A Longitudinal Study of Gait and Balance Dysfunction in Normal Older People

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Objective: To identify the causes of deteriorating gait and balance in normal older people.

Methods: We measured visual acuity, vestibulo-ocular responses, pure-tone hearing levels, vibration sense, deep tendon reflexes, and Tinetti gait and balance scores in 59 normal older subjects (mean±SD age on entry, 78.5±3.7 years) followed up at yearly examinations (range, 8-10 years). White matter hyperintensities on magnetic resonance imaging taken in mid follow-up were graded qualitatively and quantitatively.

Results: For each variable except white matter hyperintensities, we calculated a normalized change per year. There was a significant (P<.05) age-related decrease in vestibulo-ocular reflex gain at 0.05 and 0.20 Hz but not at 0.80 Hz, an increase in pure-tone hearing thresholds (at 1, 2, 4, and 8 kHz), a decrease in vibration sense and deep tendon reflexes in the feet, and a decrease in total Tinetti score. However, only changes in vibration sense in the feet and hearing at 1 kHz were significantly correlated (Spearman rank correlation) with the change in Tinetti score. White matter hyperintensities on magnetic resonance imaging had a higher correlation with the yearly change in Tinetti scores.

Conclusions: This longitudinal study showed age-related decreases in vestibular, visual, auditory, and somatosensation in normal older people, but these changes were only weakly correlated with changes in gait and balance. White matter hyperintensities on magnetic resonance imaging were more highly correlated with changes in gait and balance, but all variables together accounted for only about 29% of the measured change in gait and balance.

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FALLS DUE to loss of balance are a major source of morbidity and mortality in older people.1,2 Hip fractures and other fall-related injuries can necessitate admission to hospitals and nursing homes and result in large health care expenditures.3,4 Age-related changes have been identified in all of the sensory systems and within the brain, but whether these age-related changes contribute to problems with balance in older people is poorly understood.5

A cohort of normal older subjects are being followed up as part of a prospective study of dizziness and disequilibrium in older people.6 We selected a subset of 59 subjects who remained normal for a minimum of 8 yearly follow-up examinations (maximum, 10) and calculated a yearly rate of change for several neurological measurements that might predict the changes in gait and balance. We also measured the volume of white matter hyperintensities (WMH) on magnetic resonance imaging (MRI) taken in mid follow-up. Our goal was to determine which of these variables predicted the changes in Tinetti scores during follow-up.

METHODS

As part of a prospective study on dizziness and disequilibrium in older people sponsored by the National Institute on Aging, Bethesda, Md, we are following up patients older than 75 years who complain of dizziness and disequilibrium and an age-matched control group with no complaints of dizziness or disequilibrium. The study was approved by the appropriate institutional review board, and all subjects signed an informed consent form. From 140 original control subjects (70 men and 70 women), we identified 59 subjects (34 men and 25 women) who were able to return for a minimum of 8 yearly follow-up examinations (maximum, 10) and maintained normal function for their age. On entry, the mean±SD age of the 25 women was 78.4±4.1 years and of the 34 men was 78.6±3.3 years, for a mean±SD age on entry for the cohort of 78.5±3.7 years. Among 140 subjects, 28 died during the follow-up pe-
Table 1. Age-Related Changes in Sensory Function in 59 Normal Older Subjects*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Score on Entry</th>
<th>Change per Year</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vestibulo-ocular reflex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gain at 0.05 Hz</td>
<td>0.60 (0.10)</td>
<td>0.008 (0.010)</td>
<td>0.006 to 0.011</td>
</tr>
<tr>
<td>0.20 Hz</td>
<td>0.62 (0.10)</td>
<td>0.007 (0.009)</td>
<td>0.005 to 0.010</td>
</tr>
<tr>
<td>0.80 Hz</td>
<td>0.64 (0.11)</td>
<td>0.0002 (0.0009)</td>
<td>-0.002 to 0.002</td>
</tr>
<tr>
<td>Hearing, dB, at 1 kHz</td>
<td>24.4 (14.1)</td>
<td>-1.64 (1.11)</td>
<td>-1.92 to -1.36</td>
</tr>
<tr>
<td>2 kHz</td>
<td>33.4 (16.6)</td>
<td>-1.86 (0.99)</td>
<td>-2.12 to -1.58</td>
</tr>
<tr>
<td>4 kHz</td>
<td>50.4 (20.9)</td>
<td>-1.13 (1.11)</td>
<td>-1.41 to -0.85</td>
</tr>
<tr>
<td>8 kHz</td>
<td>69.9 (17.2)</td>
<td>-1.09 (1.09)</td>
<td>-1.37 to -0.78</td>
</tr>
<tr>
<td>Visual acuity, logMAR units</td>
<td>0.24 (0.12)</td>
<td>-0.01 (0.02)</td>
<td>-0.016 to -0.007</td>
</tr>
<tr>
<td>Deep tendon reflexes, ankle</td>
<td>1.15 (0.68)</td>
<td>0.09 (0.10)</td>
<td>0.06 to 0.11</td>
</tr>
<tr>
<td>Vibration, ankle</td>
<td>0.56 (0.57)</td>
<td>-0.15 (0.11)</td>
<td>-0.17 to -0.12</td>
</tr>
</tbody>
</table>

*Data are given as mean (SD).

Table 2. Age-Related Changes in Outcome Measures in 59 Normal Older People*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Score on Entry</th>
<th>Change per Year</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinetti score</td>
<td>27.5 (0.65)</td>
<td>0.50 (0.40)</td>
<td>0.40 to 0.60</td>
</tr>
<tr>
<td>Gait impairment</td>
<td>0.05 (0.15)</td>
<td>-0.12 (0.10)</td>
<td>-0.14 to -0.09</td>
</tr>
<tr>
<td>No. of falls</td>
<td>0.41 (0.70)</td>
<td>-0.08 (0.25)</td>
<td>-0.15 to -0.02</td>
</tr>
<tr>
<td>Mini-Mental State Exam</td>
<td>29.3 (0.91)</td>
<td>0.17 (0.30)</td>
<td>0.10 to 0.25</td>
</tr>
<tr>
<td>Examination</td>
<td>30.1 (5.05)</td>
<td>0.36 (0.62)</td>
<td>0.20 to 0.52</td>
</tr>
</tbody>
</table>

*Data are given as mean (SD).

...tional testing (0.05-0.80 Hz; peak velocity, 30°-240°/s with eyes open in darkness and constant mental alerting. For this study, we selected 3 representative frequencies (0.05, 0.20, and 0.80 Hz) at the highest velocity that could be tested for all frequencies (120°/s). Horizontal eye movements were recorded with electro-oculography. Details of the recording and analysis system have been reported. Gain was defined as peak slow-phase eye velocity divided by peak stimulus velocity (120°/s). From multiple cycles (minimum, 4), we selected the best gain achieved for a single cycle.

Brain MRIs were obtained with a 1.5-Tesla scanner (General Electric, Milwaukee, Wis) approximately midway in the follow-up. Imaging was performed in the axial and sagittal planes, with a slice thickness of 5 mm in all subjects. The MRIs were initially screened by a neuroradiologist to rule out other possible causes of balance and gait dysfunction. None were found. The MRIs were then analyzed independently by a neurologist (S.H.Y.) who was blinded to all clinical information. We used the method described by Victoroff et al. We also measured the volume of WMH using the Cavalieri principle. This method was recently described in detail.

For all variables, a normalized change per year value was calculated by averaging the values for the last 2 years, subtracting it from the mean value of the first 2 years, and dividing by the number of years in between.

RESULTS

CHANGES IN SENSORY FUNCTION

All of the measures showed significant (P<.05) age-related decrease except for vestibulo-ocular reflex (VOR) gain at 0.80 Hz (Table 1). We compared the change in variables per year in men and women using the nonparametric Wilcoxon 2-sample test. Only yearly changes in hearing at 4 kHz (women, −1.5 dB; men, −0.8 dB; P=.03) and DTRs (women, 0.05 U; men, 0.11 U; P=.01) were significantly different.

CHANGES IN GAIT AND BALANCE AND OTHER OUTCOME VARIABLES

Measures of gait and balance (Tinetti score and neurological examination findings) showed highly significant age-related changes per year (Table 2). For example, during 10 years among normal subjects in this age range, the mean Tinetti score dropped 5 U, while the mean grade for gait impairment on neurological examination increased more than 1 U (eg, mild to moderate impairment). The number of falls also significantly increased with age.
However, a subset of subjects reported most of the falls, while most subjects had no falls (as shown by the large SD). By comparison, the rates of change in the MMSE and the Purdue Pegboard scores were small.

**CORRELATIONS BETWEEN VARIABLES**

All correlations (Spearman rank order) were between rate of change per year except for WMH. Of the various measures of sensory function, Tinetti scores were significantly correlated only with hearing at 1 kHz and with vibration sense at the ankle (Table 3). Not surprisingly, Tinetti scores were highly correlated with gait impairment scores on neurological examination (r = −0.79, P < .001). By contrast, Tinetti scores were not correlated with MMSE scores or with Purdue Pegboard scores. Also, none of the measures of sensory function were significantly correlated with MMSE scores or Purdue Pegboard scores.

White matter hyperintensities on MRI (qualitative grade and volume measurements) were significantly correlated with Tinetti scores (Figure) and with gait impairment rated on neurological examination (Table 4). By contrast, measures of WMH were not significantly correlated with MMSE scores or Purdue Pegboard scores. There was a good correlation between the qualitative grade of WMH and the volume measurements (r = 0.84, P < .001).

**REGRESSION ANALYSIS**

We performed a stepwise regression analysis in an attempt to identify which variables predicted the change in Tinetti score per year. For this analysis, we used the white matter hyperintensity volume and the measures of sensory function (change per year). The final regression model retained only white matter hyperintensity volume, change in hearing level per year at 1 kHz, and change in visual acuity as important predictors of change in Tinetti score per year. The equation to predict the Tinetti score was: change in Tinetti score per year = 0.13 − (0.09 × change in hearing level per year at 1 kHz) + (0.04 × white matter hyperintensity volume) − (3.72 × change in visual acuity per year). The r for this model was 0.29. Twenty-nine percent of the variability of change in Tinetti score per year was explained by this linear combination of variables. Predictions of change in Tinetti score per year were accurate to about ±0.70 (residual SE, 0.35).

**COMMENT**

A significant correlation has previously been shown between WMH on MRI and the development of gait and balance dysfunction in older people followed up serially over time. However, during the short follow-up of this study (maximum, 3 years), only a few subjects developed gait and balance dysfunction, and other possible predictive neu-
rological features were not included in the analysis. With a longer follow-up (8-10 years), we found a highly significant correlation between the volume of WMH on MRI and the development of gait and balance dysfunction measured with the Tinetti gait and balance score. We also documented age-related changes in sensory function, but these changes were only weakly correlated with the changes in Tinetti scores. Stepwise regression analysis of all variables retained only white matter hyperintensity volume, hearing at 1 kHz, and visual acuity as important predictors of change in Tinetti scores per year.

AGE-RELATED CHANGES IN SENSORY FUNCTION

As previously found, vestibular function decreases with age. From a battery of tests of the VOR, we selected 3 stimuli over a wide frequency range with the highest peak velocity achievable with our rotatory chair. We found a significant age-related decrease in VOR gain at 0.05 and 0.20 Hz but not at 0.80 Hz. The lack of an age-related effect at 0.80 Hz might be explained by the fact that somatosensory clues and prediction at this higher frequency allow subjects to compensate for mild age-related vestibular loss. It was previously shown that the VOR responses at 0.80 Hz can be maintained in patients with well-documented bilateral vestibular loss. It also has been shown that brief impulses with high acceleration (>3000°/s) and small amplitude can identify age-related vestibular loss not identified with traditional lower frequency sinusoidal stimuli. However, this type of test requires a special high-resolution eye movement recording system (scleral search coil) and a high acceleration rotational device, features that were not practical for use in a longitudinal study such as this. With these limitations in mind, however, the age-related changes identified in the VOR were not predictive of changes in gait and balance.

The auditory system has probably been studied more for aging effects than any other sensory system. We found a highly significant decrease in hearing at 1, 2, 4, and 8 kHz in the range of 1.0 to 2.0 dB per year. These values are comparable to findings in prior longitudinal studies with shorter follow-up. Interestingly, the greatest yearly rate of change in hearing levels occurred at the lower frequencies (1 and 2 kHz). Because the earliest aging changes occur at the highest frequencies, on entry the average subject had a 70.0-dB deficit at 8 kHz. By contrast, the average subject had only a 24.0-dB loss at 1 kHz. Therefore, there was a much larger range within which to drop in the low frequencies than in the high frequencies. Surprisingly, the changes in hearing at 1 kHz were significantly correlated with changes in Tinetti scores, and hearing at 1 kHz was retained in a linear regression model predicting changes in Tinetti score per year. It seems unlikely that hearing loss itself would lead to deteriorating gait and balance. More likely, deteriorating hearing at 1 kHz is associated with some other age-related effect that leads to impairment in gait and balance (possibly some vestibular function that is more relevant to balance than the VOR).

Many of our normal older subjects have macular degeneration and glaucoma. However, subjects were excluded on entry if they had severe visual loss. Despite these exclusions, we were able to document a significant age-related deterioration in visual acuity, on average 0.01 logMAR units per year. Changes in visual acuity were weakly correlated with changes in Tinetti score, but visual acuity was retained in a linear model as a predictor of change in Tinetti score per year. Prior studies have found that visual perception is altered with age and that poor near visual acuity correlates with postural instability.

Deep tendon reflexes and vibration sense at the ankles significantly decreased with aging in this normal group of older subjects. Patients with clinical peripheral neuropathy were excluded. The average subject on entering the study had DTR scores of 1 or higher and normal vibration sense at the ankle, whereas after 10 years of follow-up, most had no or trace DTRs and mild to moderate loss of vibration sense. This is normal for subjects late in the eighth decade of life. Changes in vibration sense at the ankle were significantly correlated with changes in Tinetti scores, but neither DTRs nor vibration sense was selected as a predictor of change in Tinetti score per year in the linear regression model. Peripheral neuropathy has been associated with postural instability and falls in older people, but loss of vibration sensation alone did not distinguish fallers from nonfallers.

AGE-RELATED CHANGES IN OUTCOME VARIABLES

There was a clear age-related deterioration in gait and balance in most of these normal older subjects followed up for 8 to 10 years, all in their mid to late eighth decade and some in their ninth decade of life. The mean Tinetti score dropped one half unit per year, from a mean score of 27.5 on entry. The Tinetti score was highly correlated with the qualitative assessment of gait and balance on neurological examination (r = 0.79). The rate of falling per year increased significantly, and there was a significant correlation between the change in Tinetti score and the change in the number of falls per year. In their initial description of the semiquantitative gait and balance score, Tinetti et al found that 76% of recurrent fallers had a total score below 19. Interestingly, only 3 of our subjects had a score below 19 by the time of their last examination, and these subjects had the most total falls and the highest rate change in falls per year. Patients in the study by Tinetti et al were first-time admissions to an intermediate care facility in Rochester, NY, while our subjects were community dwelling in West Los Angeles. We also found a significant age-related decrease in Mini-Mental State Examination scores and Purdue Pegboard performance, although the magnitude of change was less impressive than the change in gait and balance. In the 3 subjects whose MMSE scores dropped below 25, it was impossible to distinguish (including on MRI) between early Alzheimer disease and normal aging effects.

WMH AND DETERIORATING GAIT AND BALANCE

The volume of WMH identified on MRI was predictive of deteriorating gait and balance in these normal older subjects. The typical gait features were a slight widening of
the base, slowing and shortening of stride length, and careful turning. None of them showed the severe gait and postural disturbances commonly called “senile gait” or “lower-half parkinsonism.” Age-related changes in the peripheral sensory systems and the brain presumably explain these changes in gait and balance. Whether the WMH identified on MRI are a direct cause of deteriorating gait and balance or simply a marker of other aging effects that are the cause of deteriorating gait and balance cannot be answered by our study. White matter hyperintensities could interfere with long loop reflexes critical for gait and balance mediated by deep white matter sensory and motor tracts. In hydrocephalus, gait dysfunction has been attributed to pressure on long descending motor tracts arising from medial cortical areas important for lower extremity motor control. These nerve fibers pass close to the lateral ventricles before entering the internal capsule. The periventricular distribution of WMH could interrupt these same descending motor tracts and produce a gait disorder similar to that seen in hydrocephalus. In future studies, we will attempt to correlate the location of WMH with specific changes in gait and balance.

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