Falls result in significant morbidity and mortality and impose a large societal cost in the United States. Vision loss is a well-recognized risk factor for falls, with several visual metrics associated with higher fall rates. Further research is crucial to better understand the reason for falls in individuals with visual impairment (VI) and to develop appropriate fall prevention strategies.

One putative link between vision and falls is poor balance. Several visual disorders are associated with diminished balance and interventions, such as cataract surgery and balancing exercises, can improve balance in individuals with VI. These studies have largely been conducted in clinic-based populations, consisting of biased samples of patients seeking care, and few population-based investigations have examined the relationship between poor vision and balance.

To objectively evaluate balance in the US population, the National Institute on Deafness and Other Communication Disorders supported the administration of the Romberg test of standing balance during the National Health and Nutrition Examination Survey (NHANES). Testing was designed to probe the relative contributions of the visual, proprioceptive, and vestibular systems to balance. For instance, the vestibular contribution to balance was evaluated by limiting visual and proprioceptive inputs.
Visual Impairment and Balance in the United States

Methods

The NHANES 2001-2002 and 2003-2004 protocols were approved by the National Center for Health Statistics research ethics review board. Informed consent was obtained from all participants. The research adhered to the tenets of the Declaration of Helsinki.

Study Population

Data were obtained from the 2001-2002 and 2003-2004 rounds of the NHANES, a cross-sectional study chosen to reflect a representative sample of the US civilian, noninstitutionalized population through a complex, multistage probability design. Survey participants were invited to undergo a comprehensive health examination in a mobile examination center, including VA testing, objective balance testing, and assessment of peripheral neuropathy. Home interviews provided self-reported medical history and basic demographic data.

Evaluation of Vision

Visual acuity was measured for each eye as previously described.27 Presenting VA for each eye was assessed using an autorefractor containing built-in VA charts (ARK-760; Nidek). Presenting VA was recorded as the smallest line for which 4 or more characters were read correctly. Those whose VA was worse than 20/200 were categorized as having 20/200 VA.

Refractometer VA was measured in all eyes with a presenting VA worse than 20/25 using autorefractor results. When autorefractor results were missing from only one eye and VA in that eye was worse than 20/40, we assumed that the VA in that eye did not refract to 20/40 or better. Participants with missing presenting VA in both eyes or those with VA worse than 20/40 and no autorefraction in both eyes were considered to have incomplete VA data and were excluded from analyses.

Participants whose better-eye presenting VA was 20/40 or better were classified as having normal vision. Individuals in whom better-eye presenting VA was worse than 20/40 but better-eye refractometer VA was 20/40 or better were characterized as having URE. Participants whose better-eye VA was worse than 20/40 after autorefraction were classified as having VI. For participants with VA data in only one eye, better-seeing eye VA was considered the acuity of the sole measured eye. Presenting VA and refractometer VA were further classified as moderate (worse than 20/40 but better than 20/200) or severe (20/200 or worse). Furthermore, presenting VA and refractometer VA were analyzed as continuous variables after conversion to logarithm of the minimum angle of resolution (logMAR) units. Specifically, a decrease in 1 line on the chart represented an increase of 0.1 logMAR unit. Therefore, 1 logMAR unit change represented a 10-line decrement change in VA.

Evaluation of Balance

Balance was assessed via the Romberg test of standing balance on a firm or compliant (foam) surface. Participants stood feet together unassisted under the following 4 increasingly challenging conditions: (1) eyes open on a firm surface, (2) eyes closed on a firm surface, (3) eyes open on a compliant surface, and (4) eyes closed on a compliant surface. We primarily focused on foam surface testing results because the foam surface minimized proprioceptive inputs and isolated the effects of the visual and vestibular systems on postural balance. The final test condition (eyes closed on a compliant surface) was designed to primarily assess vestibular contributions to balance by minimizing visual and proprioceptive inputs.

Balance was defined as pass or fail, with time to balance failure recorded. A participant was considered to have failed a test if he or she began to fall, moved the arms or feet for stability, or required intervention to maintain balance before the requisite time had elapsed (15 and 30 seconds for firm and foam surface testing, respectively). Failure also occurred if participants opened their eyes during the eyes-closed testing conditions. Participants failing an initial trial of a particular balance condition were given the option to retake that test and were graded on the basis of the second test. Participants unable to pass a particular balance test condition did not continue with subsequent more difficult balance tests. Time to balance failure was recorded in seconds and was calculated as the mean of the 2 trials in individuals failing a specific test condition twice. If there were missing data for time to balance failure for both attempts during a balance test (n = 3), the population mean for that trial was imputed.

Participants were excluded from balance testing if they weighed more than 124 kg, had a foot or leg amputation, were unable to stand unsupported, had dizziness leading to unsteadiness, needed a leg brace to stand unassisted, or could not fit into the standardized safety gait belt. In addition, the study excluded those who were totally blind or so visually impaired that they required assistance in locating the examination room. Further balance testing procedure details are available from the NHANES Balanced Procedures Manual (http://www.cdc.gov/nchs/data/nhanes/ba.pdf).

Subjective Evaluation of Difficulty With Falling

A questionnaire was administered to participants asking them about their subjective views on difficulty with falling during...
the last year. Specifically, participants were asked: “During the past 12 months, have you had difficulty with falling?” The questionnaire contained no questions on actual falls or their frequency.

**Evaluation of Peripheral Neuropathy**
Peripheral neuropathy was objectively measured by trained health technicians; peripheral neuropathy was defined as not present, mild, or severe based on the number of insensate areas. Participants with inadequate data for both legs or data in only one leg were excluded from the analysis. Details of peripheral neuropathy testing procedures are available from the NHANES Lower Extremity Disease Procedures Manual (http://www.cdc.gov/nchs/data/nhanes/nhanes_03_04/LE.pdf).

**Statistical Analysis**
Group differences in vision status were evaluated using χ² analyses and univariate linear regression. Group differences in balance testing were assessed using Kaplan-Meier analysis and multivariable Cox proportional hazards regression models incorporating data on balance failure and time to balance failure. Survival analysis better addressed the fact that participants with worse vision may be more likely to fail balance testing at an earlier time point. Analyses were also performed using presenting VA or refractometer VA as continuous variables. To isolate the effect of URE-associated vision loss, additional models were run in which the effect of presenting VA was analyzed after excluding individuals with VI. Variables previously associated with balance (age, sex, race/ethnicity, and smoking history, as well as stroke, obesity, arthritis, smoking, diabetes mellitus, and peripheral neuropathy) were included as covariates. The presence of stroke, arthritis, and diabetes mellitus was based on the participant’s responses to the following question: “Has a doctor or other health professional ever told you that you had [specific disorder]?” Analyses were restricted to individuals 40 years or older because balance and peripheral neuropathy data were fully available only for this age range. Data were analyzed using statistical software (STATA 11; StataCorp LP). All analyses used the 4-year examination weights provided with NHANES data sets to adjust for the complex survey design.

For each specific balance test, those who failed an earlier balance test were excluded from the analysis of that test. To address the issue of missing balance test data in participants who failed earlier balance tests, additional analyses were run in which time to balance failure was imputed as the failure time of the prior test. Logistic regression was used to analyze data on self-reported difficulty with falling during the last year.

**Results**
A total of 6785 persons 40 years or older participated in the NHANES during the 2001-2002 and 2003-2004 periods. Among these participants, 4590 (67.6%) had complete VA, balance test, and peripheral neuropathy data and were included in the present analysis. Compared with participants having complete data, participants having incomplete data were older, were more often obese, and differed in their sex and racial/ethnic distribution, as well as were more likely to report a history of stroke, arthritis, and diabetes mellitus (P < .01 for all) (Table 1). Among these participants with complete data, 94.0%, 4.3%, and 1.7% had normal vision, URE, and VI, respectively.

Compared with participants having normal vision, participants having VI were significantly older. After adjusting for age, the comorbid conditions evaluated herein did not significantly differ in frequency across vision status except for diabetes mellitus and obesity, which were more common in the URE and VI groups than in the group with normal vision (P ≤ .03 [P ≥ .08 for all other pairwise comparisons]) (Table 2).
Objective Measured Balance

Failure to complete balance testing on both firm surface tests (eyes open and eyes closed) was rare among participants with normal vision (1.7%), URE (2.5%), and VI (6.5%) and was not associated with presenting VA or refractometer VA in multivariable models (P > .05 for all). Among the participants progressing to eyes-open foam surface testing, failure was noted in 0.7%, 2.6%, and 3.3% of individuals with normal vision, URE, and VI, respectively. Multivariable models showed no significant association between presenting VA or refractometer VA and the likelihood of failing eyes-open foam testing (P > .22 for both).

Among participants progressing to eyes-closed foam surface testing (after having passed both firm surface tests and eyes-open testing on the foam surface), failure was noted in 34.0%, 44.4%, and 72.6% of individuals with normal vision, URE, and VI, respectively. Kaplan-Meier analysis showed a significantly higher rate of balance failure during the period of eyes-closed foam surface testing among those having VI or URE (P < .01 for both) compared with those having normal vision (Figure 1). When the VI group was subdivided by moderate and severe impairment, there was more failure associated with worse vision, although the difference was not statistically significant (P = .22).

Multivariable Cox proportional hazards regression models confirmed a statistically significant dose-response trend, whereby those with worse VA had increasingly greater failure rates during the eyes-closed foam surface test. Specifically, the rates of failing the eyes-closed foam surface test were 1.6 times (P = .01) and 1.7 times (P = .02) greater with each logMAR unit change (10 lines) in presenting VA and refractometer VA, respectively (Table 3). Additional analyses focused on the effect of presenting VA only among those with normal vision and URE to determine the effect of URE-associated vision loss. In this analysis, the rate of failing the eyes-closed foam surface test was 1.7 times (P = .04) greater with each logMAR unit change (10 lines) in presenting VA. Finally, there was no statistical difference in the rate of balance failure between those with VI and URE (P = .77). The above results did not statistically differ during sensitivity analyses in which time to balance failure was imputed for individuals who did not take a balance test because they had failed an earlier balance test.

Self-reported Difficulty With Falling

Self-reported falling difficulties were significantly more common among those having VI compared with those having normal vision (15.6% vs 3.9%, P < .01) (Figure 2). Participants with URE had a tendency to also report more difficulty with falling than participants with normal vision, although group differences did not reach statistical significance in univariate analysis (6.8% vs 3.9%, P = .14). In multivariable models, there was a significant association between presenting VA and refractometer VA and self-reported difficulty with falling. Specifically, the odds of self-reported difficulty with falling were about 3-fold (odds ratio, 3.3; P = .02) and 4-fold (odds ratio, 3.7; P = .03) greater with each logMAR unit change (10 lines) in presenting VA.

### Table 2. Characteristics of Analyzed Study Participants by Vision Status in the NHANES, 2001 Through 2004

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal Visiona (n = 4201)</th>
<th>Uncorrected Refractive Errorb (n = 248)</th>
<th>P Valuec</th>
<th>Visual Impairmentd (n = 141)</th>
<th>P Valued</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male sex, % (95% CI)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>49.0 (46.7-51.3)</td>
<td>52.6 (49.5-55.6)</td>
<td>.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>46.0 (43.0-49.0)</td>
<td>50.8 (47.6-54.0)</td>
<td>.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexican American</td>
<td>38.0 (34.1-41.9)</td>
<td>45.8 (41.5-49.9)</td>
<td>.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>38.0 (34.1-41.9)</td>
<td>45.8 (41.5-49.9)</td>
<td>.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Age, y (95% CI)</strong></td>
<td>55.8 (53.3-56.4)</td>
<td>58.9 (56.5-61.3)</td>
<td>.07</td>
<td>74.2 (71.0-76.9)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td><strong>Race/ethnicity, % (95% CI)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>80.0 (76.2-83.8)</td>
<td>72.3 (64.8-79.7)</td>
<td>.08</td>
<td>80.9 (71.8-90.0)</td>
<td>.64</td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>8.7 (6.5-10.9)</td>
<td>9.6 (5.3-13.9)</td>
<td>.77</td>
<td>8.9 (4.7-13.1)</td>
<td></td>
</tr>
<tr>
<td>Mexican American</td>
<td>4.1 (2.5-5.8)</td>
<td>6.7 (2.7-10.8)</td>
<td>.04</td>
<td>2.4 (0.4-4.9)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>7.2 (5.3-9.0)</td>
<td>11.4 (4.2-18.6)</td>
<td>.11</td>
<td>7.8 (0.6-15.0)</td>
<td></td>
</tr>
<tr>
<td><strong>Medical history, % (95% CI)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>8.6 (7.9-9.8)</td>
<td>17.3 (9.4-25.2)</td>
<td>.02</td>
<td>15.8 (9.1-22.4)</td>
<td>.66</td>
</tr>
<tr>
<td>Stroke</td>
<td>2.6 (2.0-3.1)</td>
<td>4.9 (2.6-7.3)</td>
<td>.06</td>
<td>8.5 (2.8-14.2)</td>
<td>.50</td>
</tr>
<tr>
<td>Arthritis</td>
<td>31.4 (29.5-33.4)</td>
<td>33.2 (26.7-39.6)</td>
<td>.08</td>
<td>46.8 (33.8-59.8)</td>
<td>.42</td>
</tr>
<tr>
<td>Obesity</td>
<td>32.3 (30.1-34.5)</td>
<td>26.4 (20.1-32.7)</td>
<td>.11</td>
<td>20.3 (13.0-27.6)</td>
<td>.03</td>
</tr>
<tr>
<td><strong>Peripheral neuropathy, % (95% CI)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>89.0 (87.7-90.3)</td>
<td>82.1 (75.9-88.3)</td>
<td>.74</td>
<td>74.9 (67.0-83.0)</td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>9.3 (8.1-10.5)</td>
<td>14.1 (8.9-19.2)</td>
<td>.08</td>
<td>22.6 (14.3-31.0)</td>
<td>.59</td>
</tr>
<tr>
<td>Severe</td>
<td>1.7 (1.3-2.1)</td>
<td>3.8 (1.1-6.5)</td>
<td>.11</td>
<td>2.4 (0.3-4.5)</td>
<td></td>
</tr>
<tr>
<td><strong>Smoking history %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoked</td>
<td>46.6</td>
<td>44.2</td>
<td>.76</td>
<td>35.7</td>
<td>.59</td>
</tr>
<tr>
<td>Former smoker</td>
<td>33.1</td>
<td>36.0</td>
<td>.76</td>
<td>35.7</td>
<td>.59</td>
</tr>
<tr>
<td>Current smoker</td>
<td>20.3</td>
<td>19.8</td>
<td>.76</td>
<td>15.5</td>
<td></td>
</tr>
<tr>
<td>Presenting visual acuity, logMAR (95% CI)</td>
<td>0.05 (0.05-0.05)</td>
<td>0.46 (0.43-0.49)</td>
<td>.01</td>
<td>0.60 (0.55-0.64)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Refractometer visual acuity, logMAR (95% CI)</td>
<td>0.04 (0.04-0.04)</td>
<td>0.12 (0.11-0.13)</td>
<td>&lt;.01</td>
<td>0.52 (0.48-0.56)</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>

Abbreviations: logMAR, logarithm of the minimum angle of resolution; NHANES, National Health and Nutrition Examination Survey.

*Presenting visual acuity better than or equal to 20/40.
*Presenting visual acuity worse than 20/40 but refracting to 20/40 or better.
*Relative to normal vision.
*Visual acuity worse than 20/40 after refraction.
*Age-adjusted analyses.
*Statistical analysis after categorizing peripheral neuropathy as a dichotomous variable of none vs any (mild plus severe).
VA and refractometer VA, respectively. In analyses assessing the effect of presenting VA only among participants with normal vision or URE (to assess the effect of URE-associated vision loss), the self-reported difficulty with falling was 3.4 times ($P = .14$) greater with each logMAR unit change (10 lines) in presenting VA, although this finding was not statistically significant (Table 3). There was no statistical difference in self-reported difficulty with falling between those with VI and URE ($P = .25$).

## Discussion

Loss of vision due to VI and URE is associated with worse vestibular balance as judged by worse performance on eyes-closed balance testing. To our knowledge, our work represents the first large-scale population-based study to examine vestibular (eyes-closed foam surface) balance in individuals with decreased vision. The observed association of VI-associated and URE-associated vision loss on vestibular balance may partially explain the increased risk of falls and decreased physical activity noted in individuals with VI and suggests that individuals with URE may also be at risk of balance-related problems.

Previous work has shown that poor VA and various other visual metrics are significantly associated with worse postural balance when the eyes are open. Our study failed to confirm these findings, likely because balance failure was rare under eyes-open conditions during the Romberg test of standing balance. As such, this test may not be as sensitive as other postural balance measures, such as force platforms, electromyograms, or a sway meter. As has been noted in previous investigations, removal of visual input produced by eye closure led to significantly worse postural balance, demonstrating that loss of vision, at least in the extreme, is relevant to balance.

Our finding that worse balance was associated with decreased vision during eyes-closed foam surface testing was surprising given that eye closure would be expected to neutralize the effect of decreased vision on balance. Our results suggest that balance abilities resulting from individual senses are not necessarily independent of each other. In particular, balance difficulties associated with refractive and nonrefractive vision loss may at least partially be due to vestibular dysfunction, which would continue to manifest itself under eyes-closed conditions. Therefore, our findings make it difficult to interpret the results of prior studies that examined balance in individuals with decreased vision only under eyes-open testing because it is possible that some of the observed balance difficulties were not directly attributable to their decreased vision.

Prior studies that have assessed eyes-closed balance under foam surface conditions have shown disparate conclusions relative to those of this study. Specifically, past studies have noted that postural control among individuals with VI during eyes-closed balance was not significantly different from that associated with normal vision. Yet, these investigations were limited in that they frequently excluded participants with vestibular disorders, included patients based on convenience sampling, and examined many fewer individuals than the present study, limiting the generalizability of their results.

Several plausible pathways link refractive and nonrefractive vision loss to worse vestibular (eyes-closed foam surface) balance. Visual inputs are known to be critical to maintaining the accuracy of the vestibulo-ocular reflex. The vestibulo-ocular reflex senses head movements and generates an equal and opposite eye movements to maintain image stability on the retinal fovea. The visual system provides continuous feedback about any retinal slip and the need to recalibrate the vestibulo-ocular reflex. A reduction in visual input could weaken this feedback loop and lead to a noncompensatory vestibulo-ocular reflex and consequent balance dysfunction. Poor vision would then affect balance even with the eyes closed, as was observed in the present study.

Alternatively, it is possible that individuals with refractive and nonrefractive vision loss engage in a lower level of physical and balance activities that have been shown to be beneficial for postural balance, vestibular function, and lower extremity strength. It was recently found that individuals with
A cant difference in lower extremity strength exists between those with and without decreased vision, suggesting that lower extremity strength does not mediate the relationship between vision and balance. Finally, it is possible that sensory systems have a common degenerative process such that vision loss is likely to coexist in individuals with vestibular dysfunction. This theory is plausible for individuals with nonrefractive vision loss, where a neurodegenerative cause is sometimes found, but it seems unlikely for individuals with URE, which is not a neurodegenerative process.

Nonrefractive vision loss was associated with poor vestibular balance and self-reported difficulty with falling during the last year, suggesting a possible mechanism for some vision-related falls. A recent study showed a significant association between vestibular dysfunction and increased falls, indicating that falls from vision may be partially from poor vestibular balance. The notion that VI but not URE was associated with greater difficulty with falling was not surprising considering that those with VI tend to have worse contrast sensitivity and may have had more unmeasured age-related conditions that could contribute to greater falling difficulties. Furthermore, this finding that demonstrated greater self-reported difficulty with falling in individuals with VI supports prior studies describing an association between falls and vision, but it was at odds with the only population-based prospective study evaluating falls in the context of vision loss.
which showed a relationship between falls and visual field loss but not VA. The present study asked about difficulty with falling and did not measure more specific outcome variables, as many other investigations did, limiting an effective comparison of our results with previous work. Nevertheless, optimal fall prevention programs will likely require a multifactorial approach that integrates efforts to address visual and vestibular deficits in addition to other nonvision-related fall risk factors.35-39

Our study has several limitations. A sizable number of participants (32.4%) did not complete the various examinations of the study, possibly due to inability to complete, fear of not completing, or ineligibility for completing the protocol. Balance testing nonparticipants were generally older and sicker than participants, and we may have underestimated the effect of VI-associated and URE-associated vision loss on balance if there was greater nonparticipation among the URE and VI group members with poor balance. Nonparticipation in the eyes-closed foam surface test by those who had failed earlier tests may have biased the results, although findings obtained after imputing for missing data did not significantly differ. Other limitations included the inability of the study to categorize the cause of VI, and we did not evaluate variables such as visual fields, depth perception, and contrast sensitivity.

In summary, VI-associated vision loss and URE-associated vision loss are both associated with poor vestibular balance. These findings may partially underlie the observed adverse influence of VI on falls, predisposing these individuals to injury. Further research is required to examine the relationship between the visual and vestibular systems to develop a better understanding of the mechanism of balance and the reason for falls in individuals with VI.

ARTICLE INFORMATION
Submitted for Publication: September 16, 2012; final revision received January 23, 2013; accepted January 29, 2013.
Published Online: June 6, 2013. doi:10.1001/jamaophthalmol.2013.316.

Conflict of Interest Disclosures: None reported.

REFERENCES
15. 112-M117.
17. Lord SR, Clark RD, Webster IW. Visual acuity. 6 M112-M117.

OPHTHALMIC IMAGES

Fluorescein Angiography of a Closing Funnel Retinal Detachment in Familial Exudative Vitreoretinopathy

Melinda C. Fry, BS, MPH; Aleksandra V. Rachitskaya, MD; Ditte J. Hess, CRA; Elias Mavrofrides, MD; Audina M. Berrocal, MD

Figure 1. A, RetCam (Clarity Medical Systems) external photograph of a closing funnel retinal detachment behind the lens in a 4-month-old baby with familial exudative vitreoretinopathy. B, Fluorescein angiogram at 5.25 minutes showing a funnel retinal detachment in the process of closing. The purse-string pattern of a closing funnel retinal detachment is rarely documented by fluorescein angiography.

Figure 2. Fluorescein angiography at 43 seconds illustrating peripheral nonperfusion and leakage in the other eye of the same patient.