestibular function. However, the VOR gain approached a group difference of p = .09 between the healthy control and AD groups because three AD subjects, one with mild dementia (Mini-Mental State score 23) and two with severe dementia (Mini-Mental State score 12), were above one standard deviation of the healthy control group. These AD subjects were able to compensate by decreasing the OKR gain for stabilizing gaze, so that the VOR light gain was about 1, which did not differ among the groups. The ability to suppress VOR gain with visual fixation also approached a group main effect between the healthy control and PD groups (p = .07) because four PD subjects had scores

<table>
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greater than two standard deviations of the healthy control group (Figure 1).

**Sensory Organization Test**

**Incidence of falls.**—The AD group had as many falls as the PD group and many more falls than the control group over all conditions: the AD group had 33% (43/129) total number of falls compared with 26% (46/180) in the PD group and 15% (31/204) in the healthy control group ($\chi^2(1) = 15.0, p < .0001$ between AD and control groups; $\chi^2(1) = 6.4, p < .05$ between PD and healthy control groups). Figure 2 summarizes the incidence of falls in conditions 3 to 6 expressed as a group percentage. Although the total incidence of falls was similar between the AD and PD subjects, the AD subjects, unlike the PD subjects, had the large majority of their falls in condition 6 in which both visual and somatosensory information were made incongruent with body sway and needed to be suppressed. All 11 (100%) AD subjects lost their balance in the first trial of this condition, compared to 59% (10/17) in the healthy control and 53% (8/15) in the PD groups. The total number of falls across the three trials was 79% (26/33) in the AD group, 42% (19/45) in the PD group, and 29% (15/51) in the healthy control group ($\chi^2(1) = 19.6, p < .0001$ between AD and control groups; $\chi^2(1) = 10.4, p < .01$ between PD and control groups; and $\chi^2(1) = 10.4, p < .01$ between the AD and PD groups). There were no falls in the first two conditions of quiet stance with eyes open and closed, respectively.

In condition 6, repeated trials had a positive effect in the healthy control and PD groups but not the AD group. Only three AD subjects improved with repeated trials in this condition, so that the incidence of falls remained high at 64% (7/11) and 73% (8/11) in the second and third trials, respectively. The occurrence of falls in the healthy control group decreased from 59% in trial 1 to 12% (2/17) in trial 2 and 18% (3/17) in trial 3. In the PD group, the incidence of falls decreased from 53% in trial 1 to 40% (6/15) in trial 2, and 33% (5/15) in the third trial. One control and four PD subjects did not improve with repeated trials.

AD subjects also did not improve with repeated trials in condition 5, in which subjects stood with their eyes closed. This condition required them to suppress incongruent somatosensory information while relying on the vestibular system for orientation. Falls in the AD group increased from 46% in trial 1 to 55% in trial 2 and 63% in trial 3. Two AD subjects who maintained balance in the first trial could not do so with repeated trials. Fifty percent of condition 5 trials resulted in falls in the AD group compared to only 29% in the healthy control group ($\chi^2(1) = 5.3, p < .05$). All except two subjects in the healthy group improved with repeated trials. The PD group did not fall more
than the healthy control group (37%), and also improved with repeated trials in condition 5: 9 subjects fell in the first trial and 5 of these were able to stay balanced in the second and third trials.

Although the AD subjects did not improve with repeated trials under conditions 5 and 6, they did not free fall, but struggled for many seconds before losing equilibrium. Figure 3 shows representative subjects’ sway traces from each of the three groups under condition 6, which required exclusive use of vestibular information for orientation. Control and PD subjects were able to adapt to the difficult condition and control their sway in subsequent trials. In contrast, AD subjects often showed large and rapid hip motions (dotted traces) when attempting to regain equilibrium, and showed no signs of improvements with practice.

**Peak-to-peak center of mass sway.**—The mean sway amplitude values for successful trials under each sensory condition are shown in Figure 4. There was no difference in peak-to-peak sway among the groups by condition, except the eyes-closed condition (condition 2) in which the AD subjects showed less sway than the healthy control and PD subjects (Figure 5). The Rhomberg ratio (eyes closed divided by eyes open conditions) showed that the AD subjects did not increase their sway as much as the healthy control subjects when standing with eyes closed ($q = 2.96, p < .01$). The mean and standard error Rhomberg ratio values for the healthy control, PD and AD groups are $2.2 \pm 0.4, 1.9 \pm 0.2$, and $1.2 \pm 0.2$, respectively. The healthy controls, but not the other two groups, showed large sways in the first trials of congruent visual conditions 3 and 6. Sway in the healthy control group decreased with repeated trials. The more severely demented subjects in the AD group showed large sways in the incongruent somatosensory condition 4 but all of them were able to maintain balance in the three trials. Group main effect approached significance ($p = .07$) compared to the healthy control group in this condition. There was no correlation between the severity of the dementia in the AD subjects and sway scores or incidence of falls.

**DISCUSSION**

The results of this study showed that the AD subjects without extrapyramidal signs were unable to maintain balance under...
conditions in which they must rely on vestibular information while suppressing incongruent visual and somatosensory information. Unlike patients with vestibular loss (14), however, AD subjects did not free fall when they had to rely primarily on the vestibular system for balance. This finding, and the normal vestibular-ocular reflex test results, suggest that the AD subjects have relatively normal vestibular function and were using it for controlling their balance. AD subjects fell frequently when vestibular information was essential for orientation, perhaps because they were unable to suppress incongruent visual and somatosensory information. Active neural suppression is necessary to prevent incongruent or distracting sensory information from interfering with task performance (15).

AD subjects were able to either suppress or use somatosensory information from the surface. None of them fell in all 3 trials of condition 4 in which surface information was made incongruent with body sway. The AD subjects also did not fall any more than the healthy control group in the first trial of condition 5 in which surface information was incongruent and vision was removed.

The AD subjects were especially affected by incongruent visual signals when surface information was also incongruent. Their unusually small sway with eyes closed on a firm surface, however, suggests that they were not dependent on vision for orientation; sway in every AD subject under this condition was less than the mean of the healthy control group. Perhaps removal of vision with eye closure heightened the sensory processing load for the AD subjects. Pathological changes in the primary visual cortex occur in AD (16), and eye closure may also have reduced visual disorientation in these subjects.

Other types of studies have shown that AD patients make more errors in the Stroop test (6), indicating a depression in their ability to inhibit or filter out incongruent visual information when trying to attend to the relevant stimulus. Frontolimbic problems in AD subjects result in their difficulty with habituating to unwanted or irrelevant information (17). This partially explains why we did not see significant decreases in the number of falls with repeated trials under conditions with incongruent visual and surface information.

Their difficulty with suppressing incongruent visual signals and lack of improvement with repeated trials is also consistent with hippocampal and parietal lobe dysfunction in AD. Hippocampal damage not only results in memory-related problems, but difficulty in inhibiting previously learned responses under changing environmental context or repeated stimuli (18). Parietal lobe dysfunction results in a deficit in visual attention or visual space orientation (19), particularly in the inability to disengage attention away from an invalid visual cue (20). AD patients have normal visuospatial attention but prolonged reaction times when required to direct attention away from invalid visual cues (21). This deficit also appears to affect their ability to orientate normally to unfamiliar environments (22). In our study, it could be that once the AD subjects "locked on" to the visual surround, they were unable to sufficiently disengage their attention away from it when it was incongruent with body sway. However, many of them could still maintain their balance when somatosensation and vestibular signals were available because there is redundancy in the contribution of each of the three sensory systems for balance control.

We propose that many AD patients suffer a specific sensory organization deficit for balance control that is related to problems in suppressing incongruent visual information, and that their frequent falls are not due to poor motor coordination or fear of falling. Although our method for sway-referencing the surface and visual surround based on the hip position is more challenging than clinical posturography (NeuroCom Int., Clackamas, Oregon), the AD subjects were able to maintain in-place balance well. For example, when surface information was made incongruent in condition 4, some falls occurred in the healthy control and PD groups, but no AD subject fell in all the 3 trials. In conditions 3, 4, 5, and especially 6, when AD subjects did not fall, they were able to control as large a sway as the healthy control group. In fact, in condition 4, many AD subjects swayed more than the healthy controls. Thus, AD subjects, with using vestibular information for orientation while suppressing incongruent visual and somatosensory signals could not be predicted from their peak-to-peak body center of mass sway in successful trials. AD patients appeared to have good control of their center-of-mass equilibrium in many conditions, but it remains to be clarified whether other measures of sway strategy, such as those derived from ground reaction forces, center of pressure, or body kinematics can provide extra information indicative of balance control problems in demented patients (see ref. 23 for review and specific examples).

Although the PD subjects showed obvious clinical balance control, gait, and motor deficits, they did not fall more often than the AD subjects. Instead, they fell in many, rather than specific, sensory conditions, suggesting a general problem with maintaining balance in the SOT. This could be due to difficulty quickly changing set to match changes in balance conditions. The concept of set is discussed in the companion paper (24).

Clinical Implications

The finding that all the Alzheimer subjects in this study fell in the first trial of incongruent visual and somatosensory condition is consistent with statistics showing that Alzheimer patients have at least one falling episode per year. Whether training can alleviate this specific balance abnormality remains to be studied. Many AD subjects continued to fall in the second and third trials of this condition, so suggesting short-term adaptation problems. Alzheimer's disease is progressive, so the prognosis may not be so bright for these patients. Preventive care is probably the best approach to fall avoidance in dementia. Caregivers should recognize circumstances where the information from the surface and vision may be incongruent for orientation, such as when walking on compliant surfaces in a crowded environment. Steps should then be taken to guide the AD patient safely through the situation. Holding onto his or her arm is one example.

In conclusion, patients with dementia of the Alzheimer type have normal vestibular function but have difficulty using it for orientation when they have to concurrently suppress incongruent visual and somatosensory signals. However, they are not as dependent on vision as the healthy control and Parkinson subjects because they did not increase their sway with eyes closed. They were able to adapt to either incongruent visual or surface somatosensory information, but not when information from both sensory systems was incongruent with body orientation. The PD group improved with repeated trials, and their incidence of falls were generalized across more conditions, possibly due to problems related to changing set (24).
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