ORIGINAL INVESTIGATION

Disorders of Balance and Vestibular Function in US Adults

Data From the National Health and Nutrition Examination Survey, 2001-2004

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Background: Balance dysfunction can be debilitating and can lead to catastrophic outcomes such as falls. The inner ear vestibular system is an important contributor to balance control. However, to our knowledge, the prevalence of vestibular dysfunction in the United States and the magnitude of the increased risk of falling associated with vestibular dysfunction have never been estimated. The objective of this study was to determine the prevalence of vestibular dysfunction among US adults, evaluate differences by sociodemographic characteristics, and estimate the association between vestibular dysfunction and risk of falls.

Methods: We included data from the 2001-2004 National Health and Nutrition Examination Surveys, which were cross-sectional surveys of US adults aged 40 years and older (n=5086). The main outcome measure was vestibular function as measured by the modified Romberg Test of Standing Balance on Firm and Compliant Support Surfaces.

Results: From 2001 through 2004, 35.4% of US adults aged 40 years and older (69 million Americans) had vestibular dysfunction. Odds of vestibular dysfunction increased significantly with age, were 40.3% lower in individuals with more than a high school education, and were 70.0% higher among people with diabetes mellitus. Participants with vestibular dysfunction who were clinically symptomatic (ie, reported dizziness) had a 12-fold increase in the odds of falling.

Conclusions: Vestibular dysfunction, as measured by a simple postural metric, is common among US adults. Vestibular dysfunction significantly increases the likelihood of falls, which are among the most morbid and costly health conditions affecting older individuals. These data suggest the importance of diagnosing, treating, and potentially screening for vestibular deficits to reduce the burden of fall-related injuries and deaths in the United States.

Arch Intern Med. 2009;169(10):938-944

THE VESTIBULAR SYSTEM IS INtegral to balance control. The paired vestibular organs, housed within the temporal bone, include 3 orthogonal semicircular canals (superior, posterior, and horizontal) and 2 otolith organs (the utricle and saccule). Together, the semicircular canals and otolith organs provide continuous input to the brain about rotational and translational head motion and the head's orientation relative to gravity.[1] This information from the vestibular organs and their central pathways allows for the maintenance of gaze and postural stability via the vestibulo-ocular reflex and vestibulospinal reflex, respectively. Dysfunction of the peripheral vestibular structures cannot be directly observed but can be inferred from assessment of these reflexes (eg, with caloric reflex test).

Vestibular dysfunction is typically characterized by vertigo (ie, an illusory sense of motion) and imbalance owing to disturbances in gaze and postural stability.[2,3] In some cases, vestibular dysfunction can culminate catastrophically in a fall,[4-6] which is associated with serious injury and restricted mobility and ranks among the leading causes of death among older individuals.[7-11] The costs of increased needs and diminished autonomy associated with falls also exert a tremendous societal toll.[12,13]

These costs appear to be rising; a recent study found that the prevalence and incidence of fall-induced injuries increased significantly in the past 25 years, even after adjustment for age.[14] When this increasing incidence is considered in relation to an aging population, the prospect of a significant public health problem is clear.

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Despite this concern and the known contribution of vestibular dysfunction to imbalance and falling, very little is known about the epidemiological characteristics of vestibular dysfunction in the United States. There are no estimates of the national prevalence of vestibular dysfunction, and it is unknown whether susceptibilities differ across demographic groups. Even the strength of the association between vestibular dysfunction and falls is unclear. The data are poor in part because diagnosing vestibular dysfunction can be difficult. The symptoms of dizziness and imbalance may be the nonspecific sequelae of numerous impairments, including deficits in vision, proprioception, and musculoskeletal, autonomic, and vestibular function. In addition, testing for isolated deficits of the vestibular endorgans often involves complex tools (eg, electronystamography, caloric reflex test, or assessment of postural function) that complicate widespread application.

The National Health and Nutrition Examination Survey (NHANES) is a large-scale, highly powered survey that included balance testing for more than 5000 individuals between 2001 and 2004. From these data, we estimate the prevalence of vestibular dysfunction among US adults aged 40 years and older. We evaluate the influence of sociodemographic characteristics and common cardiovascular risk factors on the prevalence of vestibular dysfunction. We also consider the association between vestibular dysfunction and clinically significant outcomes, specifically falls. Such epidemiological information can offer critical insight to help control and possibly prevent a growing burden of fall-induced morbidity and mortality in the US population.

METHODS

STUDY POPULATION

The NHANES is an ongoing cross-sectional survey of the civilian, noninstitutionalized population of the United States. Every 2 years, households were approached at random, and persons were invited to participate in the NHANES survey if they met a specific demographic profile (based on sex, race/ethnicity, age, and place of residence) and contributed to the national representativeness of the sample. In each of the last several cycles, 12 000 to 13 000 individuals were selected; the participation rate has ranged from 79% to 84%. Further details of the NHANES sampling process are available.[15]

The 2001-2002 and 2003-2004 NHANES performed balance testing on a nationally representative sample of adults aged 40 years and older. We combined these two 2-year cycles of data to analyze 4 years of data, per National Center for Health Statistics recommendations.[15] A total of 21 161 people of all ages took part in the NHANES from 2001 through 2004; 6785 participants (32.1%) were aged 40 years and older. Participants were excluded from balance testing if they were unable to stand on their own, were having dizziness sufficient to cause unsteadiness, weighed more than 275 pounds, had a waist circumference that could not accommodate proper fitting of the standard-sized safety gait belt, needed a leg brace to stand unassisted, or had a foot or leg amputation. In addition, participants who were totally blind or sufficiently visually impaired to require assistance in finding the examination room were excluded from participation. A total of 515 participants (7.6%) were excluded from balance testing for these reasons, yielding an eligible sample size of 6270 participants. Of these eligible adults, 1184 participants (18.9%) were excluded because they did not participate in the NHANES physical examination for various reasons including "safety exclusion" and "participant refusal," resulting in a final sample size of 5086 (81.1% of eligible participants). There were no significant differences between included and excluded participants with respect to sex, age, and race/ethnicity. Sample weights for the combined 4-year sample were used, per National Center for Health Statistics guidelines.[15] These sample weights accounted for individual nonparticipation and preserved the national representativeness of the sample.

BALANCE QUESTIONNAIRE AND TESTING

Before balance testing, participants were administered a balance questionnaire, which determined history of dizziness ("During the past 12 months, have you had dizziness or difficulty with balance?") and falls ("During the past 12 months, have you had difficulty with falling?"). Balance testing consisted of the modified Romberg Test of Standing Balance on Firm and Compliant Support Surfaces. This test examined the participant's ability to stand unassisted using 4 test conditions designed specifically to test the sensory inputs that contribute to balance—the vestibular system, vision, and proprioception. The fourth test condition was designed to test vestibular function exclusively: participants had to maintain balance on a foam-padded surface (to obscure proprioceptive input) with their eyes closed (to eliminate visual input).

Balance testing was scored on a pass/fail basis. Test failure was defined as participants needing to open their eyes; moving their arms or feet to achieve stability; or beginning to fall or requiring operator intervention to maintain balance within a 30-second interval. Each participant who failed a test condition was eligible for 1 retest. The protocol for retesting was the same as for the primary examination. Because each successive test condition from 1 to 4 was progressively more difficult than the condition preceding it, the balance testing component was ended whenever a participant failed to pass a test condition (either during the initial test or the retest, if the participant opted for one). We focused on test condition 4, designed to distinguish participants who could not stay standing when relying primarily on vestibular input. We categorized participants as having vestibular dysfunction if they did not pass test condition 4. Of 5086 participants, 257 (5.1%) did not pass prior test conditions and thus did not participate in test condition 4. An additional 86 participants (1.7%) had missing data for test condition 4, leading to a total of 343 excluded participants (6.7%). Further details of balance testing procedures are available at http://www.cdc.gov/nchs/data/nhanes/ba.pdf.

SOCIODEMOGRAPHIC AND CARDIOVASCULAR RISK VARIABLES

Trained interviewers administered detailed questionnaires.[16] Age at interview was categorized by decade. Race/ethnicity was grouped as non-Hispanic white (hereafter referred to as white), non-Hispanic black (hereafter, black), Mexican American, or other. Education was grouped as less than high school, high school diploma (including GED [general equivalency diploma]), and beyond high school. Of 4743 participants, 33 (0.7%) had missing education data.

A complete smoking history included the number of years smoked and the current number of cigarettes smoked per day. Pack-years of smoking were computed, and participants were divided into smoking categories including never smoked, fewer than 20 pack-years of smoking, and 20 pack-years or more of smoking. There were substantial missing data (313 participants [6.6%]) on the quantity of tobacco smoked, so a separate category was made for ever smokers with unknown pack-years (after inclusion of this category, 49 participants [1.0%] had missing data). Hypertension was defined based on physician diagnosis, use of antihypertensive medication, a mean systolic blood pressure higher than 140 mm Hg, or a mean diastolic blood pressure higher than 90 mm Hg at the time of examination. Mean blood pressure comprised up to 4 readings on 2 separate occasions (14 participants [0.3%] had missing data). Diabetes mellitus was defined based on physician diagnosis, use of antihyperglycemic medication, an 8-hour fasting serum glucose level of 126 mg/dL, or a nonfasting serum glucose level of 200 mg/dL (to convert to millimoles per liter, multiply by 0.0555).

AUDIOMETRIC MEASURES

Details of NHANES audiometric testing procedures have been published previously[17] and are available at http://www.cdc.gov/nchs/data/nhanes/au.pdf. Hearing loss was defined as a pure-tone mean of 25 dB or more normal hearing level using frequencies of 0.5, 1, 2, and 4 kHz in both ears.

ANALYSIS

We estimated the prevalence of vestibular dysfunction in the overall population and stratified by sociodemographic characteristics. The χ^2 F statistic was used to test for overall differences in proportions. Multiple logistic regression was used to estimate the odds of having vestibular dysfunction associated with sociodemographic and cardiovascular risk factors, and to estimate the odds of reporting a fall associated with vestibular dysfunction.

All analyses were adjusted for the survey design using the SURVEY procedures in SAS statistical software (SAS Institute Inc, Cary, North Carolina). Sample weights were incorporated into all analyses by using the WEIGHT statement in SAS software per National Center for Health Statistics instructions. All prevalences, odds ratios, and variance estimates are presented from weighted analyses unless otherwise specified. $P < .05$ were considered statistically significant.

RESULTS

As determined by failure to complete test condition 4, the overall prevalence of vestibular dysfunction in the US population aged 40 years and older from 2001 through 2004 was 35.4%, corresponding to 69 million Americans (**Table 1**). The prevalence of vestibular dysfunction increased markedly with age and did not significantly differ by sex or among whites, blacks, and Mexican-Americans (Table 1). Participants in the "other" race/ethnicity category, which included the categories "other Hispanic" and "other race—including multiracial," had a significantly higher prevalence of vestibular dysfunction. Individuals with more than a high school education had a markedly lower prevalence of vestibular dysfunction compared with individuals with less than a high school education.

We observed significant differences in the prevalence of vestibular dysfunction by cardiovascular risk characteristics: heavy tobacco use (≥20 pack-years), hypertension, and diabetes were associated with higher rates of vestibular dysfunction (Table 1). Participants who reported a history of dizziness were also more likely to have evidence of vestibular dysfunction, as were participants who reported falling in the past 12 months (Table 1).

The influence of demographic characteristics and cardiovascular risk factors on the odds of vestibular dysfunction was evaluated in multivariate analyses (**Table 2**). The powerful influence of age persisted in models also adjusted for race/ethnicity, sex, educational level, smoking, hypertension, and diabetes, whereas men and women had equal odds of vestibular dysfunction. Participants in the "other" race/ethnicity category had significantly higher odds of risk-adjusted vestibular dysfunction compared with whites, and individuals with more than a high school education maintained their significantly lowered odds of vestibular dysfunction in multivariate analyses (Table 2).

We observed that a history of hypertension was associated with a borderline significant increase in the odds of vestibular dysfunction ($P = .06$; Table 2). Diabetes was associated with a statistically significant increase in the odds of vestibular dysfunction (Table 2). Heavy smoking did not increase the odds of vestibular dysfunction in adjusted analyses (Table 2).

Given that anatomically linked structures subserve vestibular and auditory function, we evaluated for associations between vestibular dysfunction and hearing loss. We found that participants with vestibular dysfunction had significantly increased odds of hearing loss compared with participants without vestibular dysfunction in multivariate analyses (odds ratio, 1.9; 95% confidence interval, 1.1-3.1; data not shown). Prior work suggests that sociodemographic and cardiovascular risk factors are associated with hearing loss.[17] To test whether the associations we observed between these factors and vestibular dysfunction may be owing to confounding associations between hearing loss and vestibular dysfunction, we adjusted for hearing loss in multiple logistic regression models evaluating the association between sociodemographic and cardiovascular risk characteristics and vestibular dysfunction. The significant influences of age, educational level, and history of diabetes were unchanged (data not shown).

We explored the extent to which vestibular dysfunction was associated with clinically significant outcomes, specifically self-reported dizziness and a history of falls. Participants with vestibular dysfunction were more likely to report having dizziness and a history of falls (**Table 3**). In unadjusted analyses, vestibular dysfunction conferred a significant increase in the odds of self-reported dizziness and of falling (Table 3). Given that the association between vestibular dysfunction and self-reported dizziness or falls could be owing to shared associations with demographic and cardiovascular risk characteristics (ie, these factors could be acting as confounders), we evaluated the association between vestibular dysfunction and self-reported dizziness and history of falling in analyses adjusted for age, sex, race/ethnicity, and cardiovascular risk factors. In these adjusted analyses, vestibular dysfunction was still associated with a significant increase in the odds of self-reported dizziness and of falling (Table 3).

We evaluated the odds of falling among the 26.8% of participants who had measured vestibular dysfunction and were also symptomatic (n=536). We found that these participants had a nearly 8-fold increase in the odds of falling (odds ratio, 12.3; 95% confidence interval, 7.9-16.7) compared with participants with neither of these

Table 1. Prevalence of Vestibular Dysfunction in US Adults by Demographic and Cardiovascular Risk Characteristics, NHANES 2001-2004[a]

Characteristic	No. (%) of Participants[b]	Prevalence of Vestibular Dysfunction (95% CI), %[c]	*P* Value[d]
All participants	6785	35.4 (33.2-37.6)	. . .
Demographic Characteristics			
Sex			
Male	3326 (49.0)	34 (31.9-36.9)	.16
Female	3459 (51.0)	36 (33.6-39.1)	
Age, y			
40-49	1861 (27.4)	18.5 (15.4-21.7)	<.001
50-59	1336 (19.7)	33.0 (28.9-37.1)	
60-69	1482 (21.8)	49.4 (45.6-53.0)	
70-79	1187 (17.5)	68.7 (65.0-72.5)	
≥80	919 (13.5)	84.8 (81.3-88.4)	
Race/ethnicity			
White, non-Hispanic	3873 (57.1)	34.7 (32.1-37.4)	.08
Black, non-Hispanic	1249 (18.4)	35.5 (31.1-40.0)	
Mexican American	1220 (18.0)	34.3 (27.4-41.2)	
Other	443 (6.5)	42.4 (35.9-48.9)	
Educational level[e]			
<High school	2229 (33.0)	50.9 (47.1-54.6)	<.001
High school diploma, including GED	1621 (24.0)	40.3 (36.9-43.7)	
>High school	2902 (43.1)	28.6 (26.2-31.0)	
Cardiovascular Risk Factors			
Smoking, No. of pack-years smoked[f]			
Never smoked	3197 (47.5)	34.2 (31.3-37.2)	.005
<20	1515 (22.5)	31.7 (27.4-36.2)	
≥20	1711 (25.4)	40.9 (38.3-43.6)	
Unknown	313 (4.7)	32.0 (21.4-42.6)	
History of hypertension[g]			
No	3087 (45.6)	27.9 (25.4-30.4)	<.001
Yes	3684 (54.4)	44.6 (41.5-47.7)	
History of diabetes mellitus			
No	5649 (83.3)	33.2 (30.8-35.6)	<.001
Yes	1136 (16.7)	53.6 (49.0-58.2)	
Self-reported dizziness[h]			
No	4943 (72.9)	31.8 (29.5-34.2)	<.001
Yes	1834 (27.0)	49.4 (45.5-53.3)	
History of falls[i]			
No	6238 (92.1)	34.3 (32.0-36.5)	<.001
Yes	537 (7.9)	64.9 (55.2-74.6)	

Abbreviations: CI, confidence interval; ellipses, not applicable; GED, general equivalency diploma; NHANES, National Health and Nutrition Examination Survey.
[a] Sample weights applied unless otherwise indicated.
[b] Unweighted number of participants. Owing to rounding, percentages may not total to 100.
[c] Definition of vestibular dysfunction based on Romberg testing and difficulty with balance or falling in the past 12 months; 86 participants had missing data.
[d] χ^2 F test.
[e] Data were missing for 33 participants.
[f] Data were missing for 49 participants.
[g] Data were missing for 14 participants.
[h] Participants reported dizziness and difficulty with balance or falling in the past 12 months; 8 participants had missing data.
[i] Participants reported falling in the past 12 months; 10 participants had missing data.

risks in adjusted analyses (data not shown). We also evaluated whether participants with evidence of vestibular dysfunction who were asymptomatic were at increased risk of falling. We found that participants with subclinical vestibular dysfunction also had significantly increased odds of falling (odds ratio, 6.3; 95% confidence interval, 2.9-13.8; data not shown).

COMMENT

This study suggests that vestibular dysfunction, as evaluated by a simple postural metric, is common among US adults; 35% of Americans aged 40 years and older had objective evidence of vestibular dysfunction, corresponding to 69 million individuals. Comparisons of our prevalence findings with other national estimates are difficult because of differences in the definition of vestibular dysfunction, as well as differences in the age distribution of the populations surveyed. Our estimate of 35% is comparable to the 21% to 29% prevalence rates of self-reported vertigo observed in community-based samples from the United Kingdom and Finland.[18-20] Our estimate is significantly higher than the 7.4% prevalence of vestibular vertigo observed in a national survey of Germans aged 18 years and older, in which a preva-

Table 2. Unadjusted and Adjusted ORs of Vestibular Dysfunction by Demographic and Cardiovascular Risk Characteristics, NHANES 2001-2004[a]

Characteristic	Vestibular Dysfunction[b] Unadjusted OR (95% CI)	Adjusted OR[c] (95% CI)
Demographic Characteristics		
Sex		
Male	1 [Reference]	1 [Reference]
Female	1.1 (1.0-1.2)[d]	1.0 (0.9-1.1)
Age, y		
40-49	1 [Reference]	1 [Reference]
50-59	2.2 (1.6-2.9)	2.1 (1.5-2.9)
60-69	4.3 (3.4-5.4)	3.7 (2.9-4.7)
70-79	9.7 (7.9-11.9)	8.1 (6.4-10.0)
≥80	24.5 (19.0-31.5)	22.7 (16.8-30.7)
Race/ethnicity		
White, non-Hispanic	1 [Reference]	1 [Reference]
Black, non-Hispanic	1.0 (0.9-1.3)	1.1 (0.9-1.3)
Mexican American	1.0 (0.7-1.3)	1.1 (0.8-1.5)
Other	1.4 (1.1-1.8)	1.7 (1.3-2.3)
Educational level[e]		
<High school	1 [Reference]	1 [Reference]
High school diploma, including GED	0.7 (0.6-0.7)	0.9 (0.7-1.0)[d]
>High school	0.4 (0.3-0.5)	0.6 (0.5-0.7)
Cardiovascular Risk Factors		
Smoking, No. of pack-years smoked[f]		
Nonsmoker	1 [Reference]	1 [Reference]
<20	0.9 (0.7-1.1)	1.0 (0.8-1.2)
≥20	1.3 (1.1-1.5)	1.1 (0.9-1.3)
Unknown	0.9 (0.5-1.5)	1.1 (0.6-1.8)
History of hypertension[g]		
No	1 [Reference]	1 [Reference]
Yes	2.1 (1.8-2.4)	1.2 (1.0-1.4)[d]
History of diabetes mellitus		
No	1 [Reference]	1 [Reference]
Yes	2.3 (1.9-2.8)	1.7 (1.4-2.0)

Abbreviations: CI, confidence interval; GED, general equivalency diploma; NHANES, National Health and Nutrition Examination Survey; OR, odds ratio.
[a] Sample weights applied.
[b] Participants had objective evidence of vestibular dysfunction based on Romberg testing; 5086 participants were eligible to participate, and 86 had missing data.
[c] Adjusted for age, race/ethnicity, sex, educational level, smoking status, and history of diabetes and hypertension.
[d] Not significant at $P < .05$.
[e] Data were missing for 33 participants.
[f] Data were missing for 49 participants.
[g] Data were missing for 14 participants.

lent case was defined based on self-reported symptoms with validation by neurotological examination in a subset of cases.[21]

A major source of variability in estimates of the prevalence of vestibular dysfunction is in the definition of a case. All of the studies cited previously primarily used questionnaires to define a case of vertigo. The NHANES was unique in its use of the modified Romberg Test of Standing Balance on Firm and Compliant Support Surfaces, an objective test that was administered to all participants. This measure has been shown to approximate computerized dynamic posturography testing, which is one of the instruments used in the clinical diagnosis of vestibular dysfunction.[22] Posturography, as well as test condition 4 in this study, assesses a patient's ability to maintain balance when vestibular information is the only reliable sensory input (ie, in the absence of parallel visual and proprioceptive cues). Effective use of vestibular information requires appropriately receiving and processing vestibular input and making compensatory postural (ie, musculoskeletal) changes; abnormalities located anywhere along this pathway can result in test results outside the normal range.[23,24] The emphasis of postural assessment on global functional status likely explains its greater association with clinical outcomes such as falls when compared with other vestibular measures, such as vestibulo-ocular reflex testing (eg, caloric reflex or rotary chair tests).[25,26] We also observed that individuals with evidence of vestibular dysfunction had significantly increased odds of falling.

We found that a substantial proportion of participants (32%) without a history of self-reported dizziness had evidence of vestibular dysfunction. Others have also found that postural assessment is more likely to yield an abnormal result than other vestibular function tests in asymptomatic and symptomatic (ie, history of vertigo or falls) patients.[26,27] A possible explanation for the increased sensitivity of postural assessment is that performance is influenced by information arising from all 6 semicircular canals and the utricle and saccule, whereas conventional tests may have more restricted substrates. For example, the caloric reflex test only evaluates function of the horizontal semicircular canals. In addition, the observed higher yield of postural assessment may explain why the prevalence of vestibular dysfunction found in this study is significantly higher than the prevalence of self-reported vertigo observed in the national surveys cited previously. Of interest, we found that individuals without a history of dizziness but who had abnormal findings on postural assessment also had significantly increased odds of falling. This finding suggests that the subclinical vestibular dysfunction captured by the postural tests in this study is clinically significant.

Postural assessment cannot uniquely determine the site or origin of vestibular dysfunction nor distinguish between central and peripheral vestibular dysfunction, in contrast to tests of the vestibulo-ocular reflex, such as caloric reflex testing, which specifically assess peripheral vestibular function. However, our finding that individuals with vestibular dysfunction were significantly more likely to have hearing loss suggests that peripheral vestibular structures played a role in vestibular function as measured in this study. A shared susceptibility to vestibular dysfunction and hearing loss likely reflects the common anatomic location of the vestibular and hearing organs, as well as a common blood supply, making both systems potentially vulnerable to the same degenerative, ischemic, traumatic, or toxic insults. Again, in contrast to tests of the vestibulo-ocular reflex, postural tests may be affected by a participant's strength and musculoskeletal status (eg, presence of arthritis), as well as by motivational and volitional factors that may affect test compliance. However, in this study, these considerations may be mitigated by the fact that participants were only tested in condition 4 if their systems were adequate to pass the 3 prior conditions.

Table 3. Prevalence and Odds of Self-Reported Dizziness and History of Falls by Vestibular Dysfunction, NHANES 2001-2004[a]

	Self-Reported Dizziness[b]			History of Falls[c]		
	Prevalence (95% CI), %	Unadjusted OR (95% CI)	Adjusted OR[d] (95% CI)	Prevalence (95% CI)	Unadjusted OR (95% CI)	Adjusted OR[d] (95% CI)
Vestibular dysfunction[e]						
No	16.0 (13.8-18.1)	1 [Reference]	1 [Reference]	2.0 (1.2-2.9)	1 [Reference]	1 [Reference]
Yes	28.4 (25.7-31.1)	2.1 (1.8-2.5)	1.8 (1.5-2.2)	6.9 (5.6-8.3)	3.6 (2.3-5.4)	2.6 (1.6-4.1)

Abbreviations: CI, confidence interval; NHANES, National Health and Nutrition Examination Survey; OR, odds ratio.
[a]Sample weights applied.
[b]Participants reported dizziness and difficulty with balance or falling in the past 12 months; 8 participants had missing data.
[c]Participants reported falling in the past 12 months; 10 participants had missing data.
[d]Adjusted for age, race/ethnicity, sex, educational level, smoking, and history of diabetes mellitus and hypertension.
[e]Participants had objective evidence of vestibular dysfunction based on Romberg testing; 5086 participants were eligible to participate; 86 had missing data.

Increasing age was significantly associated with vestibular dysfunction, as has been well documented in the literature.[21,28,29] Temporal bone studies in animals and humans have demonstrated a depletion of vestibular hair cells and otoliths, dysfunction of the remaining hair cells, and loss of vestibular ganglion cells associated with aging.[30-32] The association between age and a history of falls was attenuated with the addition of vestibular dysfunction into multivariate models. For example, among participants aged 80 years and older, the odds of falling were 7-fold higher compared with participants in their 40s, but the odds were only 2.5-fold greater after adjustment for vestibular dysfunction. This suggests that the effect of age on postural instability may in part be mediated by vestibular dysfunction.

We observed significantly increased odds of vestibular dysfunction among members of the "other" race/ethnicity group, in contrast to prior reports.[33] Perhaps genetic factors play a role, and, indeed, several genes have been implicated in the pathophysiologic mechanism of one particular vestibulopathy, Meniere disease.[34,35] We also found a marked protective effect of higher educational attainment on the odds of vestibular dysfunction, as noted in previous studies.[21,36] Incomplete adjustment for risk factors such as hypertension and diabetes may explain these socioeconomic and ethnic disparities. Finally, we found that diabetes had a significant negative influence on vestibular function, as noted in several other studies.[37-39] Diabetes has been postulated to be vestibulotoxic because of its microangiopathic effects, which lead to ischemia of the vestibular structures. In addition, impaired glucose metabolism has been suggested to alter the metabolism of inner ear fluids, leading to labyrinthine dysfunction.[37]

Although the NHANES data offer significant power, they are cross-sectional and thus cannot support causal inferences. We have attempted to minimize the potential effects of confounding variables by adjusting for potential predictors of vestibular dysfunction, including age, race/ethnicity, sex, and cardiovascular risk factors, in our analyses.

In this article, we observed a high prevalence of vestibular dysfunction in the US population and noted a significant link between vestibular dysfunction and the risk of falling. These findings suggest the importance of diagnosing and treating vestibular deficits to reduce the burden of fall-related injuries and deaths. Given the high prevalence of this impairment, notably among the elderly, and the extraordinary costs associated with falls (exceeding $20 billion annually),[40] screening for vestibular dysfunction in assisted living or nursing home facilities, for example, could be a life-saving and cost-effective practice. Screening may be particularly effective in groups at heightened risk of vestibular dysfunction, specifically nonwhites, individuals with less than a high school education, people with diabetes, and the hearing impaired. In cases in which vestibular dysfunction is diagnosed, vestibular physical therapy can be offered to aid in balance control and fall prevention.[41-43] Vestibular physical therapy, which challenges and retrains a dysfunctional vestibular system through various exercises, shows promise as a therapeutic modality but has not been validated in large-scale trials. There is further need for prospective clinical studies that evaluate specific interventions aimed at treating patients with vestibular dysfunction and preventing falls in these individuals.

Accepted for Publication: January 8, 2009.
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Author Contributions: Dr Agrawal had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design*: Agrawal. *Analysis and interpretation of data*: Agrawal, Carey, Della Santina, Schubert, and Minor. *Drafting of the manuscript*: Agrawal. *Critical revision of the manuscript for important intellectual content*: Carey, Della Santina, Schubert, and Minor. *Statistical analysis:* Agrawal. *Study supervision:* Carey, Della Santina, and Minor.
Financial Disclosure: None reported.
Additional Contributions: Michael M. E. Johns, MD, provided helpful comments on an earlier version of the manuscript.

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Correction

Numerical Error. In the article titled "Disorders of Balance and Vestibular Function in US Adults: Data From the National Health and Nutrition Examination Survey, 2001-2004," by Agrawal et al, published in the May 25th issue of the *Archives* (2009;169[10]:938-944), a value was reported erroneously. On page 940, "Results" section, right-hand column, fifth paragraph, the second sentence should have read as follows: "We found that these participants had a nearly 12-fold increase in the odds of falling (odds ratio, 12.3; 95% confidence interval, 7.9-16.7) compared with participants with neither of these risks in adjusted analyses (data not shown)."