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Visual Acuity, Contrast Sensitivity, and Mortality in Older Women: Study of Osteoporotic Fractures

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OBJECTIVES: To determine whether poorer visual acuity and contrast sensitivity are independent risk factors for all-cause and traumatic mortality in older women.

DESIGN: Twelve-year prospective cohort study (1986–2003).

SETTING: Four U.S. clinical centers.

PARTICIPANTS: Nine thousand seven hundred four postmenopausal white women aged 65 and older.

MEASUREMENTS: Habitually corrected binocular visual acuity and low- and high-frequency contrast sensitivity were measured at baseline using a standard protocol. A study physician adjudicated the primary cause of death from death certificates and medical record review.

RESULTS: During an average of 12.2 years of follow-up, 3,427 women died (35%), 72 (0.7%) from traumatic events. In multivariate models adjusted for age, chronic medical problems, and smoking, all-cause mortality risk was 19% greater for persons in the worst quartile of visual acuity than for those in the best (hazard ratio (HR) = 1.19, $P = .008$) and 39% greater for persons with the worst contrast sensitivity (HR = 1.39, $P < .001$) than for those with the best. Traumatic mortality risk was 2.4 times greater for women with the worst contrast sensitivity than for those with the best (HR = 2.44, $P = .03$).

CONCLUSION: Poorer visual acuity and contrast sensitivity are associated with greater risk of traumatic and all-cause mortality in older women, even after controlling for demographic and clinical characteristics. Although further research is necessary to determine how treating reversible causes of visual impairment or improving current refraction affects mortality in older women, clinical detection and follow-up of these visual impairments holds promise for identifying those who are at risk of mortality from other systemic conditions. **J Am Geriatr Soc 54:1871–1877, 2006.**

Key words: mortality; visual acuity; contrast sensitivity

Visual impairment is one of the most common conditions affecting older individuals. Approximately 92% of persons aged 70 and older require corrective lenses, and 2% are legally blind without correction.[1] Additionally, 14% of persons aged 70 to 74 and 32% of persons aged 85 and older report trouble seeing even while wearing glasses.[1]

Visual impairment likely reflects biological aging and disease processes, and its health effect is substantial. Impaired vision increases the risk of falls, hip fractures,[2–8] and decline in functional status.[9–13] Although previous studies have demonstrated a relationship between sensory impairment and quality of life, they conflict on its relationship with mortality.[14–24] Cross-sectional design, small study sample, self-reported visual impairment, and limited adjustment for the independent influence of other chronic medical conditions have limited prior studies.

It was hypothesized that any association between visual impairment and all-cause mortality is likely a consequence of other comorbidities related to vision and mortality. It was also hypothesized that, after adjustment for these medical conditions, visual impairment would not be related to total mortality. Nevertheless, it was theorized that visual impairment is independently associated with traumatic events and would remain predictive of traumatic mortality even after adjustment for other risk factors. This longitudinal study attempts to address these hypotheses by evaluating the relationship of visual acuity and contrast sensitivity to all-cause and traumatic mortality in a population of older women.

METHODS

Research Setting and Study Population

The Study of Osteoporotic Fractures (SOF) is a multicenter study of elderly women recruited to identify risk factors for osteoporotic fractures and other health outcomes irrespect-

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ive of osteoporosis status. The sample consisted of 9,704 ambulatory white women aged 65 and older recruited from 1986 to 1988 in four metropolitan areas of the United States: Portland, Oregon; Minneapolis, Minnesota; Baltimore, Maryland; and the Monongahela Valley, Pennsylvania. Details of the study design have been reported elsewhere.[2] All participants received a standardized interview and clinical examination approximately every 2 years after baseline, covering multiple domains of health, potential lifestyle and dietary risk factors for falls and fractures, and sociodemographic characteristics. The institutional review boards at each site approved the study, and all the women provided written informed consent.

Measurements

Visual Acuity and Contrast Sensitivity

Visual acuity was assessed at baseline for all participants using a standard protocol with trained examiners. Subjects were asked to read the Bailey-Lovie letter chart with both eyes open, wearing their current spectacle correction if they usually wore glasses for distance.[25] Results of this visual acuity testing were expressed as current binocular vision. For analytical purposes, the log minimum angle of resolution (logMAR) visual acuity[25] was evaluated as quartiles of increased impairment.

Pelli-Robson letter charts were used to measure binocular contrast sensitivity (the ability to detect subtle differences between objects that are not black and white).[26] Log contrast sensitivity scores were calculated for low and high spatial frequencies (i.e., fat gratings and thin gratings) normalized to the median of the study population and then averaged across all spatial frequencies. Thus a score of 1.0 indicates a contrast sensitivity equivalent to the median for the study population. Scores greater than 1.0 indicate a level of contrast sensitivity better than the population median. For analytical purposes, this average was then evaluated as quartiles of decreasing contrast sensitivity.

Mortality

From 1986 to 2003, participants or designated proxies were contacted by mail or telephone every 4 months for outcomes and to verify vital status (>95% complete). Death certificates were physician-adjudicated to determine the primary cause of death, using codes from the *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM). Traumatic deaths were defined as ICD-9-CM codes 800 to 995.

Other Measurements

Demographic characteristics, self-reported health status, history of medical conditions, falls, and smoking status were obtained via a questionnaire reviewed by trained interviewers. For medical conditions such as diabetes mellitus, stroke, and cataract, the subject was asked if a doctor had ever told her that she had the condition. Medication use was determined according to questionnaire and from the pill bottles that participants brought to the examination.

Weight and height (using a stadiometer) and knee height were measured. Body mass index (BMI; kg/m^2) was calculated with knee height substituted for total height, because knee height is less likely to change with age. Hypertension was defined as having measured blood pressure greater than 160/90 mmHg or taking thiazide diuretics. Frailty measures included whether the subject could rise from a chair (without using her arms) five times and whether the subject was resting (off her feet) more than 4 hours per day. Functional disability was based on participants' ability to perform six activities: walking, climbing stairs, descending stairs, preparing meals, shopping, and doing housework.[27,28]

Statistical Methods

Binocular visual acuity was analyzed in three ways: as a continuous variable using the logMAR score, as a Snellen equivalent of 20/40 or worse, and in quartiles based on the logMAR score. Binocular contrast sensitivity was analyzed as a continuous measure using the average normalized score across high and low spatial frequencies and as a categorical variable using quartiles of contrast sensitivity. Contrast sensitivity was averaged across low and high spatial frequencies, because the low-frequency contrast sensitivity, high-frequency contrast sensitivity, and combined-frequency contrast sensitivity exhibited similar associations with mortality. However, the combined frequency association was the largest and had the greatest level of statistical significance.

Baseline attributes were compared across quartiles of visual acuity and contrast sensitivity using the Mantel-Haenszel chi-square test for trend. Cox proportional hazards analyses were used to evaluate the independent contribution of visual acuity and contrast sensitivity to mortality, adjusted first for age only and then multivariate for other significant ($P < .05$) risk factors. Covariates tested in the multivariate analyses were those found to be associated with mortality in prior SOF analyses and included age; BMI; mean pulse; pack-years smoked; currently living alone; use of thiazide diuretics, nonthiazide diuretics, and estrogen; history of diabetes mellitus, hyperthyroidism, hypertension, stroke, and cataract; having fallen in past year; number of falls in past year; self-reported health status; history of fracture after age 50; education; functional disability; resting off feet more than 4 hours per day; and requiring use of arms to stand from a chair. When contrast sensitivity and visual acuity were both independent predictors of mortality, hazard ratios for each were adjusted for the other.

Mortality hazard ratios (HRs) with 95% confidence intervals (CIs) are based on the adjusted analysis. All statistical analyses were conducted using SAS version 6.12 (SAS Institute, Inc., Cary, NC). All reported statistical tests are two-sided, and the term "statistically significant" implies $P < .05$. For ease of interpretation, there was no adjustment for multiple comparisons.

RESULTS

Women in this cohort had average age of 71.7 ± 5.3 and a mean BMI of $26.5 \pm 4.7\,kg/m^2$. A total of 682 (7.0%) reported a history of diabetes mellitus, 292 (3.0%) a history of stroke, and 3,747 (38.9%) had hypertension. Forty-one percent reported estrogen use (ever/current) and 35% thiazide diuretic use. Thirty-nine percent reported past or current smoking; 62% of these reported having smoked 15

Table 1. All-Cause and Traumatic Mortality Rates According to Log of the Minimum Angle of Resolution (LogMAR) Visual Acuity and Contrast Sensitivity

		All-Cause Mortality			Traumatic Mortality		
Vision Measurement	N	Deaths n	Deaths per 100,000 Person-Years	95% CI*	Deaths n	Deaths per 100,000 Person-Years	95% CI*
LogMAR visual acuity quartile							
–0.28–0.02 (best)	2,897	687	1,816	1,681–1,951	14	37	20–62
0.03–0.08	1,979	606	2,451	2,258–2,644	13	53	28–91
0.09–0.20	2,793	1,084	3,261	3,070–3,452	21	63	39–96
0.21–1.40 (worst)	2,035	1,050	4,715	4,436–4,993	24	108	69–161
Contrast sensitivity quartile							
1.74–4.96 (best)	2,412	527	1,648	1,508–1,788	10	31	15–57
1.12–1.73	2,440	669	2,145	1,985–2,306	17	55	32–88
0.69–1.11	2,397	926	3,249	3,043–3,455	15	53	30–87
0.00–0.68 (worst)	2,455	1,305	4,942	4,680–5,203	30	114	77–163

* Confidence intervals (CIs) were calculated using the normal approximation for all-cause mortality rates and on the Poisson probability distribution for traumatic mortality rates, because the number of trauma-related deaths was small.

pack-years or more. A total of 8,070 (83%) reported being in good to excellent (as opposed to fair to poor) health, and 42% were currently living alone. Thirty-seven percent reported at least one functional impairment, whereas 6.5% had four or more. Approximately 10% of women were off their feet for 4 or more hours per day, 4.2% required the use of their arms to stand from a chair, and 30.1% had fallen within the previous 12 months.

Overall, average logMAR binocular visual acuity was 0.12 ± 0.15 and ranged from –0.28 to 1.40. This is approximately equivalent to 20/25 (range 20/12–20/500) on the Snellen scale.[29] Eight percent of subjects had currently corrected binocular visual acuity of 20/40 or worse. Less than 1% of participants had a logMAR of 1.0 or greater, commonly considered legal blindness (Snellen visual acuity 20/200 or worse).[30] Mean binocular normalized contrast sensitivity was 1.27 ± 0.75 (range 0–4.96). Thus, the average normalized contrast sensitivity across all spatial frequencies was 27% higher than the population median.

During a mean follow-up of 12.2 years, 3,427 women (35.3%) died. Of these deaths, 1,264 (36.9%) were due to cardiovascular disease, 852 (24.9%) to cancer, 368 (10.7%) to stroke, 296 (8.6%) to respiratory diseases, 169 (4.9%) to mental diseases, 89 (2.6%) to digestive diseases, and 82 (2.4%) to genitourinary diseases. Trauma caused 72 deaths (2.1%); no other category of death accounted for more than 2%. The most common causes of traumatic death were motor vehicle accidents (n = 21); sequelae of hip, vertebra, or skull fractures (n = 18); lethal hemorrhage from the trauma (n = 10); complications of falls (n = 5); and other causes from other injuries (n = 5).

Table 1 shows that persons with poorer visual acuity and poorer contrast sensitivity were at higher risk of all-cause mortality and, in particular, deaths due to trauma. All-cause mortality rates (per 100,000 person-years) ranged from 1,816 for persons with the best baseline binocular visual acuity to 4,715 for persons with the poorest visual acuity. Similar rates were seen for contrast sensitivity, with an all-cause mortality rate ranging from 1,648 per 100,000 person-years for persons with the best binocular contrast sensitivity to 4,942 for persons with the poorest contrast sensitivity. Traumatic mortality rates were about three times higher for persons in the poorest visual acuity (108 per 100,000) and contrast sensitivity (113 per 100,000) quartiles than for those in the best visual acuity (37 per 100,000) and contrast sensitivity (31 per 100,000) quartiles.

Average logMAR visual acuity ± standard deviation in survivors was 0.09 ± 0.13, compared with 0.16 ± 0.17 in those who died from any cause ($P < .001$) and 0.14 ± 0.14 in those who died from trauma ($P = .002$). Average contrast sensitivity in the surviving group was 1.40 ± 0.75, compared with 1.02 ± 0.67 in those who died from any cause ($P < .001$) and 1.03 ± 0.62 in those who died from trauma ($P < .001$). Of deaths due to all causes, 431 (12.6%) persons had a visual acuity of 20/40 or worse at baseline, compared with 358 (5.7%) survivors ($P < .001$). Eight individuals (11.1%) who died from trauma had visual acuity of 20/40 or worse ($P = .07$ compared with survivors).

In age-adjusted Cox proportional hazards models, logMAR visual acuity and contrast sensitivity were associated with all-cause mortality (Table 2). Relative to the first (best) quartile of visual acuity, each of the second, third, and fourth quartiles showed significantly greater risks of all-cause mortality. A similar association was seen between contrast sensitivity and all-cause mortality (Table 2). The greatest risk occurred for the fourth (worst) quartile of contrast sensitivity, with an HR of 1.76 (95% CI = 1.58–1.97).

In addition to age, other risk factors that were independently predictive of all-cause mortality included BMI; pulse; pack-years smoked; living alone; history of diabetes mellitus, hyperthyroidism, stroke, or hypertension; use of nonthiazide diuretics; no estrogen use; history of falls; functional disability; poorer self-reported health status; off feet 4 or more hours per day; and required use of arms to stand from chair. After adjustment for these, binocular

Table 2. Association of Log of the Minimum Angle of Resolution (LogMAR) Visual Acuity and Contrast Sensitivity to All-Cause and Traumatic Mortality Based on Adjusted Proportional Hazards Model

	Age-Adjusted Model			Multivariate-Adjusted Model*†		
Mortality	Hazard Ratio	(95% Confidence Interval)	*P*-value	Hazard Ratio	(95% Confidence Interval)	*P*-value
All-cause						
LogMAR visual acuity quartile						
–0.28–0.02 (best)	1.00	—		1.00	—	
0.03–0.08	1.18	(1.05–1.31)	.004	1.06	(0.94–1.19)	.31
0.09–0.20	1.35	(1.22–1.49)	<.001	1.11	(0.99–1.24)	.07
0.21–1.40 (worst)	1.58	(1.42–1.76)	<.001	1.19	(1.04–1.36)	.01
Contrast sensitivity quartile						
1.74–4.96 (best)	1.00	—		1.00	—	
1.12–1.73	1.13	(1.01–1.27)	.04	1.08	(0.96–1.23)	.20
0.69–1.11	1.44	(1.29–1.61)	<.001	1.23	(1.08–1.38)	.001
0.00–0.68 (worst)	1.76	(1.58–1.97)	<.001	1.39	(1.20–1.58)	<.001
Traumatic						
LogMAR visual acuity quartile						
–0.28–0.02 (best)	1.00	—		1.00		
0.03–0.08	1.30	(0.61–2.77)	.50	1.00	(0.45–2.21)	1.00
0.09–0.20	1.45	(0.73–2.90)	.29	1.23	(0.64–2.56)	.49
0.21–1.40 (worst)	2.23	(1.16–4.75)	.02	1.39	(1.01–4.12)	.05
Contrast sensitivity quartile						
1.74–4.96 (best)	1.00	—		1.00	—	
1.12–1.73	1.55	(0.70–3.39)	.28	1.40	(0.63–3.10)	.41
0.69–1.11	1.38	(0.61–3.14)	.44	1.14	(0.49–2.63)	.76
0.00–0.68 (worst)	2.86	(1.32–6.20)	.008	2.45	(1.12–5.30)	.03

* All-cause mortality models were adjusted for age, body mass index, pulse, pack-years smoked, living alone, history of diabetes mellitus, hyperthyroidism, stroke, hypertension, use of non-thiazide diuretics, estrogen use, history of falls, self-reported health status, functional impairment, off feet 4 hours or more per day, and required use of arms to stand from chair. The model with LogMAR visual acuity was also adjusted for contrast sensitivity, and the model with contrast sensitivity was adjusted for LogMAR visual acuity.

† Traumatic mortality models were adjusted for age, body mass index, stroke, pulse, self-reported health status and hypertension. A small number of traumatic events and correlation between LogMAR visual acuity and contrast sensitivity (correlation coefficient = 0.65) prevented simultaneous inclusion of both terms in the traumatic mortality model. Thus, the traumatic mortality models do not include adjustment for the other visual impairment measure.

logMAR visual acuity and contrast sensitivity remained significant predictors of all-cause mortality, although only the fourth quartile of logMAR visual acuity and the third and fourth quartiles of contrast sensitivity remained significantly different from the first (best) quartile of the respective measure (Table 2).

Figure 1 displays the adjusted all-cause mortality curves for each of the four quartiles of visual acuity (A) and contrast sensitivity (B). This figure suggests that visual impairment is associated with both short-term and long-term mortality. In separate analyses, women in quartiles 3 and 4 of logMAR visual acuity and contrast sensitivity demonstrated significantly higher mortality risk ($P < .05$) than those in quartile 1 as soon as 3 years of follow-up (data not shown).

In age-adjusted analyses modeling traumatic mortality (Table 2), only the fourth quartile of impairment was significantly associated with greater risk of traumatic mortality (HR = 2.23, 95% CI = 1.16–4.75 for logMAR visual acuity and HR = 2.86, 95% CI = 1.32–6.20 for contrast sensitivity). After multivariate adjustment for age, BMI, stroke, pulse, self-reported health status, and hypertension, persons with the worst contrast sensitivity had 2.45 times as great a risk of traumatic mortality as those with the best contrast sensitivity (95% CI = 1.12–5.30). Because of the correlation between contrast sensitivity and logMAR visual acuity ($r = 0.65$), and the relatively small number of traumatic deaths, both visual impairment terms could not be included in the same model. Nevertheless, when contrast sensitivity was not included in the model, persons with the worst logMAR visual acuity had a 39% greater risk of traumatic mortality than those with the best visual acuity (HR = 1.39, 95% CI = 1.01–4.12).

Figure 2 displays the adjusted traumatic mortality curves for each of the four quartiles of visual acuity (A) and contrast sensitivity (B). Although the worst quartile of logMAR visual acuity and contrast sensitivity exhibited a greater risk of mortality than the other quartiles, 10 years of follow-up was required before the association with contrast sensitivity was significant. The entire follow-up period was required to detect a greater risk of traumatic mortality for persons in the fourth quartile of logMAR visual acuity than for those in the first quartile.

DISCUSSION

This population-based longitudinal study of older postmenopausal women showed that poorer visual acuity and contrast sensitivity were independent predictors of all-cause mortality. The risk of all-cause mortality over a 12.2-year interval was 19% greater for persons with the worst

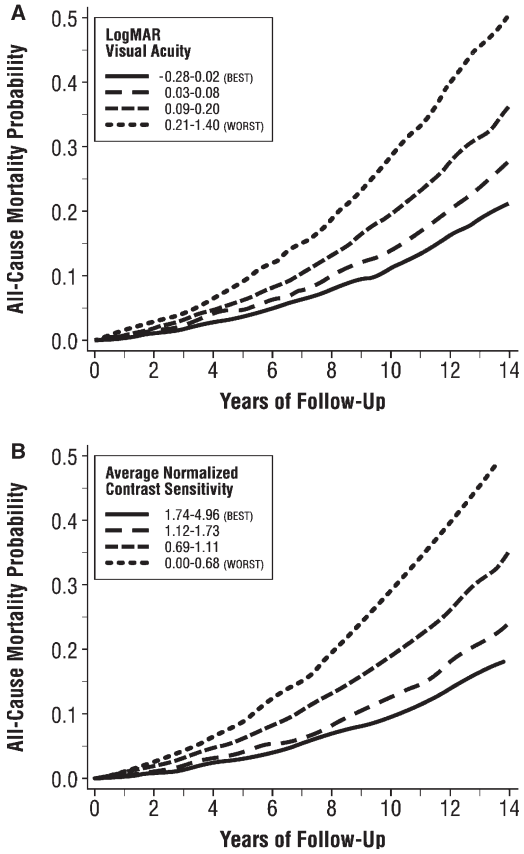

Figure 1. Adjusted all-cause mortality probabilities according to (A) logMAR visual acuity and (B) contrast sensitivity quartiles. Probabilities were calculated from Cox proportional hazards model and adjusted for age; body mass index; pulse; pack-years smoked; living alone; history of diabetes mellitus, hyperthyroidism, stroke, and hypertension; use of nonthiazide diuretics; estrogen use; history of falls; self-reported health status; functional impairment; off feet for 4 or more hours per day; required use of arms to stand from chair; and contrast sensitivity.

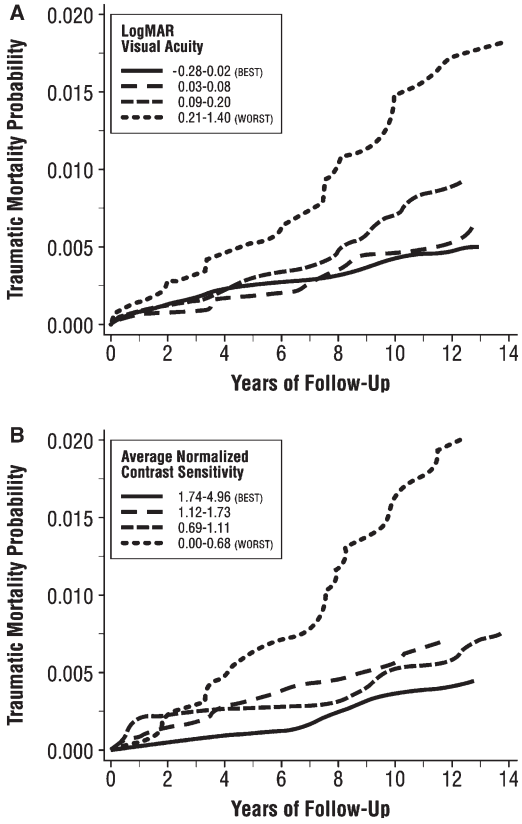

Figure 2. Adjusted traumatic mortality probabilities according to (A) logMAR visual acuity and (B) contrast sensitivity quartiles. Probabilities were calculated from Cox proportional hazards model and adjusted for age, body mass index, stroke, pulse, self-reported health status, and hypertension.

logMAR visual acuity than for those with the best. Women with contrast sensitivity in the third and fourth quartiles had 23% and 39% greater risks, respectively, of all-cause mortality than women with the best contrast sensitivity. In addition, the risk of traumatic mortality was 2.44 times as great for persons in the worst quartile for contrast sensitivity as for those in the best quartile.

Relationships between visual impairment and mortality have been noted in other studies.[19–22,24,31] The Beaver Dam Eye Study found that, although persons with visual acuity of 20/40 or worse were 1.6 times as likely to die within 5 years as those with better visual acuity, the relationship disappeared after adjusting for other clinical conditions such as hypertension and diabetes mellitus.[17] A similar relationship remained significant even after adjustment in the Melbourne Visual Impairment Project.[18] In some studies, longer follow-up was necessary to detect associations, indicating that the effect might be indirect and mediated by other factors. However, the current study found significant associations of visual acuity and contrast sensitivity to all-cause mortality within 3 years of follow-up, suggesting that visual impairment is associated with short-term and long-term mortality.

The relationship between visual impairment and all-cause mortality did not support the a priori hypothesis that this association would disappear after adjustment for other covariates. It may be that visual impairment is indeed an independent predictor of all-cause mortality, in which case there may be opportunities to reduce death risk with interventions as simple as refraction improvement. However, it is possible that the association that was found was due to the presence of other unmeasured chronic medical conditions. Leading causes of visual impairment include glaucoma, age-related cataract, macular degeneration, and diabetic retinopathy.[1] Underlying conditions that are associated with these eye diseases (e.g., hypertension, smoking, diabetes mellitus, and aging) are also commonly associated with greater mortality.[19,20,23,32] In this study, every attempt was made to adjust for known confounders. Hypertension, tobacco use, and diabetes mellitus were all independent predictors of all-cause mortality. A history of age-related cataracts was significantly associated with mortality in the unadjusted analyses but did not remain significant after adjustment. Information was unavailable about glaucoma or macular degeneration at the baseline examination, so adjustment for these conditions was not possible. However, these diseases were not found to be related to worse survival in other studies.[17,22] Still, it is possible that visual impairment is a marker for other systemic conditions related to mortality that were not measured precisely (e.g., severity of diabetes mellitus).

When contrast sensitivity was included in the model, the association between logMAR visual acuity and

traumatic mortality was no longer significant. Other studies have also failed to detect an independent relationship between visual acuity and traumatic mortality.[18,33] The visual acuity assessment in the current study was measured using both eyes and with current correction. Other studies suggest that monocular impaired vision causes greater loss of stereopsis than binocular impairment and that monocular impaired vision is more strongly predictive of hip fracture,[3,34,35] yet in persons with age-related macular degeneration, monocular vision has been shown to provide better visual function than binocular vision, especially at medium to low spatial frequencies.[36] It is not clear which method of assessing visual acuity is most valid when evaluating nonophthalmic outcomes. Testing both eyes together and using the participant's current correction attempted to obtain the most accurate measure of the individual's everyday functional acuity. It is possible that the results would be different had best-corrected visual acuity in the better (or worse) eye or some other measure of visual acuity been used. It is also possible that, with the small number of traumatic deaths, the correlation between logMAR visual acuity and contrast sensitivity (correlation coefficient = 0.65) was such that logMAR visual acuity did not add significantly to the prediction model.

Poor contrast sensitivity has been linked to accidents, self-reported limitation of night-time driving, and falls and fractures.[37–39] The results of the current study relating poorer contrast sensitivity to deaths that follow these types of events amplify the importance of identifying contrast sensitivity as a risk factor, especially because evidence suggests that improvement in visual functioning can positively affect quality of life and reduce accidents.[40]

Strengths of this study include the long follow-up and low attrition of this cohort, although because this study consisted of community-dwelling elderly white women, relationships may differ for men, frailer or younger women, or women from other racial or ethnic groups. Furthermore, although other clinical characteristics known to be related to mortality were controlled for, it is possible that other unmeasured factors may have modified the results.

In conclusion, it was found that women with poorer visual acuity using current correction and those with poorer contrast sensitivity were at greater risk of mortality; this association remained despite controlling for several potential confounders including health status and medical comorbidities. It is not clear that decreasing visual impairment would reduce mortality, but if improvement in visual function reduces accidents and falls, then mortality resulting from these traumatic events could also decrease. In addition, clinically identifying persons with poor visual acuity and contrast sensitivity may help to identify those with underlying conditions that, when treated, could reduce all-cause mortality.

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Author Contributions: Kathryn L. Pedula had full access to all of the data in the study; led the study design, data analysis,; and manuscript preparation; and made the final decision to submit this manuscript for publication. Drs. Coleman, Hillier, Ensrud, Nevitt, Hochberg, and Mangione contributed to study design, data analysis, and manuscript preparation specific to this article. The Study of Osteoporotic Fractures Research Group contributed to the study design, study and data coordination, statistical analysis, and review of the entire study operation.

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