Significant Vestibular System Impairment Is Common in a Cohort of Elderly Patients Referred for Assessment of Falls Risk

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Abstract

Background: Falls in elderly patients are associated with morbidity, mortality, and cost to the health-care system. The development of falls risk assessment programs have represented a method of responding to what is known about injurious falls. The multidimensional assessments involve the comparison against normative data of a patient's performance on metrics known to influence the likelihood of future falls. The factors assessed usually include falls and medication history, measures of mentation, depression, orthostatic hypotension, simple or choice reaction time, gait stability, postural stability, and the integrity of the patient's vision, somesthetic, and vestibular senses.

Purpose: This investigation was conducted to measure the proportion of patients referred for falls risk assessment who have evidence of vestibular system impairment.

Research Design: Qualitative, retrospective review of data collected from 2003 to 2007.

Study Sample: The cohort was 185 consecutive patients referred for multidimensional assessments of falls risk.

Data Collection and Analysis: Patients underwent quantitative assessments of peripheral and central vestibular system function consisting of electro- or videonystagmography (i.e., ENG/VNG), and sinusoidal harmonic acceleration testing. Results of these tests were compared to normative data.

Results: We found that 73% of the sample who underwent vestibular system assessment had quantitative evidence of either peripheral or central vestibular system impairment.

Conclusions: Our results suggest that quantitative assessments of the vestibulo-ocular reflex should be conducted on patients who are evaluated for falls risk. These examinations should include at least caloric testing and, where available, rotational testing.

Key Words: Aging, elderly, risk of falls, vestibular impairment

Abbreviations: DHI = Dizziness Handicap Inventory; ENG = electronystagmography; LED = light-emitting diode; OH = orthostatic hypotension; SHA = sinusoidal harmonic acceleration; SOT = Sensory Organization Test; SPV = slow phase velocity; VNG = videonystagmography; VOR = vestibulo-ocular reflex

Sumario

Antecedentes: Las caídas en pacientes ancianos se asocian con morbilidad, mortalidad y costos para el sistema de atención en salud. El desarrollo de programas de evaluación del riesgo de caídas ha representado un método de respuesta a lo que conocemos sobre caídas con lesión. Las evaluaciones multidimensionales involucran comparaciones contra datos normativos del desempeño del paciente, en medias que sabemos influyen en la posibilidad de futuras caídas. Los factores evaluados usualmente

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incluyen caídas e historia de medicación, medidas del estado mental, de depresión, hipotensión ortostática, tiempo de reacción simple o por escogencia, estabilidad en la marcha, estabilidad postural, y la integridad de los sentidos de visión, el somestésico y el vestibular del paciente.

Propósito: Esta investigación fue conducida para medir la proporción de pacientes referidos para evaluación por riesgo de caídas quienes tenían evidencia de trastorno del sistema vestibular.

Diseño de la Investigación: Revisión cualitativa y retrospectiva de datos colectados del 2003 al 2007.

Muestra del Estudio: La cohorte estuvo constituida por 185 pacientes consecutivos referimos para evaluación multi-dimensional de riesgo de caídas.

Recolección y Análisis de los Datos: Los pacientes se sometieron a un análisis cuantitativo del sistema vestibular central y periférico, constituido por electro y videonistagmografía (p.e., ENG/VNG), y prueba de aceleración armónica sinusoidal. Los resultados de estas pruebas fueron comparados con datos normativos.

Resultados: Encontramos que 73% de la muestra que se sometió a evaluación del sistema vestibular tenía evidencia cuantitativa de trastorno vestibular central o periférico.

Conclusiones: Nuestros resultados sugieren que la evaluación cuantitativa del reflejo óculo-vestibular debe realizarse en pacientes que son evaluados por riesgo de caídas. Estos exámenes deben incluir al menos pruebas calóricas y prueba de rotación, donde esté disponible.

Palabras Clave: Envejecimiento, anciano, riesgo de caída, trastorno vestibular

Abreviaturas: DHI = Inventario de Impedimento Vestibular; ENG = electronistagmografía; LED = diodo emisor de luz; OH = hipotensión ortostática; SHA = aceleración armónica sinusoidal; SOT = Prueba de Organización Sensorial; SPV = velocidad de fase lenta; VNG = videonistagmografía; VOR = reflejo vestíbulo-ocular

Injurious falls rank as the 6th leading cause of death in the elderly population. Besides mortality there is significant morbidity associated with falls. The greatest falls risk is that of hip fracture. It has been estimated that 350,000 hip fractures will occur annually as a result of falls (Watters and Moran, 2006). At an average cost of $26,912 to repair these fractures, the total cost, including rehabilitation, is estimated to be $8–10 billion annually (Elixhauser and McCarthy, 1996; Kaufman et al, 2003). In this country 20% of elderly people who sustain a hip fracture from a fall will die within a year (Todd et al, 1995). Another 20% will be moved to an inpatient long-term care center for the first time. Likewise, in the United Kingdom it has been reported that of those elderly people who sustain an injury from falling that is sufficient to require medical attention, 17–25% will die within 12 months of the fall (Wild et al, 1981). Of those who sustain hip fractures 49% will die within 6 months (Grimley Evens et al, 1979). Seventy-five percent of the deaths due to falls that occur each year involve elderly individuals, who constitute 12% of the population (Rubenstein et al, 1988). The cost of caring for elderly patients who fall has been estimated to be between $10 and $20 billion per year (Tibbits, 1996; Tinetti et al, 2000). Accordingly, falls in the elderly population are associated with significant morbidity (and reductions in quality of life), mortality, and, expense to the health-care system.

It is these sobering statistics that have moved clinicians in several medical specialties including primary care, physical therapy, and audiology, to develop centers for the assessment of patients who have fallen in the past, or for whom there is concern that a fall will occur in the future. It has been the stated purpose of these clinics to identify those elderly patients at risk for falling and then intervene wherever and however possible to reduce or eliminate the risk(s). A pool of research has emerged that addresses those variables that are predictive of patients who may fall in the future. The risk factors include a history of falls and the use of four or more prescription medications, decreased mentation, depression, prolonged simple and choice reaction time, orthostatic hypotension, altered gait, impaired static and dynamic postural stability, and the integrity of the visual, somesthetic, and vestibular senses.

The extent that vestibular system impairment influences falls has been controversial. For example, Whitney et al (2006) have suggested that patients with vestibular system impairments are not at increased risk of falling compared to control subjects. Other investigators have presented evidence suggesting that although unilateral vestibular impairment may not be associated with increased falls risk (over that observed in the well community) for patients ≥65 years of age, bilateral impairment, at least for patients 65–74 years of age, *is* associated with increased risk (Herdman et al, 2000). Still others have presented compelling evidence that unilateral vestibular impairment is associated with an increased risk of wrist and hip fractures (Kristinsdottir et al, 2000, 2001).

A basis for the variability in findings may be related to the different methods used by clinicians to "assess" vestibular system function. These methods have included structured questionnaires and less quantitative, more qualitative techniques (i.e., "bedside" tests) for assessing vestibular system function including head thrust and head shake tests and dynamic visual acuity testing. In general, bedside tests are more sensitive to the detection of large magnitude vestibular system impairments (McCaslin et al, 2008).

It was our observation that many patients referred for falls risk assessment with complaints of unsteadiness and gait ataxia had evidence of vestibular system impairments when they were evaluated using conventional quantitative test techniques (e.g., electro- and videonystagmography, rotary chair testing, and vestibular evoked myogenic potential [VEMP] tests). In this regard, in a previous report, we have identified in a smaller subset of a falls cohort a pattern of quantitative test results suggestive of central vestibular system impairment (Jacobson et al, 2004). The finding of unilateral or bilateral vestibular system impairment in the majority of a large cohort of patients referred for falls risk assessment would attest to the importance of a quantitative assessment of vestibular function in this population.

Accordingly, the present report is a retrospective investigation of quantitative vestibular system assessments in a large cohort of falls risk patients referred to the Vanderbilt Bill Wilkerson Balance Disorders Center between 2003 and 2007. The aim of this investigation was to determine what proportion of patients referred for a multidimensional assessment of falls risk showed quantitative evidence of vestibular system impairment.

METHODS

Subjects

Subjects were 185 patients with a mean age of 75 years (±11 years). Of the total, 129 or 70% were female. The patients were referred for assessment of falls risk at the Vanderbilt Bill Wilkerson Center Balance Disorders Clinic. Of the sample, 113 (61%) had a prior history of one or more falls. Patients were usually evaluated in the late morning or early afternoon. The assessments required 3–3.5 hours to complete. Time constraints meant that not all patients received all assessments and not all components of each test were completed (e.g., on occasion, sinusoidal harmonic acceleration testing consisted of the lowest, middle, and highest frequencies only if phase, gain, and symmetry measures were normal at each of the three frequencies).

Falls Risk Assessment

The components of our risk of falls assessment have been described in detail elsewhere (e.g., Jacobson, 2002; Jacobson and McCaslin, 2008) but will be described briefly here.

Focused History

A case history was obtained that focused heavily on general medical history, medication use (i.e., numbers and types of medications), and falls history (i.e., numbers of falls and circumstances underlying each fall).

Mentation

A Mini-Mental State Examination (MMSE; Folstein et al, 1975) was conducted for each patient. This is a standardized assessment consisting of 11 items (e.g., short-term memory, confrontation naming). A score of 23 points or less suggests that a patient may be at risk for abnormally decreased mentation.

Depression

The Geriatric Depression Scale (Yesevage et al, 1983) was administered. This is a 30-item scale that is answered using a "yes" or "no" response. A score of ≥9 suggests that the patient may be at risk for clinically significant depression.

Simple Reaction Time

Simple reaction time was assessed with a device developed by Lord et al (2003). The device is a counter that the examiner activates with a button press on a controller box. Triggering the device illuminates a light-emitting diode (LED) on a computer mouse (i.e., for testing upper extremity reaction time) or a footswitch (i.e., for testing lower extremity reaction time). The patient is instructed to depress the computer mouse button or the footswitch to extinguish the LED. The timer displays the elapsed time in milliseconds.

Orthostatic Hypotension (OH)

OH was assessed by obtaining both lying and standing blood pressures. A decrease of greater than 20 mm/Hg in the systolic blood pressure or a diastolic blood pressure of <90 mm/Hg upon standing, whether or not the patient became symptomatic, was suggestive of OS.

Gait

Gait was assessed with the Timed "Up and Go" test (TUG; Podsiadlo and Richardson, 1991). For this assessment a patient is seated in an armchair. The patient is asked to, on command, rise from the chair, walk 3 m, turn, walk back to the chair, and sit. An elapsed time of 13–14 sec has been reported to show

87–89% sensitivity, and 93% specificity sensitivity for fallers (Schumway-Cook et al, 2000, Dite and Temple, 2002).

Static Postural Stability and Sensory Integration

Static postural stability was assessed with the Sensory Organization Test (SOT) protocol from the Equitest system (Neurocom, Clackamas, OR). Whenever possible, patients completed the conditions of the SOT that are designed to provide evidence that patients are making appropriate use of vestibular, visual, and somesthetic information for postural stability. The patient's performance was compared to age-corrected norms obtained from the manufacturer. Normative data for the 70- to 79-year-old age group was used for comparison for patients whose age exceeded 79 years of age.

Visual Acuity

Distance visual acuity under monocular and binocular conditions with and without corrective lenses was assessed with a Snellen chart that was placed 20 ft in front of the patient at eye height. Testing was conducted in normal room light.

Somesthesia (Vibration)

Somesthetic system function, and specifically thresholds of vibration, were measured using an audiometric bone vibrator calibrated in dB HL. The stimulus frequency was 250 Hz. The vibrator was handheld separately at the plantar surface of the great toe, medial malleolus, and tibial protuberance. Patients were asked to report when vibration was perceived. A bracketing method was used to establish a threshold. A threshold of vibration at the great toe and medial malleolus >40 dB HL was abnormal. Though unusual, this technique for establishing a measure of vibration sensitivity has been reported by others (Bergin et al, 1995; Bronstein, 1996; Bronstein, 2003).

Vestibular System Function (i.e., Vestibulo-Ocular Reflex [VOR]) and Self-Report Dizziness Handicap

The Dizziness Handicap Inventory (DHI; Jacobson and Newman, 1990) was administered to patients. The DHI is a 25-item self-assessment measure of dizziness disability/handicap. A score of >26 points represents significant self-report handicap (i.e., a score that equals or exceeds 28 points represents a value above the 50th percentile obtained from a large sample of dizzy and vertiginous patients (Jacobson and McCaslin, unpublished observations). The VOR was assessed using either electro- or videonystagmographic (ENG/VNG) recording techniques, and rotary chair tests. The ENG/VNG test battery was conducted using an ICS CHARTR system. The examination consisted of assessments of gaze stability and pursuit, as well as saccade and optokinetic subsystem function. Additionally, tests for positional nystagmus and benign paroxysmal positional vertigo (BPPV) were conducted. Finally, either a monothermal warm or bithermal caloric test (Jacobson and Newman, 1993a, 1993b) was conducted using water stimuli (ICS CHARTR NCI-480) with temperatures that were either 30° C or 44° C. The equivalency of monothermal to bithermal caloric tests have been addressed in previous research (Jacobson and Means, 1985; Jacobson et al, 1995).

Sinusoidal harmonic acceleration (SHA) testing included frequencies of 0.01 Hz, 0.02 Hz, 0.04 Hz, 0.08 Hz, 0.16 Hz, and 0.32 Hz (Jacobson and Newman, 1991). Rotational testing was conducted with a Micromedical System 2000 rotary chair system. Either VNG or bitemporal ENG techniques were used to record eye movements as each patient was oscillated at 0.01, 0.02, 0.04, 0.08, 0.16, and 0.32 Hz (i.e., maximum velocity, 50°/sec, maximum acceleration, 3, 6, 25, 50, and 101°/sec^2 for frequencies 0.01, 0.02, 0.04, 0.08, 0.16, and 0.32 Hz, respectively). VOR gain, phase, and symmetry were quantified. To calculate the magnitude of VOR suppression, VOR gain at .08 Hz was measured in the vision-present condition with the patient foveating a target that oscillated with the chair.

Data Reduction and Analysis

The following variables were tabulated for this group of patients: age, sex, DHI total score (DHIt), caloric examination "normal" or "abnormal," total caloric response (i.e., occurred where bithermal caloric testing was performed [the total caloric response represented the sum of all four caloric maximum slow phase velocities]), asymmetry (i.e., measured as a percent difference left versus right following monothermal or bithermal testing), nystagmus preponderance (i.e., directional preponderance where bithermal testing was conducted), rotational test "normal" or "abnormal," rotational phase (in degrees), gain (in percent) and asymmetry (in percent) for octave frequencies between 0.01 and 0.32 Hz, and VOR suppression ability (i.e., normal or abnormal). A normal warm monothermal caloric test occurred when the asymmetry was <25% (Jacobson et al 1995). Operational definitions of what constituted "abnormal" function on both caloric and whole body sinusoidal harmonic acceleration testing are given below.

Caloric Testing

When the total bithermal caloric test slow phase eye velocity (SPV) exceeded 30°/sec, a unilateral weakness was defined as a left/right asymmetry ≥22%. When the total bithermal caloric test SPV exceeded 30°/sec, a directional preponderance was defined as an asymmetry in left beating versus right beating caloric responses ≥28%. A bilateral weakness occurred when the total caloric SPV was <30°/sec.

Whole Body Sinusoidal Harmonic Acceleration

Abnormal performance occurred when (1) VOR gain was reduced at ≥2 frequencies and the gain reductions were accompanied by abnormally increased phase leads (i.e., characteristic of peripheral vestibular system impairments)[1]; or (2) VOR gain was reduced at ≥2 frequencies and the gain reductions were accompanied by both abnormally increased phase leads *and* VOR gain asymmetries (i.e., characteristic of peripheral vestibular system impairments); or (3) VOR gain was normal but abnormally increased phase leads occurred at ≥2 frequencies (i.e., characteristic of a central vestibular system impairment; e.g., Jacobson et al, 2004); or (4) the VOR gain in the visual fixation condition at 0.08 Hz was >.20 (i.e., characteristic of central vestibular system impairment).

RESULTS

The DHI was completed by 166 subjects (90%). The mean DHI total score (DHIt) was 44.25 points (±20.69 points) representing overall moderate self-report, dizziness handicap for this cohort.[2]

Although all 185 patients completed caloric testing, only 182 completed SHA testing. This means that complete data were available for 98% of the patients. For those with complete data, only 50 (27%) demonstrated normal performance on both caloric testing and SHA testing. Both tests were abnormal for 55 patients (30%). Caloric testing was abnormal, and SHA testing was normal for a small subgroup of 23 patients (13%). These patients generally had less severe caloric asymmetries (i.e., mean asymmetry = 42.16 ± 27.53) that had been compensated for by the central vestibular system.[3] Lastly, caloric testing was normal, but SHA testing was abnormal for 54 patients (30%). In total, 73% of the sample demonstrated abnormal performance on vestibulometric tests. The three patients who did not complete rotational testing showed abnormal caloric test results. Adding these patients into the group with abnormal test results did not alter the percent of the total sample that had evidence of vestibular system impairment (73%). Table 1 summarizes these findings.

Table 2 shows the group mean DHIt, total caloric response, percent unilateral weakness, and percent directional preponderance on the bithermal caloric test and percent asymmetry on the monothermal warm caloric test for those patients with "normal" and "abnormal" caloric tests. For those patients who received bithermal caloric tests, a monothermal asymmetry was calculated as well. The mean unilateral weakness of 41% for bithermal testing (and 46% for monothermal testing) for the "abnormal results" group attests to the magnitude of caloric asymmetries in this group. Additionally, of the total, 13 patients or 7% of the entire sample demonstrated evidence of a bilateral peripheral vestibular system impairment (i.e., a total bithermal caloric maximum SPV of ≤30°/sec). Not surprisingly a two-sample t-test showed that all caloric test measures were significantly different when results from the "normal" caloric test results group and "abnormal" caloric test results groups were compared.

Table 1. Proportions of the Sample with Normal and Abnormal Results on Caloric and SHA Tests

	Normal Caloric Test	Abnormal Caloric Test
Normal SHA Test	50 (27%)	23 (13%)
Abnormal SHA Test	54 (30%)	55 (30%)

Table 3 shows the gain, phase, and asymmetry data for patients with "normal" and "abnormal" SHA test results. A two-sample t-test showed that VOR gains were lower and phase leads were greater from approximately 0.01 Hz to 0.16 Hz for the "abnormal" group than for the "normal" group.

Of the total number of patients in this investigation only 13 (i.e., 7%) demonstrated impaired suppression of the VOR at 0.08 Hz.

DISCUSSION

The aim of the present investigation was to determine what proportion of a falls risk assessment cohort demonstrated quantitative evidence of vestibular system impairment. The results of this investigation have suggested that, in a sample of patients referred for an assessment of falls risk (not vertigo), almost three out of four had evidence of vestibular system impairment. Only 27% demonstrated normal performance on both caloric and rotational tests. Another 13% demonstrated evidence of having a unilateral vestibular system impairment that was in a compensated state (i.e., they showed an abnormal caloric examination and a normal rotational examination). Of the total, 30% demonstrated evidence of an uncompensated unilateral or bilateral peripheral vestibular system impairment.[4] These patients demonstrated both abnormal caloric tests and abnormal rotational examinations (e.g., caloric asymmetry with multifrequency rotational phase impairments with or without asymmetries). Finally, 30% of the sample showed a normal caloric examination and abnormal

Table 2. Summary Means (sd) of DHI and Caloric Results for the Subsample of Falls Risk Patients Who Were Classified as "Normal" and "Abnormal" on Caloric Testing

Group	DHIt	Right warm caloric max SPV (deg/sec)	Left warm caloric max SPV (deg/sec)	Right cool caloric max SPV (deg/sec)	Left cool caloric max SPV (deg/sec)	Total caloric max SPV (deg/sec)	UW (%)	DP (%)	Mono-thermal asymmetry (%)
"Normal"	44.24 (19.31)	25.83 (17.61)	27.56 (17.98)	19.04 (14.56)	21.07 (17.33)	91.81 (73.04)	10.50 (5.71)	9.58 (6.68)	10.84 (8.18)
"Abnormal"	44.26 (22.43)	15.31 (11.27)*	21.15 (16.74)***	12.29 (10.24)**	15.67 (12.25)***	64.32 (37.19)**	41.19 (27.10)*	21.56 (22.53)*	46.12 (29.90)*

*$p \le 0.001$.
**$p \le .01$.
***$p \le 0.05$.

VOR phase with and without accompanying reductions in VOR gain. In this subsample of 54 patients, 22 (41% of the subsample) demonstrated abnormally reduced VOR gain with abnormally large phase leads, evidence of a peripheral vestibular system impairment. Alternately, 32 patients (59% of the subsample) demonstrated normal VOR gain and abnormally large phase leads (35% of the subsample or 10% of the total sample) with or without impaired VOR suppression (24% of the subsample, 7% of the total sample). Both of these findings are suggestive of central vestibular system impairment. Thus, in total, 17% of the entire falls risk cohort demonstrated evidence of central vestibular system impairment on electroneurodiagnostic testing.

A review of the existing literature has shown that subject samples chosen to evaluate the relationship between vestibular system impairment and falls have varied widely. Herdman et al (2000) chose to study a sample of all patients evaluated in their clinic who had unilateral or bilateral vestibular impairments (i.e., the sample was not solely patients referred for falls risk). Kristinsdottir et al (2000 and 2001), Pothula et al (2004) and Murray et al (2005) studied patients who had sustained injuries requiring medical treatment or hospitalization. Whitney et al (2006) studied patients referred to both balance disorders and falls risk clinics.

Falls risk assessment and intervention clinics have been developed and operated by a broad range of health-care providers including physical therapists and internists. It has been only recently that audiologists have developed both interest and skill in the assessment of falls risk (Jacobson, 2000). It is not surprising then that techniques used by nonaudiologists to investigate the presence of vestibular system impairment have included structured questionnaires and "bedside" (i.e., informal) assessments of vestibular system function. It has been rare that results of vestibular electroneurodiagnostic techniques have been reported in studies of falls risk. Aside from the technical expertise required, instrumentation for vestibular electroneurodiagnostic testing (e.g., electro- or videonystagmography, sinusoidal whole body acceleration testing) is expensive ($40,000–100,000 or more), which has resulted in limited access to these tests by clinicians. Therefore, few clinicians other than audiologists who assess falls risk have measured vestibular system function using electroneurodiagnostic methods. Several investigators have shown that "bedside" vestibular assessment techniques (i.e., including head thrust, headshake, and noncomputerized dynamic visual acuity tests) have performance characteristics far poorer than the caloric test for the detection of significant vestibular system impairments (e.g., Jacobson et al, 1990; Goebel and Garcia, 1992; Perez and Rama-Lopez, 2003; Iwasaki et al, 2004, head-shake test; Jorns-Haderli et al, 2007, head-thrust test).

Table 3. Mean (sd) SHA Test Results for the "Normal" and "Abnormal" Groups

		.01 Hz	.02 Hz	.04 Hz	.08 Hz	.16 Hz	.32 Hz
GAIN (%)	"Normal"	40.24 (13.74)	48.75 (17.22)	56.36 (15.21)	65.54 (15.72)	61.60 (23.74)	67.46 (15.76)
	"Abnormal"	23.78* (12.55)	35.09** (14.24)	42.88* (16.74)	54.21* (17.67)	60.20 (18.54)	60.81* (21.15)
PHASE (deg)	"Normal"	44.69 (8.36)	27.25 (4.00)	15.85 (15.88)	5.77 (8.86)	−3.13 (13.87)	.43 (18.07)
	"Abnormal"	64.80* (12.77)	42.54* (11.50)	26.47* (11.26)	12.62* (10.44)	3.75*** (11.46)	−4.43 (18.36)
SYMMETRY (%)	"Normal"	4.28 (6.03)	5.22 (8.620)	2.84 (7.46)	3.82 (5.57)	.33 (7.12)	3.15 (6.52)
	"Abnormal"	4.32 (12.97)	2.77 (10.28)	2.57 (8.44)	2.69 (8.44)	1.95 (9.87)	2.47 (9.01)

*$p < 0.001$.
**$p \leq .01$.
***$p \leq 0.05$.

Herdman et al (2000) evaluated falls history in a sample of all patients seen at their clinic who had unilateral and bilateral peripheral vestibular system impairments determined from bithermal caloric testing. They reported that those patients who had unilateral vestibular system impairments demonstrated a greater falls risk than patients of equivalent age in the general population. The difference was 51% for patients versus 25% for the general population in the 65–74 year age group. Of the sample >65 years of age with bilateral impairments, 15% experienced falls requiring medical attention. The investigators reported that patients with unilateral impairments were more likely to have multiple falls than those with bilateral impairments (i.e., 38% of patients with unilateral impairments versus 21% of patients with bilateral impairments).

In two studies investigators evaluated patients who had fallen and sustained fractures. In the first investigation, Kristinsdottir et al (2000) reported their observations for 19 patients who had sustained hip fractures. They were compared with 28 age- and sex-matched controls that had not sustained a hip fracture. They found that 68% of the experimental group and 36% of the control group demonstrated nystagmus on the headshake test. Most interestingly, for those who demonstrated headshake nystagmus, the slow phase was directed toward the side of the hip fracture for 75% of this subsample. In a subsequent investigation, Kristensdottir et al (2001) evaluated 66 consecutive patients who had sustained wrist fractures resulting from a fall. Headshake nystagmus was observed in 50 of the patients (i.e., 76% of the sample). Of this subgroup, 60% who showed horizontal nystagmus also had a wrist fracture on the same side as the direction of the slow phase of the headshake nystagmus. It was the investigator's opinion that undiagnosed unilateral peripheral vestibular system impairments could represent an "epidemiologically important contributory factor to falls and wrist fractures in the elderly population" (Kristinsdottir et al, 2001, p. 481).

Murray et al (2005) evaluated 20 patients (mean age 78 years, 75% female) who had sustained a fall that required medical treatment. These patients were age and sex matched to a group of subjects who had not fallen in at least the last 12 months. The authors reported that although there were no significant group differences in reports of dizziness, the group of fallers demonstrated significantly poorer performance on condition 5 of the Clinical Test of Sensory Interaction on Balance (CTSIB), which is sensitive to the presence of vestibular system impairment. The authors concluded that, "More research is required in the area to clarify the relationship between vestibular dysfunction and falling in older people" (Murray et al 2005, p. 504).

Pothula et al (2004) employed a vestibular symptom questionnaire to determine the presence and severity of vestibular symptoms that occurred in the 12 months period prior to an unexplained fall that required treatment in an emergency room. Subjects were 428 patients (mean age: 72 years; 1:2.4 ratio of men to women). The authors reported that 80% of these patients had symptoms of a vestibular system impairment and 41% had frank vertigo. The authors stressed that their finding was particularly important since vestibular impairment is a falls risk factor, and vestibular rehabilitation techniques are effective at reducing motion-provoked vertiginous symptoms (e.g., Hall et al, 2004).

In a recent study, Whitney et al (2006) reported their findings obtained from a group of 100 patients referred to a balance and falls clinic. The sample contained nonfallers (n = 70), one-time fallers (n = 13), and recurrent fallers (n = 17). This was a younger cohort than that of other studies (mean age: 59 years ±17 years). In this sample, quantitative vestibular function tests were performed (i.e., caloric testing, ocular motor and positional tests and rotational tests). The investigators reported that there was no relationship between quantitative evidence of peripheral vestibular system impairment and falls. That is, the control subjects were found to have evidence of peripheral vestibular system impairment as often as patients who had a history of one or more falls.

Subjects in the present investigation were referred by their physicians because they either had fallen in the past or were felt to be at high risk for a fall. The sample was similar in age and sex distribution to other investigations of falls risk. Similar to Pothula et al (2004) and Kristensdottir et al (2000, 2001), we found evidence, quantitative in this case, of peripheral and central vestibular system impairment in more than seven out of ten patients. Most often these were previously undiagnosed unilateral peripheral vestibular system impairments. Rotational test results suggested that a subgroup of these patients had significant strength (i.e., gain) and timing (phase) differences in the VOR compared to normals. In this sense the peripheral vestibular system impairments were uncompensated for by the central vestibular system.

A key question is, "How might vestibular system impairments contribute to postural instability and falls?" It is our feeling that the contributions may be both direct and indirect. Direct effects occur in the acute stages of a vertiginous episode. Direct effects also can occur long after a unilateral vestibular impairment has occurred when it is severe enough to cause changes in the timing of the VOR. When this occurs, a head movement (e.g., in the yaw axis) when gaze is fixed on a point, can result in smearing of the visual image. The apparent movement of the environment could initiate inappropriate postural stabilization reflexes resulting in unsteady gait during head movement. This could contribute to destabilization and a fall. Additionally, bilateral vestibular system impairment produces oscillopsia during head movement. Thus, a patient with bilateral peripheral vestibular system impairment also could experience disorientation and postural instability during movement of the head, or head and body together. In darkness, with the loss of two of the three interdependent senses (e.g., vision and vestibular system) and if the somesthetic system was not intact, the result again could be a fall.

Indirect effects may occur when preexisting "mild" visual and somesthetic system impairments become "unmasked" when an impairment of the vestibular system (i.e., the third interdependent sense for spatial orientation) occurs. In this regard, it is noteworthy that in our study sample 13% demonstrated an impairment affecting a single sensory modality (i.e., usually somesthesia), 15% demonstrated impairments in vision and somesthesia, 3% demonstrated impairments in vision and vestibular system function, 50% demonstrated impairments in vestibular system function and somesthesia, and 19% demonstrated impairments in all three of the interdependent senses for spatial orientation. It is well-known that intact somesthesia (e.g., vibration perception) is required for static postural stability and the addition of intact vestibular function is required for postural stability during ambulation. Drachman and Hart (1972) coined the term *multisensory system impairment* to describe the origin of unsteadiness in the elderly caused by impairments affecting the three interdependent senses. Tinetti et al (2000) also have suggested that dizziness, and falling in the elderly represent geriatric syndromes.

In summary, this is the first report of vestibular electroneurodiagnostic test results obtained from a large sample of patients referred for a multidimensional assessment of falls risk. The data in the present study show that peripheral and central vestibular system impairment may be an underappreciated contributor to postural instability and falls in the elderly.

NOTES

1. Lower limits for VOR gain were 25, 37, 45, 50, 50, and 50% for .01, .02, .04, .08, .16, and .32 Hz, respectively. Upper limits for VOR phase leads were 60, 35, 23, 13, 13, and 8° for .01, .02, .04, .08, .16, and .32 Hz, respectively.

2. Jacobson and McCaslin (unpublished data, 2003) calculated interquartile ranges for the total DHI score for a clinical sample of 200 consecutive dizzy patients. This assessment suggested that a DHI total score of 0–14 points (i.e., first quartile) could be classified as no activity limitation and participation restriction; a score of 16–26 (second quartile) could be classified as mild activity limitation and participation restriction; a score of 28–44 points (third quartile) could be classified as moderate activity limitation and participation restriction; and a total score of 46 points or greater (fourth quartile) could be classified as a severe activity limitation and participation restriction.

3. A "compensated" unilateral vestibular system impairment was operationally defined as a unilateral weakness on caloric testing accompanied by an abnormal reduction in VOR gain and an abnormal VOR phase lead at .01 Hz or .01 and .02 Hz in the absence of a gain asymmetry.

4. An "uncompensated" unilateral peripheral vestibular system impairment was operationally defined as a unilateral weakness on caloric testing accompanied by spontaneous nystagmus, and abnormally reduced VOR gains at a minimum of .01 and .02 Hz, with accompanying VOR phase leads and gain asymmetries.

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