CLINICAL INVESTIGATIONS

# Visual Risk Factors for Falls in Older People

*Stephen R. Lord, PhD, and Julia Dayhew, BAppSc (Occupational Therapy)*

**OBJECTIVES:** To determine the tests most predictive of falls in community-dwelling older people from a range of visual screening tests (high and low contrast visual acuity, edge contrast sensitivity, depth perception, and visual field size). To determine whether one or more of these visual measures, in association with measures of sensation, strength, reaction time, and balance, can accurately predict falls in this group.

**DESIGN:** Prospective cohort study of 12 months duration.

**SETTING:** Falls and Balance Laboratory, Prince of Wales Medical Research Institute.

**PARTICIPANTS:** 156 community-dwelling men and women age 63 to 90 (mean age 76.5, standard deviation = 5.1).

**MEASUREMENTS:** Screening tests of vision, sensation, strength, reaction time and balance, falls.

**RESULTS:** Of the 148 subjects available at follow-up, 64 (43.2%) reported falling, with 32 (21.7%) reporting multiple falls. Multiple fallers had decreased vision, as indicated by all visual tests, with impaired depth perception, contrast sensitivity, and low-contrast visual acuity being the strongest risk factors. Subjects with good vision in both eyes had the lowest rate of falls, whereas those with good vision in one eye and only moderate or poor vision in the other eye had elevated falling rates—equivalent to those with moderate or poor vision in both eyes. Discriminant analysis revealed that impaired depth perception, slow reaction time, and increased body sway on a compliant surface were significantly and independently associated with falls. These variables correctly classified 76% of the cases, with similar sensitivity and specificity.

**CONCLUSION:** The study findings indicate that impaired vision is an important and independent risk factor for falls. Adequate depth perception and distant-edge-contrast sensitivity, in particular, appear to be important for maintaining balance and detecting and avoiding hazards in the environment. **J Am Geriatr Soc 49:508–515, 2001.**

**Key words: vision; visual acuity; contrast sensitivity; depth perception; visual field loss; older; accidental falls**

A number of studies of older people's risk of falling have included measures of visual impairment as a possible risk factor. Standard tests of visual acuity have been most commonly used to measure vision, but the published findings have been inconsistent regarding whether impaired performance in these tests indicates and increased risk of falls. On the one hand, there are several reports that indicate that impaired distant visual acuity is a risk factor for falls in community-dwelling[1–3] and institutionalized older people.[4] However, other studies have not found this to be the case, particularly after adjusting for confounding factors such as age.[5–9] Large prospective studies have also assessed whether reduced visual acuity is a risk factor for hip fractures—a serious consequence of falls in older people. Two of these studies found a significant association,[10,11] but the other did not.[12]

In previous studies, we have found edge contrast sensitivity to be more strongly associated with falls than is visual acuity.[3,5] This was also found in the Blue Mountains Eye Study, which compared the predictive power of a range of visual tests including visual acuity and visual field size,[1] and in the Study of Osteoporotic Fractures.[12]

In addition to visual acuity and contrast sensitivity, researchers have examined whether poor depth perception and visual field loss are risk factors for falls and fractures. Nevitt et al. found that older persons who had poor stereoacuity were at significantly higher risk of suffering recurrent falls,[2] and Cummings et al. reported that poor depth perception was an important risk factor for hip fracture.[12] A study by Felson et al., who found that older persons who had good vision in one eye but only moderately good vision in the other had an elevated risk of hip fracture, also provides indirect support for the hypotheses that impaired depth perception is a risk factor for falls.[10]

Although not as important as contrast sensitivity and visual acuity, Ivers et al. found that visual field loss was an independent risk factor for falls;[1] however, Nevitt et al. reported no significant association between visual field loss and recurrent falls[2] and Glyn et al. found that visual field loss was only weakly associated with falls in patients attending a glaucoma clinic.[13]

From the Prince of Wales Medical Research Institute.
Funded by the Vincent Fairfax Family Foundation.
Address correspondence and requests for reprints to Dr. Stephen Lord, Prince of Wales Medical Research Institute, High Street, Randwick, Sydney, NSW, 2031, Australia.

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The above findings suggest that, while standard measures of visual functioning, such as high-contrast visual acuity, are reasonable predictors of falls, other tests that appear to address more closely the visual functions required for maintaining balance and detecting hazards in the environment are superior in this regard. In this study, we examine the relative predictive power of nine vision screening assessments, either alone or in combination with other known physiological risk factors, for predicting falls in a large population of older community-dwelling people.

## METHODS

### Subjects

The sample comprised 57 men and 99 women age 63 to 90 (mean = 76.5, standard deviation (SD) = 5.1). Community-dwelling subjects (n = 77) were randomly selected from electoral rolls for eastern Sydney, Australia. The remainder (n = 79) lived in a retirement village within the study area. Transport was provided to maximize participation rates of people with mobility limitations. Subjects with limited English were excluded from the study and those with Short Portable Mental Status Questionnaire scores[14] of ≤7 were excluded from the falls follow-up phase because cognitive impairment can lead to underreporting of falls. The participation rate of eligible subjects for the electoral roll and retirement village samples were 47% and 43%, respectively.

Sixty-nine subjects (44.2%) reported a history of cataracts and of these 50 (72.5%) had undergone cataract surgery; 21 (13.5%) reported glaucoma and five (3.2%) reported macular degeneration. Almost all subjects (98.7%) wore glasses; 104 (66.7%) wore multiple focal glasses, 18 (11.7%) wore single-lens distance glasses, 50 (32.5%) wore reading glasses, and one (0.6%) wore contact lenses. Most subjects were receiving regular eye care in that only seven (4.5%) had not seen an eye care specialist within the past 2 years; 58 (37.2%) had obtained new glasses within the past 12 months and 62 (39.7%) had obtained new glasses within the past 2 to 3 years.

Twelve subjects (7.7%) reported stroke, 30 (19.2%) heart disease, 57 (36.5%) high blood pressure, 22 (14.1) lung problems, eight (5.1%) diabetes mellitus, and 70 (44.9%) arthritis. Thirty-seven subjects (23.7%) were taking psychoactive medications, 102 (65.4%) were taking cardiovascular system medications, and 17 (10.9%) were taking musculoskeletal system medications. Twenty-five subjects (16.0%) used a walking aid, 15 (9.6%) reported difficulty shopping, and 14 (9.0%) reported difficulty with household duties.

The Human Studies Ethics Committee at the University of New South Wales, Sydney, approved this study and informed consent was obtained from all subjects.

### The Visual Tests

#### *Visual Acuity*

Visual acuity was measured using a letter chart[3] containing high- (85%) and low-contrast (10%) letters. Acuity was measured monocularly for each eye and binocularly at a distance of 4 meters. Subjects wore their distance correction eyeglasses while undertaking these tests. Visual acuity was measured in terms of logarithm of the minimum angle resolvable in minutes of arc.[3]

#### *Contrast Sensitivity*

Contrast sensitivity was assessed using the Melbourne Edge Test (MET) in both standard (near) and enlarged (distant) forms.[15] The near MET was presented on a card positioned at the subject's preferred reading distance and viewed through reading glasses or the lower lens sections of bifocal glasses, as applicable. The test presents 20 plates with a series of edges of reducing contrast and variable orientation. The distant version of the MET was used to test subject's edge contrast sensitivity for targets positioned 135 cm in front of them at ground level. This distance approximates two steps, the critical distance required for detecting hazards when walking.[16,17] Subjects performed this test wearing their distance vision correction spectacles or using the upper segments of their bifocal spectacles, as applicable. In neither test were subjects restricted from moving their heads in the lateral plane. A four-alternative, forced-choice method of presentation was used to determine the lowest contrast plate correctly identified by the subjects in both tests. Contrast sensitivity was measured in decibels (dBs) where dB = -10log contrast. The MET is a well-accepted screening test of contrast sensitivity[18] with established high test-retest reliability,[16] and good external validity as a predictor of falls.[3,5]

#### *Depth Perception*

Depth perception was measured using a Howard-Dohlman depth perception apparatus (Balance Systems, Sydney, Australia).[19] This device presented two vertical rods, one stationary and the other moveable. Seated subjects looked through a rectangular aperture (20 × 12 cm) in a screen at the two rods (0.8 cm diameter) from a distance of 3 meters. They then manipulated two pull cords to align the movable vertical rod with the stationary rod. Subjects performed this test wearing their distance vision correction spectacles or using the upper segments of their bifocal spectacles, as applicable. The movable rod was set either 15 cm in front of or behind the fixed rod and the subject was instructed to adjust the position of the moving rod so that it was positioned the same distance away as (aligned with) the fixed rod. Any error in aligning the rods was measured in centimeters. The test was repeated six times, with the starting position of the moveable rod alternating between in front of and behind the fixed rod. The mean of these scores was taken as the test score. Test-retest reliability of this test was determined from a sample of 75 people age 75 to 94 tested on two occasions 26 weeks apart. The intraclass correlation coefficient (2,1) was 0.83, 95% confidence interval (CI) = 0.75–0.89.

#### *Stereoacuity*

Stereoacuity was measured using the Frisby Stereotest (Clement Clarke International, London, United Kingdom), a test that provides a precise and reliable measure of stereopsis.[20] This test consists of three clear acrylic plates (1.5 mm, 3 mm, and 6 mm thick) marked with four random-pattern squares. Within one of the squares is a "circle" of pattern components printed on the opposite side of the plate from its surrounds. Subjects initially viewed each plate at a distance of 50 cm. If they failed to detect the circle stimulus at that distance, they viewed them at 40 cm and 30 cm. The subjects' lowest disparity, measured in seconds of arc, was used as the measure of stereoacuity.

### *Lower Visual Field Size*

This test was devised to measure lower visual field loss to gain a measure of subjects' ability to detect hazardous objects at ground level. Subjects stood at the end of a white board measuring 2.4 × 1.2 meters, which lay on the floor. They placed their chin on a chin-rest and a visual target (a 90-mm diameter solid black circle on a 30 × 21 mm white background) was placed at eye level 2.25 meters in front of them. Subjects were asked to close their eyes, and a 110 $mm^2$ black card was placed in front of them on the white board at various distances, offset either 60 cm left or right of their midline. They were then asked to open their eyes and look directly and continually at the circular target and point to the black square card if they could see any part of it "out of the corner of their eye." The test administrator monitored the subjects to ensure that they did not look down. The closest distance from the furthest edge of the square target to the subject was recorded for both the left and right sides. The visual angle (from eye height to the target) was calculated using the formula:

$$\text{visual angle} = 90° - [\tan^{-1}(\text{target distance}/\text{eye height})]$$

The visual field angle measure was the average of the left and right visual scores. During this test, subjects wore the glasses they usually wore when walking outside their homes.

### Sensorimotor Function Assessments

In addition to the vision tests, subjects underwent assessments of proprioception, muscle strength, reaction time, and postural sway. [3] In the test of proprioception in the lower limbs, subjects sat on a tall chair with eyes closed and attempted to align the big toes of both feet by extending the knees. In five experimental trials, the error in matching the toes in degrees was measured by using a protractor inscribed on a vertical clear acrylic sheet (60 × 60 × 1 cm) placed between the legs. Quadriceps strength in kilogram force was measured in the seated position with the angles of the hip and knee set at 90°. A spring gauge was used to record the strength in the subject's dominant leg. Reaction time was measured in milliseconds with a simple reaction time task, using a light as the stimulus and depression of a switch by the hand as the response. Postural sway was measured using a swaymeter that measured displacement of the body at the level of the waist. Testing was performed with the subject standing in the center of a foam rubber mat (70 × 62 × 15 cm).

These tests were included because, along with assessments of vision, they provide direct measures of the functional capacity of the physiological systems that play important roles in the control of postural stability, and take into account both "normal" age-related functional declines and any additional impairments resulting from medical conditions, whether diagnosed or not.[2] In previous studies we have found that these tests have good test-retest reliability[21,22] and discriminate between fallers and nonfallers with sensitivities and specificities over 75% .[3,23]

### Falls

The subjects were followed up over 1 year to determine the incidence of falls. Falls were defined as events that resulted in a person coming to rest unintentionally on the ground or other lower level, not as the result of a major intrinsic event (such as a stroke) or overwhelming hazard.[3] Questionnaires were given to subjects each month, seeking details on the number of falls in the past month, such as the location and cause and any injuries suffered.

### Statistical Analysis

Pearson correlations were used to assess the associations among the visual measures and between the visual measures and age. Analysis of covariance procedures were used to assess differences in the means of the vision and sensorimotor measures between the faller and nonfaller groups while controlling for age. For variables with right skewed distributions, logs of variables were analyzed. Relative risks for multiple falls for visual test scores in the highest (worst performance) quartile were calculated using the Mantel-Haenszel procedure, adjusting for age in three age bands. Stepwise discriminant function analysis was then used to determine which visual and sensorimotor measures discriminated between the multiple and nonmultiple fallers. This categorization was used because it has frequently been found that multiple falls are more likely to indicate physiological impairments and chronic conditions.[1–3,5] Using our functional capacity model, we were able to constrict the number of variables required for inclusion in the multivariate analysis: five measures representing the domains of vision, sensation, strength, speed, and balance. This represents one variable for every 30 cases, which is above the suggested minimum number of 10.[24] After deriving the discriminant function, cross-validation was carried out using the jackknife procedure. The data were analyzed using SPSS for Windows.[25]

## RESULTS

### Vision and Age and Sex

The prevalence of visual impairment in this sample was similar to that reported in large population studies.[3,26–28] Ten subjects (6.4%) had high-contrast visual acuity of 6/15 or worse, and seven (4.5%) had high-contrast visual acuity of 6/18 or worse. Table 1 shows that all the visual measures, with the exception of visual field angle, declined significantly with age. Men performed worse than women in the distant MET test ($t_{154} = 2.09$, $P < .05$), but in all other tests there were no sex differences. The subjects recruited randomly using the electoral roll performed similarly to the subjects recruited from the retirement village in each vision test, so all results for these two samples were combined.

### Associations Among the Visual Measures

Table 2 shows the associations among the visual measures. Binocular visual acuity and visual acuity in the better eye were very strongly correlated ($r = 0.96$ and $r = 0.95$ for high- and low-contrast acuity respectively), so only data for binocular acuity are reported. Moderate-to-strong associations were evident among the visual acuity, contrast sensitivity, and depth perception tests. Of particular interest, visual acuity in the worse eye was more strongly associated with the two measures of depth perception, than was binocular visual acuity, which indicates that good vision in both eyes is important for depth perception.

Performances in the two versions of the MET were only moderately associated ($r = 0.70$); however, when comparing decibel scores for these tests, there was good agreement, in that 87 subjects (56%) scored within 1 decibel and 120 (77%) scored within 2 decibels for both tests. There was also only a moderate correlation ($r = 0.58$) between depth perception measured with the Howard-Dohlman apparatus and the Frisby Stereotest; however, the two tests were in good agreement in identifying those with significant depth perception impairment, in that, of the 37 subjects in the highest quartile range for the Frisby Stereotest (disparities ≥215 seconds of arc), 23 (62.2%) were also in the highest quartile for depth perception (error in matching rods ≥2.4 cm). In comparison, of the 117 subjects with Frisby disparities <215 seconds, only 15 (12.8%) were in the highest quartile for depth perception $\chi^2 = 36.8$, $df = 1$, $P < .001$). Visual field angle was weakly but significantly associated with the other visual function measures.

### Visual Risk Factors for Falls

One hundred and forty eight subjects (94.9%) were available at follow-up; two subjects died and one withdrew from the study. A further five subjects had Short Portable Mental Status Questionnaire scores ≤7 and were excluded from the follow-up phase. Sixty-four subjects (43.2%) reported one or more falls. Of those who fell, 32 fell once only and 32 fell two or more times. The mean ages of the nonfallers, once-only fallers, and multiple fallers were 75.9 (SD = 5.0), 75.7 (SD = 5.1), and 78.2 (SD = 5.4), respectively ($F_{2,145} = 2.80$, $P = .064$.

Table 3 shows the mean scores and standard deviations for the visual measures for the nonfallers, once-only

**Table 1. Associations Between the Visual Measures and Age (*r*)**

| Test | *r* |
|---|---|
| Visual acuity—both eyes† | 0.33* |
| Visual acuity—worse eye† | 0.25* |
| Visual acuity (lc)—both eyes† | 0.33* |
| Visual acuity (lc)—worse eye† | 0.26* |
| Contrast sensitivity (near MET)‡ | −0.37* |
| Contrast sensitivity (distant MET)‡ | −0.35* |
| Depth perception§ | 0.32* |
| Frisby Stereotest score‖ | 0.24* |
| Visual field angle¶ | −0.12 |

*$P < .01$.
†Smallest visual angle (minutes) correctly reported at 4 meters.
‡Decibel log contrast.
§Centimeter difference in matching rods.
‖Frisby Stereotest score in sec arc.
¶ Visual angle from eye height to target on floor.
MET = Melbourne Edge Test; lc = low contrast.

**Table 2. Associations Among the Visual Measures (R)**

| Test | Visual Acuity: Both Eyes | Visual Acuity: Worse Eye | Visual Acuity (lc): Both Eyes | Visual Acuity (lc): Worse Eye | Contrast Sensitivity (Near MET) | Contrast Sensitivity (Distant MET) | Depth Perception | Frisby Stereotest | Visual Field Angle |
|---|---|---|---|---|---|---|---|---|---|
| Visual acutiy—both eyes* | — | | | | | | | | |
| Visual acuity—worse eye* | 0.71 | — | | | | | | | |
| Visual acuity (lc)—both eyes* | 0.91 | 0.73 | — | | | | | | |
| Visual acuity (lc)—worse eye* | 0.68 | 0.90 | 0.76 | — | | | | | |
| Contrast sensitivity (near MET)† | −0.62 | −0.51 | −0.64 | −0.57 | — | | | | |
| Contrast sensitivity (near MET)† | −0.70 | −0.56 | −0.69 | −0.61 | 0.69 | — | | | |
| Depth perception‡ | 0.52 | 0.67 | 0.53 | 0.63 | −0.50 | −0.53 | — | | |
| Frisby stereoacuity score§ | 0.46 | 0.56 | 0.49 | 0.57 | −0.46 | −0.58 | 0.58 | — | |
| Visual field angle‖ | −0.26 | −0.19 | −0.22 | −0.17 | 0.27 | 0.22 | −0.22 | −0.23 | — |

*Notes*: correlation coefficients >0.17, significant at $P < .05$; correlation coefficients >0.20, significant at $P < .01$; correlation coefficients >0.25, significant at $P < .001$.
*Smallest visual angle (minutes) correctly reported at 4 meters.
†Decibel log contrast.
‡Centimeter difference in matching rods.
§Frisby Stereotest score in sec arc.
‖Visual angle from eye height to target on floor.
MET = Melbourne Edge Test; lc = low contrast; R = Pearson correlation coefficient.

**Table 3. Visual and Sensorimotor Measures: Non-Faller, Once-Only Faller, Multiple Faller Comparisons**

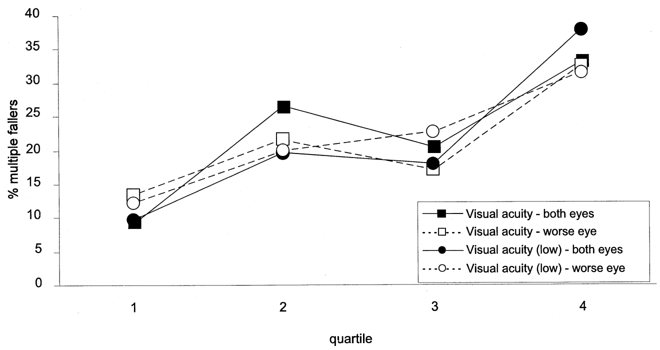
| Test | Nonfallers | 1 Fall | 2+ Falls | Total |
|---|---|---|---|---|
| Visual acuity—both eyes† | 1.30 (0.45) | 1.51 (1.15) | 2.69 (4.10)** | 1.65 (2.06) |
| Visual acuity—worse eye† | 2.91 (3.92) | 3.20 (4.49) | 5.04 (6.24)* | 3.43 (4.68) |
| Visual acuity (lc)—both eyes† | 2.31 (0.96) | 2.66 (2.17) | 4.44 (4.92)** | 2.85 (2.71) |
| Visual acuity (lc)—worse eye† | 5.06 (4.98) | 4.84 (4.43) | 7.19 (6.52)*** | 5.47 (5.28) |
| Contrast sensitivity (near MET)‡ | 20.1 (1. 9) | 20.0 (3.0) | 18.8 (3.7)* | 19.8 (2.7) |
| Contrast sensitivity (distant MET)‡ | 20.7 (2.2) | 20.8 (1.9) | 19.0 (3.8)** | 20.3 (2.7) |
| Depth perception§ | 1.99 (3.25) | 1.98 (3.61) | 5.76 (7.28)** | 2.80 (4.72) |
| Frisby Stereoacuity score‖ | 139 (180) | 132 (190) | 303 (288)** | 173 (219) |
| Visual field angle¶ | 66.7 (7.4) | 67.3 (6.6) | 63.2 (10.8)* | 66.1 (8.2) |
| Proprioception# | 1.75 (1.02) | 1.60 (1.01) | 2.06 (1.51) | 1.79 (1.14) |
| Quadriceps strength (kg) | 29.7 (11.7) | 27.9 (12.0) | 24.5 (10.4)*** | 28.2 (11.6) |
| Reaction time (ms) | 267 (43) | 278 (52) | 311 (80)** | 279 (57) |
| Sway†† | 159 (79) | 143 (70) | 229 (112)** | 171 (90) |

*Significant difference between multiple and nonmultiple fallers after controlling for age ($P < .05$).
**Significant difference between multiple and nonmultiple fallers after controlling for age ($P < .01$).
***Significant difference between multiple and nonmultiple fallers in bivariate analyses ($P < .05$), but not significant after controlling for age.
†Smallest visual angle (minutes) correctly reported at 4 meters.
‡Decibel log contrast.
§Centimeter difference in matching rods.
‖Frisby Stereotestscore in sec arc.
¶Visual angle from eye height to target on floor.
#Degrees difference.
††Millimeter squares traversed by swaymeter pen in 30 seconds.
MET = Melbourne Edge Test; lc = low contrast.

fallers, and multiple fallers. Compared with those who did not fall or fell only once, the multiple fallers performed significantly worse on each visual test. The multiple fallers also performed worse than the nonmultiple fallers in the quadriceps strength, reaction time, and sway tests. With the exception of low-contrast visual acuity in the worse eye and quadriceps strength, these associations remained significant after controlling for age in analysis of covariance procedures.

Figure 1 shows the proportion of subjects who suffered multiple falls in each quartile range of the visual tests. In general, the proportion who fell increased with each quartile reduction in visual function, with the proportion of subjects who fell lowest in the first (best performance) quartile, and highest in the fourth (worst performance) quartile in each test. Table 4 shows the unadjusted and age-adjusted relative risks for multiple falls for test scores in the highest (worst performance) quartile. Based on these analyses, impaired depth perception was the best predictor of multiple falling, followed by reduced low-contrast visual acuity, poor distant-edge-contrast sensitivity, reduced high-contrast visual acuity, and decreased visual field size.

Figure 2 shows the proportion of subjects who suffered multiple falls classified in relation to visual acuity in each eye, using the criteria of Felson et al.,[10] and associated average scores for the depth perception test and Frisby Stereotest. Those with good vision in both eyes suffered the fewest falls. Those with moderate vision in both eyes had a rate of falling similar to those with good vision in one eye and moderate vision in the other and a lower rate than those with good vision in one eye and poor vision in the other. Those with moderate vision in one eye and poor vision in the other or poor vision in both eyes had the highest rate of falls. There was a corresponding increase in poor depth-perception scores with reductions in visual acuity in the worse eye.



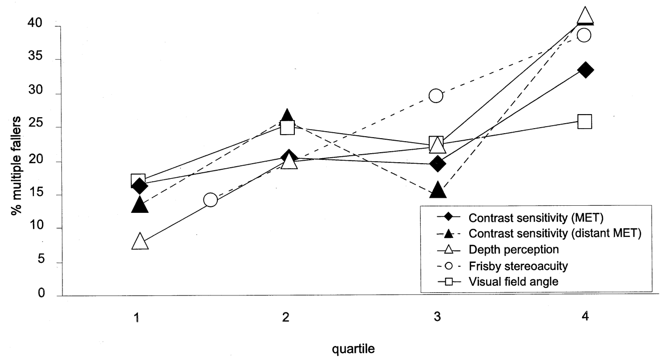




**Figure 1.** Proportion of subjects who suffered multiple falls in each quartile of the visual tests. MET = Melbourne Edge Test.

**Table 4. Relative Risk of Multiple Falling for Persons in the Highest (Worst) Quartile Group for each Visual Test**

| Measure | Criterion* | RR (95% CI) | MH RR† (95%CI) |
|---|---|---|---|
| Visual acuity—both eyes | ≥6/10 | 1.83 (0.98–3.39) | 1.59 (0.85–2.98) |
| Visual acuity—worse eye | ≥6/18 | 1.85 (1.01–3.38) | 1.59 (0.87–2.90) |
| Visual acuity (lc)—both eyes | ≥6/18 | 2.33 (1.29–4.21) | 2.08 (1.17–3.71) |
| Visual acuity (lc)—worse eye | ≥6/36 | 1.69 (0.91–3.15) | 1.45 (0.77–2.71) |
| Contrast sensitivity (near MET) | ≤18 decibels | 1.76 (0.94–3.27) | 1.46 (0.77–2.78) |
| Contrast sensitivity (distant MET) | ≤18 decibels | 2.24 (1.21–4.12) | 1.93 (1.01–3.68) |
| Depth perception | ≥2.4 cm | 2.51 (1.40–4.51) | 2.26 (1.24–4.14) |
| Frisby Stereotest score | ≥215 sec arc | 2.29 (1.25–4.19) | 1.99 (1.11–3.59) |
| Visual field angle | ≤60 degrees | 1.21 (0.62–2.36) | 1.25 (0.63–2.48) |

*Criterion score for lower bound of fourth quartile.
†Risk ratio (RR) adjusted for age using the Mantel-Haenszel (MH) procedure.
CI = confidence interval; MET = Melbourne Edge Test; lc = low contrast.

### Vision, Sensorimotor Function, and Falls

The stepwise discriminant analysis revealed that impaired depth perception, reaction time, and postural sway on the compliant surface were significant and independent risk factors for falls. With depth perception in the model, no other visual measures met the inclusion criteria because their correlations with this measure were too high. The three-variable model discriminated significantly between the nonmultiple and multiple faller groups, as indicated by a Wilk's lambda of 0.82 ($P < .001$) and a canonical correlation for the discriminant function of 0.43. The standardized canonical correlation coefficients (which give an indication of the relative importance of each variable in explaining the variance in the dependent variable) were 0.49 for depth perception, 0.41 for reaction time, and 0.52 for sway. These variables precluded any medical risk factors for falls, such as impaired cognitive status, psychoactive medication use, stroke, and age, from entering the discriminant model because they could not provide any nonredundant information. The final model classified 76% of the cases (74% after cross-validation using the jackknife procedure), with similar sensitivity and specificity.

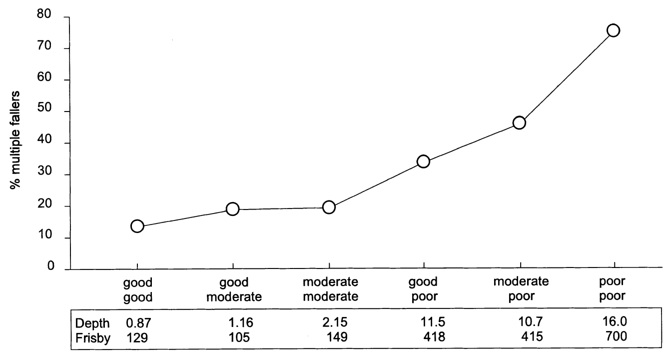



**Figure 2.** Proportion of subjects who suffered multiple falls classified with respect to visual acuity in each eye.
Visual acuity classification: good ≤6/7.5; moderate 6/9–6/24; poor ≥6/30.[10]
Depth perception scores in cm error, Frisby stereoacuity scores in sec arc.

## DISCUSSION

The prevalence of visual impairment of 4% to 6% in this community-dwelling population was similar to that found in other population studies,[3,26–29] but conventional criteria for visual loss (visual acuity of 6/15 or 6/18 or worse) were found to be too imprecise for identifying older people at risk of falls. Persons with only moderate visual acuity loss were also at significantly increased risk of falls as were persons with impairments of visual functions more closely related to hazard detection and mobility requirements.

The ability to accurately judge distances and perceive spatial relationships would appear to be important for making appropriate decisions about navigating through obstacles and hazards in the environment; however, only two previous studies have found that depth perception is a risk factor for falls or fractures,[2,12] although this appears to be due to the omission of depth perception tests in studies of risk factors for falls. We found that poor performances in both the Howard-Dohlman depth perception test and the Frisby Stereotest were among the most significant risk factors for multiple falls of the nine visual measures in our assessment. In addition, those with good vision in both eyes had the lowest rate of falls, whereas those with good vision in one eye and only moderate or poor vision in the other had elevated falling rates—equivalent to those with moderate or poor vision in both eyes.

The strong association between depth perception and falls suggests that stereoacuity is especially important in preventing falls; however, an ability to detect objects is also important, as indicated by the significant associations between contrast sensitivity and visual acuity and falls. Impaired distant contrast sensitivity, in particular, was strongly associated with falls, which may indicate that this measure reflects the necessary requirements for detecting hazards, especially while walking.[16,17] Thus, as suggested by Owen,[30] a loss of edge-contrast sensitivity may impair older people's ability to detect and discriminate between objects in cluttered environments and predispose them to tripping over obstacles within the home and outdoor hazards such as steps, curbs, tree roots, and pavement cracks and misalignments.

In previous studies, we found that low-contrast visual acuity was a better predictor of falls than high-contrast visual acuity.[3,5] In this population, both binocular high- and low-contrast visual acuity were significantly associated with multiple falls but when comparing those with the poorest vision, as defined by the lowest quartile performance in each test, those with poor binocular low-contrast acuity incurred a higher risk of multiple falling (adjusted relative risk = 2.08) than did those with poor high-contrast visual acuity (adjusted relative risk = 1.59). This suggests that the low-contrast test better reflects the visual requirements of everyday situations, where contrast conditions are often suboptimal.

In this study, we used a novel approach to measure visual field loss. This test, which measures a subject's ability to detect a stimulus in the lower visual field, was designed to assess the visual function required to detect objects in the environment that could be tripped over when walking. The test was relatively easy to administer, and fixation loss and false negatives—problems in the administration of visual field tests that can result in a loss of over 30% of subject test results[1]—could be continually monitored. Visual field loss, as measured by this test, was significantly associated with falls, although this association was not as strong as the association between falls and measures of visual acuity, contrast sensitivity, or depth perception. Although the reliability of this test is yet to be determined, this finding of a weak association between visual field loss and falls is consistent with two other studies that have used specialized ophthalmic screening tests.[1,13]

The stepwise discriminant analysis identified depth perception as an independent and significant predictor of falls. When measures of other physiological domains (reaction time and sway on the compliant surface) were included in the model, these variables correctly classified over 75% of cases into nonmultiple and multiple faller groups. The identification of these three measures as the most important predictors is consistent with the proposed three-stage response model for fall avoidance,[31,32] which involves perception of a postural threat (depth perception), selection of an appropriate corrective response (reaction time), and proper response execution (challenged postural sway). The similar-sized standardized discriminant function coefficients suggest that these three measures are of comparable importance in predicting multiple falls.

Because falling is a major problem for older people, the study findings have implications for vision screening assessments for this group. Ophthalmologic, optometric, and clinic-based assessments of risk of falling would be enhanced with the inclusion of the distant MET and the Howard-Dohlman depth perception test. The visual field test could also be of benefit because it has advantages over perimeter tests, which often only measure central visual field loss, with regard to test administration.[13] Further, the findings suggest that a compact, portable assessment screen comprising the dual contrast visual acuity chart, the near MET, and the Frisby Stereotest could also help primary healthcare workers identify older persons at risk of falling.

The study has certain limitations. First, because resources precluded the inclusion of older people who could not speak English, the findings relate only to English-speaking people. Second, because some of the tests were moderately to strongly correlated, it is possible that in identifying the best visual tests for predicting falls, another sample could reveal some differences from the test ranking found here. Therefore, these findings require validation by other studies.

In conclusion, this study provides further evidence that visual impairment, and in particular impaired depth perception, is an important risk factor for falls in older people. Because it has been found that visual loss in older people is correctable in most cases,[26,27,33] simple intervention strategies such as a change of glasses or cataract surgery have the potential to improve contrast sensitivity, stereoacuity, depth perception, and visual acuity in older people. Strategies to maximize vision in both eyes could also be particularly beneficial in preventing falls.

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