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## Relationship Between Fear of Falling and Mobility Varies with Visual Function Among Older Adults

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ORIGINAL ARTICLE: EPIDEMIOLOGY,  
CLINICAL PRACTICE AND HEALTH**Relationship between fear of falling and mobility varies with visual function among older adults**Orna A Donoghue,<sup>1</sup> Harriet Ryan,<sup>3</sup> Eoin Duggan,<sup>4</sup> Ciaran Finucane,<sup>1</sup> George M Savva,<sup>1</sup> Hilary Cronin,<sup>1</sup> James Loughman<sup>5,6</sup> and Rose Anne Kenny<sup>1,2</sup>

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**Aim:** The present study examined the association between vision, fear of falling and fear-related activity restriction, and assessed the effect of vision on the relationship between fear of falling and mobility, using data from a nationally representative sample of community-dwelling adults aged  $\geq 50$  years.

**Methods:** Participants ( $n = 5003$ ) completed an interview and health assessment (including Timed Up-and-Go, vision and cognitive tests). Visual acuity and contrast sensitivity were assessed using an Early Treatment Diabetic Retinopathy Study logMAR chart and Functional Vision Analyzer, respectively. Participants self-reported their vision as excellent, very good, good, fair or poor. They were assigned to no fear of falling, fear without activity restriction and fear with activity restriction groups. Logistic regression models examined the relationship between vision, fear of falling and activity restriction. Linear regression models were used to examine the main and interaction effects of fear of falling, self-reported vision, visual acuity, and contrast sensitivity on mobility after adjusting for confounders.

**Results:** Poorer self-reported vision was independently associated with fear of falling and fear-related activity restriction ( $P < 0.05$ ), but visual acuity and contrast sensitivity were not. Participants with the lowest visual acuity and contrast sensitivity levels, combined with fear-related activity restriction, had slower Timed Up-and-Go than those in the highest visual performance quartiles ( $P < 0.05$ ).

**Conclusions:** Participants' perceptions of visual function were related to fear of falling and activity restriction, but this was not explained by other visual factors measured here. However, poorer visual acuity and contrast sensitivity did moderate the relationship between fear-related activity restriction and mobility, highlighting the importance of a comprehensive vision assessment especially in individuals with fear of falling. **Geriatr Gerontol Int 2013; ••: ••–••.**

**Keywords:** accidental falls, aged, contrast sensitivity, gait, locomotion.

**Introduction**

Fear of falling (FOF) has been defined as "a lasting concern about falling that leads to an individual avoiding activities that he/she remains capable of performing".<sup>1</sup> It affects up to 30% of community-dwelling older adults,<sup>2,3</sup> and occurs in those with and without a history

of falls. It is more common in females, and is independently associated with previous falls, depression, poor self-reported health, reduced social activity and impaired mobility.<sup>4–8</sup> The consequences of fear-related activity restriction include a decline in physical and social function, which can increase the risk of mobility decline, falls and functional disability.<sup>9,10</sup>

Visual impairment can include deficits in visual acuity (VA), contrast sensitivity (CS), visual field (VF) and depth perception (DP). Lower VA, CS and VF have been associated with poorer mobility in community-dwelling adults,<sup>11–16</sup> whereas deficits in VA, CS, VF and DP have been associated with falls, especially recurrent falls.<sup>17–21</sup>

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1 Estimates of the effect of vision on FOF and activity  
2 restriction have been mixed. No independent relation-  
3 ship between self-reported visual impairment and FOF  
4 or associated activity restriction was seen in community  
5 representative samples;<sup>22,23</sup> however, moderate and  
6 severe self-reported visual impairments were indepen-  
7 dently associated with FOF-related activity restriction  
8 among community-dwelling older adults in receipt of  
9 home care services.<sup>24</sup> Deshpande *et al.* found that psy-  
10 chophysically measured visual function, specifically CS  
11 and VA, was not linked to FOF; however, reduced CS  
12 was associated with FOF-related activity restriction  
13 among those without depressive symptoms.<sup>25</sup> Finally,  
14 longitudinal studies have shown that reduced VA pre-  
15 dicted the development of FOF<sup>18</sup> and mobility impair-  
16 ment<sup>26</sup> after 5 years.

17 Currently, studies examining associations between  
18 FOF, vision and mobility are limited. Both FOF and  
19 poor vision have been associated with impaired mobil-  
20 ity, but it is unclear how visual impairment and FOF  
21 interact with respect to mobility impairment, and if so,  
22 which components of vision are most important.  
23 Understanding this would allow specific groups to be  
24 identified and targeted for assessment and intervention.  
25 Therefore, the aims of the present study were first, to  
26 examine the role of vision (self-reported vision, VA and  
27 CS) in FOF and FOF-related activity restriction, and  
28 second, to examine the influence of vision in the rela-  
29 tionship between FOF and mobility, using data from  
30 a nationally representative sample of community-  
31 dwelling adults aged 50 years and older.

## 32 **Methods**

### 33 **Study design**

34 The Irish Longitudinal Study on Aging (TILDA) is a  
35 prospective cohort study of the social, economic and  
36 health circumstances of community-dwelling older  
37 adults in Ireland. Analysis is based on the first wave of  
38 data, collected between October 2009 and July 2011.  
39 The sampling frame is the Irish Geodirectory, a listing of  
40 all residential addresses in the Republic of Ireland. A  
41 clustered sample of addresses was chosen, and house-  
42 hold residents aged  $\geq 50$  years and their spouses/  
43 partners (of any age) were eligible to participate. Ethical  
44 approval was obtained from the Trinity College Dublin  
45 Research Ethics Committee, and participants provided  
46 written informed consent.

47 The study design is described elsewhere.<sup>27</sup> Briefly,  
48 data collection included: (i) a computer-assisted per-  
49 sonal interview that included detailed questions on  
50 sociodemographics, wealth, health, lifestyle, social  
51 support and participation, use of health and social care,  
52 and attitudes to aging; (ii) a self-completion question-  
53 naire; and (iii) a detailed health assessment carried out

54 by research nurses including cognitive, cardiovascular,  
55 mobility, strength, bone and vision tests. In total, 8175  
56 individuals aged  $\geq 50$  years were interviewed, of whom  
57 5037 attended the health center assessment (61.3%).  
58 Inclusion criteria for this analysis was a Mini-Mental  
59 State Examination (MMSE) score  $\geq 18$ , no history of  
60 Parkinson's disease, Alzheimer's disease or dementia,  
61 participation in a health center assessment, and comple-  
62 tion of the FOF and activity restriction questions in the  
63 interview ( $n = 5003$ ).  
64  
65  
66

### 67 **Outcome measures**

#### 68 *Demographics and health*

69 Age, sex and highest level of education attained were  
70 recorded. Primary, secondary and tertiary education  
71 corresponded to  $\leq 8$ , 9–13 and  $\geq 13$  years of education,  
72 respectively. Height and weight were measured, and  
73 body mass index (BMI) was calculated. Participants self-  
74 reported doctor-diagnosed chronic conditions from the  
75 following: heart attack or heart failure or angina, stroke,  
76 diabetes, chronic lung disease, asthma, arthritis, osteo-  
77 porosis, cancer, peptic ulcer, hip fracture, hypertension  
78 and high cholesterol. The number of medications was  
79 also recorded. Depressive symptoms were assessed  
80 using the 20-item Center for Epidemiological Studies  
81 Depression (CES-D) scale, where a score of  $\geq 16$  repre-  
82 sents clinically relevant depressive symptoms.<sup>28</sup>  
83  
84

#### 85 *Fear of falling and falls*

86 Fear of falling was assessed with the question "Are you  
87 afraid of falling?". Those that answered "Yes" were  
88 asked "Do you ever limit your activities, for example,  
89 what you do or where you go, because you are afraid of  
90 falling?". It should be noted that this latter question  
91 might combine both physical and social activity limita-  
92 tions. Similar questions have been used in previous  
93 studies,<sup>3,23,29</sup> and allowed participants to be classified  
94 into three groups: (i) no FOF; (ii) FOF, but no activity  
95 restrictions (FOF-NAR); and (iii) FOF with activity  
96 restrictions (FOF-AR). Participants were also asked how  
97 many times they had fallen in the previous year.  
98

#### 99 *Cognitive function*

100 Participants completed the MMSE,<sup>30</sup> which assesses  
101 global cognition (maximum score 30). A letter fluency  
102 task (list as many words as possible beginning with "F"  
103 in 1 min) measured expressive language and executive  
104 function,<sup>31</sup> and a computer-based choice reaction time  
105 test measured processing speed.<sup>32</sup> In this test, partici-  
106 pants depressed a button, released it in response to an  
107 on-screen stimulus and pressed the appropriate target  
108 button (this occurred approximately 100 times). The

1 mean time from appearance of the stimulus to pressing  
2 this button was the choice reaction time. Both verbal  
3 fluency and choice reaction time have been shown to be  
4 independent predictors of Timed Up-and-Go (TUG)  
5 performance.<sup>33</sup>

### 6 *Physical function*

8 Maximum grip strength was the highest score from two  
9 tests on each hand using a Baseline hydraulic hand  
10 dynamometer (Fabrication Enterprises, White Plains,  
11 NY, USA). Grip strength declines with age and indicates  
12 overall strength.<sup>34</sup> Mobility was assessed with the TUG  
13 test using a chair with armrests and seat height of  
14 46 cm. Participants were asked to rise from the chair,  
15 walk 3 m at normal pace, turn around, walk back and sit  
16 down again.<sup>35</sup> Walking aids were allowed, and no  
17 instructions were given about the use of participants'  
18 arms. The time taken from the command "Go" to when  
19 the participant sat with their back resting against the  
20 back of the chair was recorded using a stopwatch.

### 21 *Vision*

22 Participants self-reported their vision as excellent, very  
23 good, good, fair or poor;<sup>36</sup> one participant reported  
24 being registered blind and was added to the poor vision  
25 group. A history of cataracts and related surgery, glau-  
26 coma and age related macular degeneration (ARMD)  
27 was also recorded.

28 VA represents a high contrast letter recognition task,  
29 and was assessed using an Early Treatment Diabetic  
30 Retinopathy Study (ETDRS) logMAR chart (Precision  
31 Vision, La Salle, IL, USA) at a viewing distance of  
32 4 m.<sup>37,38</sup> VA was measured psychophysically for both  
33 eyes, using the habitual distance vision correction if  
34 required. For statistical purposes, the best acuity value  
35 measured from either eye was selected and converted  
36 to a Visual Acuity Score (VAS).<sup>38</sup> This score inverts  
37 the logMAR scale using the formula:  $VAS = 100 -$   
38  $50 \times \logMAR$ , so that a VAS of 100 represents a  
39 logMAR score of 0 or 20/20 vision. For each letter that  
40 is read correctly using the ETDRS chart, there is a  
41 corresponding 1-point increase in the VAS. This allows  
42 a more intuitive interpretation of the acuity scores, as  
43 higher values indicate better acuity. The VAS was sub-  
44 sequently expressed in quartiles and deciles.

45 CS represents the ability to distinguish an object from  
46 the background in varying size and contrast conditions.  
47 It was measured in the eye with better VA using a  
48 Functional Vision Analyser (Stereo Optical, Chicago,  
49 IL, USA) under mesopic (3 cd/m<sup>2</sup>) background illumi-  
50 nation conditions. Testing was then repeated for the  
51 same background illumination conditions, but in  
52 the presence of a radial glare source.<sup>39</sup> During the test,  
53 the respondent viewed a Functional Acuity Contrast  
54

Test (FACT), which comprised sinusoidal gratings pre-  
55 sented as Gabor patches at five spatial frequencies of  
56 1.5, 3, 6, 12 and 18 cycles per degree (cpd) respectively.  
57 For each spatial frequency, a series of nine patches were  
58 presented in order of decreasing contrast (0.15 log unit  
59 or 50% loss of contrast between consecutive patches).  
60 Respondents were instructed to indicate if the gratings  
61 tilted to the left (+15°), right (-15°) or upright (0°),  
62 moving from patch 1 to 9 for each spatial frequency  
63 tested, in order of increasing frequency. The CS score  
64 corresponds to the contrast of the last grating that was  
65 accurately identified on each row.

66 Factor analysis was used to reduce the dimension of  
67 the 10 CS scores (each of five frequencies in two glare  
68 conditions). As the CS variables are based on ordinal  
69 scores, factor analysis using a polychoric correlation  
70 matrix was carried out. Two factors were identified and  
71 retained based on their eigenvalues and amount of vari-  
72 ance explained (69.2% in total). Oblique rotation using  
73 the direct oblimin criterion suggested two factors cor-  
74 responding to the contrast sensitivity at high spatial  
75 frequencies (6, 12, 18 cpd) and low spatial frequencies  
76 (1.5, 3, 6 cpd). CS at the middle spatial frequency  
77 (6 cpd) loaded onto both factors (Table 1). No factor  
78 separated the glare from the "no glare" condition. Two  
79 factor scores were derived for each individual corre-  
80 sponding to their "high frequency" and "low frequency"  
81 CS. Each factor score was divided into quartiles and  
82 deciles for use as independent variables in regression  
83 analyses.  
84

### 85 *Statistical analysis*

86 Statistical tests were carried out using Stata v12  
87 (StataCorp LP, College Station, TX, USA). All analyses  
88 were weighted with respect to age, sex and education to  
89 the Quarterly National Household Survey (2010) to  
90 ensure that data were nationally representative. Data  
91 were further weighted by health status (self-reported  
92 health, disability status) and sociodemographic factors  
93 (age, education) to account for those who did not attend  
94 a health assessment. Baseline characteristics of each  
95 group were compared using regression analysis and  
96  $\chi^2$ -tests.

97 Logistic regression analysis was used to examine the  
98 relationship of vision with FOF and FOF-related activity  
99 restriction. VA, CS factors 1 and 2 (all expressed as  
100 deciles), and self-reported vision were entered into sepa-  
101 rate models, which also included the effects of age, sex  
102 and education.

103 Linear regression was then used to examine the asso-  
104 ciations between FOF groups and TUG before and after  
105 adjusting for age, sex, education, BMI, chronic condi-  
106 tions, medications, history of falls in the previous year,  
107 CES-D score, letter fluency, choice reaction time,  
108 maximum grip strength and doctor-diagnosed cataracts  
109



**Table 1** Rotated factor loadings and unique variance for each contrast sensitivity variable

|               | Factor 1<br>(high spatial<br>frequencies) | Factor 2<br>(low spatial<br>frequencies) | Unique<br>variance |
|---------------|---|--|--------------------|
| CS (no glare) |   |  |                    |
| 1.5 cpd       | -0.1555                                   | 0.7598                                   | 0.5312             |
| 3 cpd         | 0.088                                     | 0.7823                                   | 0.3029             |
| 6 cpd         | 0.4526                                    | 0.472                                    | 0.3324             |
| 12 cpd        | 0.839                                     | 0.0079                                   | 0.2885             |
| 18 cpd        | 0.6489                                    | -0.1213                                  | 0.6526             |
| CS (glare)    |   |  |                    |
| 1.5 cpd       | -0.0798                                   | 0.78                                     | 0.4551             |
| 3 cpd         | 0.1751                                    | 0.7176                                   | 0.3133             |
| 6 cpd         | 0.5783                                    | 0.3742                                   | 0.2825             |
| 12 cpd        | 0.8757                                    | -0.0286                                  | 0.2604             |
| 18 cpd        | 0.6793                                    | 0.025                                    | 0.5189             |

High loadings ( $\geq 0.3$ ) are shown in bold. cpd, cycles per degree; CS, contrast sensitivity.

(treated or untreated), glaucoma and ARMD. TUG was not normally distributed and was therefore log transformed for analysis.

Next, the visual variables (self-reported vision and quartiles of VA, high and low frequency CS) were added to the regression models separately and simultaneously to assess the independent effect of each aspect of visual function on mobility, and to explore whether visual impairment mediated any of the relationship between FOF and mobility.

Finally, moderation effects were examined by adding interaction terms between FOF and each vision variable to the regression models. Marginal mean TUG times from these models were plotted to graphically explore these interactions after adjusting for all covariates.

Complete data was available for 4498 participants (89.9%), and complete case analysis was used for multivariate analyses. Significance level was set at  $P < 0.05$ .

## Results

Baseline characteristics of the no FOF ( $n = 3974$ ), FOF-NAR ( $n = 727$ ) and FOF-AR ( $n = 302$ ) groups are provided in Table 2. Both FOF groups had more participants aged  $\geq 75$  years, were more likely to be female, have greater comorbidities and poorer physical health, mental health, cognitive function, and visual function than the no FOF group ( $P < 0.001$ ). Most pronounced differences were observed in the FOF-AR group.

Psychophysical measures of vision (deciles of VA and CS) were not associated with FOF after adjusting for

age, sex and education ( $P > 0.05$ ; Fig. 1). However, there was a statistically significant worsening of FOF with poorer self-reported vision. This was particularly marked among those who rated their vision as “fair” or “poor” ( $P < 0.05$ ). An identical relationship was observed for FOF-related activity restriction.

Both FOF groups had slower TUG times than the no FOF group in univariate and multivariate analysis ( $P < 0.001$ ; models 1 and 2, Table 3). The exponent of additive coefficients for log(TUG) can be interpreted as multiplicative coefficients for TUG, and so the coefficients in Table 3 correspond to those in the FOF-NAR group completing TUG 3.8% more slowly than those without FOF, whereas those with FOF-related activity restriction completed TUG 13.7% more slowly.

Poorer self-reported vision was independently associated with slower TUG after adjusting for all covariates ( $P < 0.05$ ), whereas VA and CS had no independent effect on TUG performance (results not shown). Similar effects were observed when all psychophysical and self-reported vision variables were entered simultaneously (model 3, Table 3). However, adjusting for these vision variables had little effect on the FOF coefficients, and therefore did not explain the relationship between FOF, activity restriction and mobility.

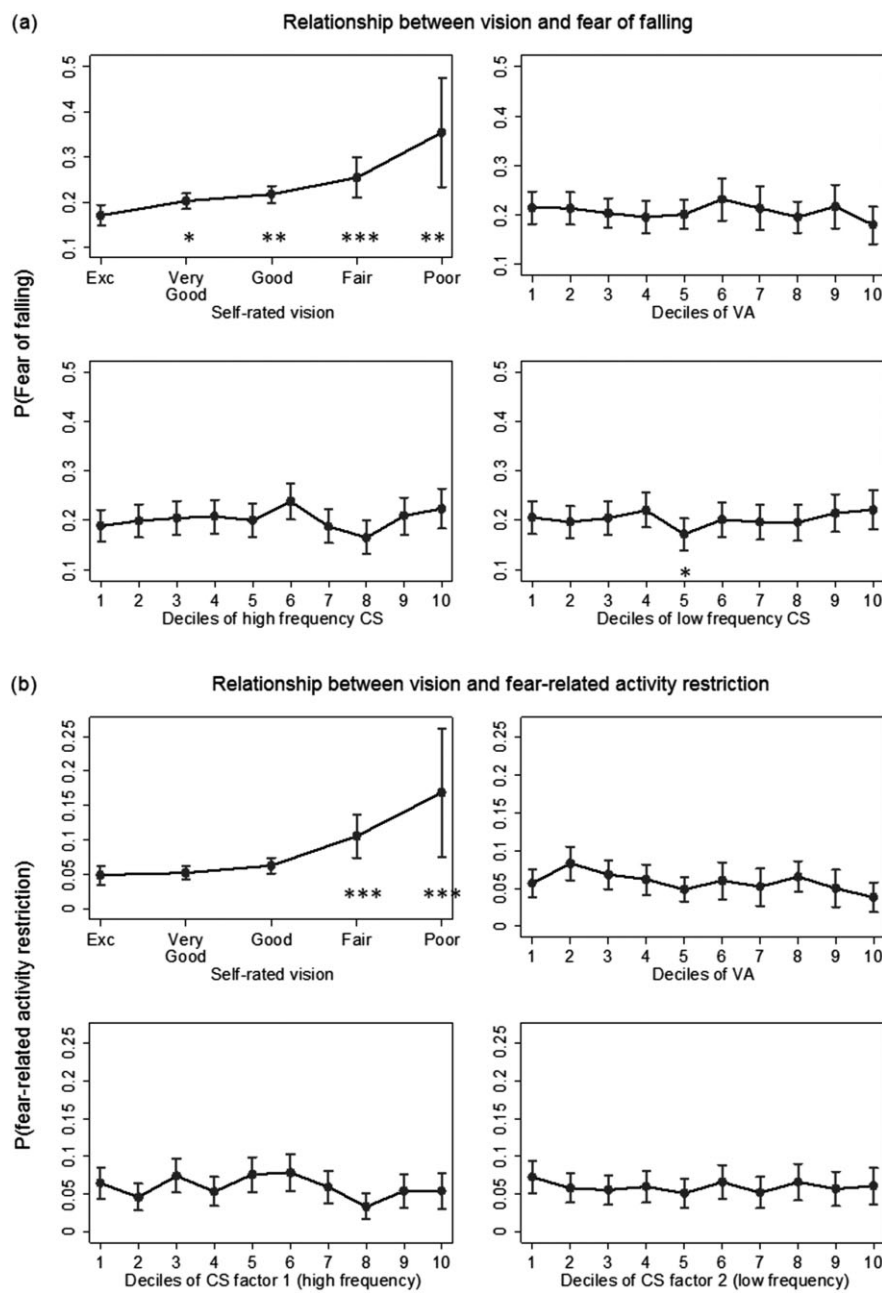
Interaction effects for FOF with VA, high frequency and low frequency CS were statistically significant in the FOF-AR group ( $P < 0.001$ ), but interaction effects with self-reported vision were not (Fig. 2). Specifically, marginal interaction plots adjusting for covariates show that individuals with FOF-related activity restriction who were in the lowest quartile of VA and CS had slower TUG than those in the highest quartiles ( $P < 0.05$ ).

Fear of falling, vision and mobility

**Table 2** Baseline characteristics of no fear of falling, fear of falling with activity restriction and fear of falling with no activity restriction groups

|                              | no FOF<br>(n = 3974)<br>Mean ± SD / n (%) | FOF-NAR<br>(n = 727)<br>Mean ± SD / n (%) | FOF-AR<br>(n = 302)<br>Mean ± SD / n (%) | Total<br>(n = 5003)<br>Mean ± SD / n (%) |
|------------------------------|---|---|--|--|
| Age (years)                  |   |   |  |  |
| 50–64                        | 2657 (64.1)                               | 396 (46.9)                                | 159 (43.8)                               | 3212 (59.8)                              |
| 65–74                        | 1016 (22.8)                               | 217 (23.4)***                             | 98 (25.6)***                             | 1331 (23.1)                              |
| ≥75                          | 301 (13.1)                                | 114 (29.7)                                | 45 (30.6)                                | 460 (17.1)                               |
| Sex (female)                 | 1938 (45.3)                               | 557 (76.1)***                             | 218 (71.4)***                            | 2713 (52.2)                              |
| Education (%)                |   |   |  |  |
| Primary                      | 805 (33.7)                                | 190 (45.9)                                | 94 (51.9)                                | 1089 (37.0)                              |
| Secondary                    | 1675 (45.8)                               | 300 (39.5)***                             | 117 (35.5)***                            | 2092 (44.0)                              |
| Tertiary                     | 1492 (20.5)                               | 237 (14.6)                                | 91 (12.6)                                | 1820 (19.0)                              |
| BMI (kg/m <sup>2</sup> )     | 28.54 ± 4.78                              | 29.10 ± 5.51*                             | 29.49 ± 5.86*                            | 28.70 ± 5.00                             |
| Chronic conditions           |   |   |  |  |
| 1 condition                  | 1199 (29.4)                               | 189 (23.9)                                | 49 (13.6)                                | 1437 (27.3)                              |
| 2 conditions                 | 881 (22.5)                                | 192 (24.3)***                             | 75 (21.1)***                             | 1148 (22.7)                              |
| ≥3 conditions                | 859 (23.4)                                | 234 (38.6)                                | 143 (56.0)                               | 1236 (28.3)                              |
| Medications                  | 1.23 ± 1.08                               | 1.71 ± 1.04***                            | 2.08 ± 1.01***                           | 1.37 ± 1.10                              |
| History of falls (%)         |   |   |  |  |
| 1 fall                       | 467 (11.8)                                | 133 (16.8)                                | 52 (18.2)                                | 652 (13.1)                               |
| ≥ 2 falls                    | 205 (5.4)                                 | 86 (11.9)***                              | 49 (14.3)***                             | 340 (7.1)                                |
| Depressive symptoms          | 5.06 ± 6.34                               | 7.93 ± 8.47***                            | 10.94 ± 10.21***                         | 5.96 ± 7.29                              |
| MMSE                         | 28.37 ± 1.87                              | 28.13 ± 2.05                              | 27.72 ± 1.99***                          | 28.28 ± 1.92                             |
| Letter fluency               | 11.53 ± 5.00                              | 10.62 ± 4.61***                           | 10.79 ± 5.03*                            | 11.33 ± 4.96                             |
| Choice reaction time (ms)    | 825 ± 280                                 | 907 ± 370***                              | 935 ± 320***                             | 846 ± 301                                |
| Max grip strength (kg)       | 28.65 ± 9.95                              | 21.83 ± 8.24***                           | 21.17 ± 9.12***                          | 26.99 ± 10.09                            |
| TUG (s)                      | 8.58 ± 1.81                               | 9.72 ± 2.57***                            | 11.41 ± 5.05***                          | 8.97 ± 2.46                              |
| Cataracts – with surgery (%) | 160 (4.9)                                 | 53 (12.8)                                 | 28 (13.1)                                | 241 (6.8)                                |
| Cataracts – no surgery (%)   | 126 (4.2)                                 | 48 (7.1)***                               | 18 (7.1)***                              | 192 (4.9)                                |
| Glaucoma (%)                 | 71 (1.9)                                  | 21 (3.5)                                  | 13 (5.3)**                               | 105 (2.4)                                |
| ARMD (%)                     | 57 (1.7)                                  | 22 (3.4)*                                 | 5 (1.2)                                  | 84 (2.0)                                 |
| Self-reported vision (%)     |   |   |  |  |
| Excellent                    | 894 (19.7)                                | 121 (14.7)                                | 48 (11.3)                                | 1063 (18.2)                              |
| Very good                    | 1522 (37.8)                               | 287 (36.7)                                | 100 (29.0)                               | 1909 (37.0)                              |
| Good                         | 1273 (33.4)                               | 255 (36.3)                                | 104 (35.5)***                            | 1632 (34.1)                              |
| Fair                         | 252 (7.6)                                 | 53 (9.7)                                  | 39 (15.9)                                | 344 (8.6)                                |
| Poor                         | 33 (1.4)                                  | 11 (2.6)                                  | 11 (8.3)                                 | 55 (2.1)                                 |
| VA (VAS)                     | 96 ± 10                                   | 95 ± 10*                                  | 93 ± 9***                                | 96 ± 10                                  |
| CS (no glare)                |   |   |  |  |
| 1.5 cpd                      | 36.4 ± 19.9                               | 34.9 ± 21.1                               | 34.0 ± 20.8                              | 36.0 ± 20.2                              |
| 3 cpd                        | 67.2 ± 32.0                               | 62.7 ± 31.3**                             | 58.6 ± 34.3**                            | 65.9 ± 32.2                              |
| 6 cpd                        | 31.9 ± 25.6                               | 28.0 ± 24.5**                             | 26.1 ± 25.8**                            | 30.8 ± 25.5                              |
| 12 cpd                       | 6.6 ± 9.6                                 | 5.0 ± 9.1***                              | 5.2 ± 14.1                               | 6.2 ± 9.9                                |
| 18 cpd                       | 0.8 ± 2.7                                 | 0.6 ± 2.0*                                | 0.2 ± 1.1***                             | 0.7 ± 2.5                                |
| CS (glare)                   |   |   |  |  |
| 1.5 cpd                      | 38.2 ± 19.1                               | 35.4 ± 18.1**                             | 33.9 ± 19.6**                            | 37.5 ± 19.0                              |
| 3 cpd                        | 69.4 ± 32.8                               | 63.9 ± 32.1**                             | 57.1 ± 33.8***                           | 67.6 ± 33.0                              |
| 6 cpd                        | 32.2 ± 25.1                               | 28.7 ± 25.4**                             | 24.3 ± 22.5***                           | 31.1 ± 25.1                              |
| 12 cpd                       | 6.8 ± 10.2                                | 5.6 ± 9.5**                               | 4.2 ± 7.6***                             | 6.5 ± 9.9                                |
| 18 cpd                       | 0.8 ± 2.7                                 | 0.6 ± 2.8*                                | 0.2 ± 1.0***                             | 0.7 ± 2.6                                |

\**P* < 0.05; \*\**P* < 0.01; \*\*\**P* < 0.001. Prevalence is weighted by age, sex and education to the Quarterly National Household Survey (2010) to ensure that data were nationally representative and further weighted by health status and sociodemographic factors to account for those who did not attend a health assessment. Regression analysis for continuous variables; chi squared analysis for categorical variables. No fear of falling (FOF) group was compared to the fear of falling with no activity restriction (FOF-NAR) group and the fear of falling with activity restriction (FOF-AR) group. ARMD, age-related macular degeneration; BMI, body mass index; cpd, cycles per degree; CS, contrast sensitivity; FOF, fear of falling; MMSE, Mini-Mental State Examination; SD, standard deviation; TUG, Timed Up-and-Go; VA, visual acuity; VAS, visual acuity scale.



**Figure 1** Relationship between (a) vision and fear of falling; (b) vision and fear-related activity restriction. Lowest deciles reflect lowest level of contrast sensitivity (CS) and visual acuity (VA) performance. Logistic regression analysis adjusted for age, sex and education. \* $P < 0.05$ ; \*\* $P < 0.01$ ; \*\*\* $P < 0.001$  (indicates a category that is a significant predictor of the outcome relative to the highest level of visual function). P(fear of falling), probability of reporting fear of falling; P(fear-related activity restriction), probability of reporting fear-related activity restriction.

## Discussion

The findings of the current study show that poorer self-reported vision was independently associated with FOF and FOF-related activity restriction, but that psychophysically measured vision (VA, CS) was not. FOF and self-reported vision were also linked to mobility impairment, but mesopic and photopic vision did not explain much of the relationship between FOF and mobility. These findings show that although participants' perceptions of visual function are related to FOF and activity restriction, other visual (e.g. DP, VF, eye disease) or non-visual factors (e.g. cognitive processing)

could be important determinants of self-reported vision.

However, reduced psychophysical visual function was associated with slower TUG in the FOF-related activity restriction group, illustrating the moderating effect of psychophysical vision on the relationship between FOF and mobility. FOF is associated with poorer function across multiple domains (physical, psychological, cognitive), and this is more pronounced in those with activity restriction. It is possible that reduced vision compounds the existing deficits in this group, resulting in greater mobility impairment. Viljainen *et al.* reported that when multiple self-reported sensory deficits



Fear of falling, vision and mobility

**Table 3** Univariate and multivariate linear regression showing relationship between fear of falling, vision and log(Timed Up-and-Go) after adjusting for covariates

| log(TUG)                                  | Model 1<br>β (95% CI)   | Model 2<br>β (95% CI)   | Model 3<br>β (95% CI)    |
|---|-------------------------|-------------------------|--------------------------|
| No FOF                                    | Reference               | Reference               | Reference                |
| FOF-NAR                                   | 0.113 (0.086, 0.141)*** | 0.037 (0.017, 0.058)*** | 0.034 (0.012, 0.055)**   |
| FOF-AR                                    | 0.237 (0.183, 0.290)*** | 0.128 (0.084, 0.172)*** | 0.115 (0.073, 0.158)***  |
| Self-reported vision                      |                         |                         |                          |
| Excellent                                 | –                       | –                       | Reference                |
| Very good                                 | –                       | –                       | 0.014 (–0.001, 0.029)    |
| Good                                      | –                       | –                       | 0.017 (0.001, 0.033)*    |
| Fair                                      | –                       | –                       | 0.040 (0.009, 0.071)*    |
| Poor                                      | –                       | –                       | 0.097 (0.020, 0.175)*    |
| VA (VAS)                                  |                         |                         |                          |
| Lowest (20–93)                            | –                       | –                       | –0.018 (–0.038, 0.002)   |
| 2 <sup>nd</sup> quartile (94–99)          | –                       | –                       | –0.012 (–0.029, 0.004)   |
| 3 <sup>rd</sup> quartile (100–103)        | –                       | –                       | –0.021 (–0.038, –0.004)* |
| Highest (104–115)                         | –                       | –                       | Reference                |
| CS factor 1 (high frequencies)            |                         |                         |                          |
| Lowest (–1.44 to –0.75)                   | –                       | –                       | 0.002 (–0.023, 0.029)    |
| 2 <sup>nd</sup> quartile (–0.75 to –0.17) | –                       | –                       | –0.005 (–0.027, 0.017)   |
| 3 <sup>rd</sup> quartile (–0.17 to 0.54)  | –                       | –                       | –0.014 (–0.031, 0.003)   |
| Highest (0.54 to 7.80)                    | –                       | –                       | Reference                |
| CS factor 2 (low frequencies)             |                         |                         |                          |
| Lowest (–2.29 to –0.64)                   | –                       | –                       | 0.007 (–0.020, 0.034)    |
| 2 <sup>nd</sup> quartile (–0.64 to –0.17) | –                       | –                       | 0.012 (–0.010, 0.034)    |
| 3 <sup>rd</sup> quartile (–0.17 to –0.61) | –                       | –                       | 0.009 (–0.010, 0.027)    |
| Highest (0.61 to –3.85)                   | –                       | –                       | Reference                |

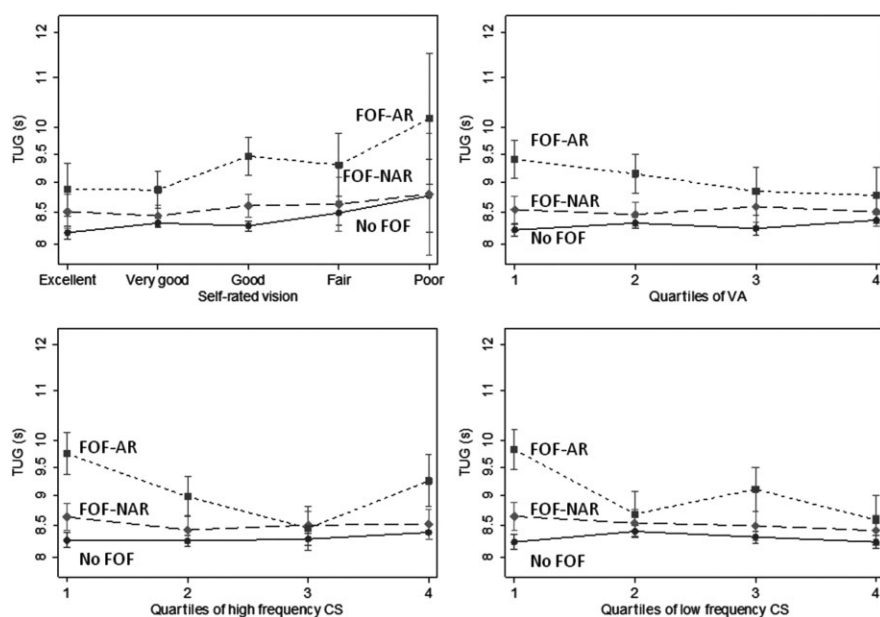
\**P* < 0.05; \*\**P* < 0.01; \*\*\**P* < 0.001. Model 1: Unadjusted linear regression. Model 2: Linear regression adjusted for age, sex, body mass index, education, medications, chronic conditions, history of falls, depressive symptoms, choice reaction time, word fluency, maximum grip strength, history of cataracts (treated or untreated), glaucoma, age related macular degeneration. Model 3: all vision variables entered simultaneously and adjusted as for Model 1. β, coefficient; CI, confidence intervals; cpd, cycles per degree; CS, contrast sensitivity; FOF, fear of falling; FOF-AR, fear of falling with activity restriction; FOF-NAR, fear of falling with no activity restriction; TUG, Timed Up-and-Go; VA, visual acuity; VAS, visual acuity scale.

combined with FOF, there is an increased risk of developing walking difficulties.<sup>40</sup>

The ability to maintain dynamic postural stability requires an interaction between the sensory and motor systems. TUG involves transfers, turning and walking, and therefore requires muscle strength and balance; therefore, it was speculated that vision might play a more important role in this task compared with straight line walking. In challenging balance situations, an individual relies on the visual system, particularly CS and DP, to gain information about body positions, movements and the environment to maintain stability.<sup>41</sup> CS might also reflect the ability to detect and recognise objects in the environment, and see ground level obstacles more accurately.<sup>42</sup> Visual functions, such as VA and CS, decrease with age<sup>43,44</sup> as do cognitive processes such as executive function, processing speed and visual attention.<sup>45,46</sup> Similar cognitive deficits have been observed in recurrent fallers, and could reflect a difficulty in coordination of the

visual, cognitive and motor aspects required to negotiate the everyday environment.<sup>47</sup> If an individual with reduced vision, especially CS, does not detect all of the environmental and body position information available, this might predispose them to cautious gait and/or a greater risk of falling. If a vision deficit is combined with FOF or other age-related factors, such as increased risk of osteoporosis, low muscle tone, poorer muscle strength, slow reaction times and postural instability, the risk of mobility impairment, falls and injury could be amplified even further.

Owsley *et al.* found that age and CS at 6 cpd were the best predictors of the ability to detect and identify real-world targets, such as faces, signs and objects.<sup>48</sup> Although the present results suggest that CS at both high and low frequencies are important for mobility, we are unaware of any research that has identified which spatial frequencies relate most closely to specific environmental objects that might affect mobility.



**Figure 2** Interaction effects between fear of falling (FOF) and each vision variable with respect to their effect on functional mobility (measured by Timed Up-and-Go [TUG] time). Lowest quartiles reflect lowest level of CS and VA performance. Linear regression analysis adjusted for age, sex, body mass index, education, medications, chronic conditions, history of falls, depressive symptoms, choice reaction time, word fluency, maximum grip strength, history of cataracts (treated or untreated), glaucoma, age related macular degeneration. cpd, cycles per degree; CS, contrast sensitivity; FOF-AR, fear of falling with activity restriction; FOF-NAR, fear of falling with no activity restriction; VA, visual acuity.

The main strength of the present study was the detailed, psychophysical measures of CS and VA obtained in a large, nationally representative population. However, the study also had some limitations. Given the restraints inherent in a multidisciplinary study of this size (e.g. participant time, cost), a fully comprehensive assessment within each domain was not feasible. Therefore, measures of visual function, such as VF and DP, along with other aspects of sensory function were not obtained, although they have been associated with FOF, falls and mobility in previous research, and therefore might have added to the analysis. Also, only those who attended a health assessment center were included, making the results directly applicable to community-dwelling adults, but not those who are housebound or resident in nursing homes and other facilities. These individuals are likely to have greater mobility limitations and to be in poorer health, so the relationship between FOF, vision and mobility might be different in this group. Finally, CS was tested under mesopic conditions, so the CS results are only directly applicable to low light conditions.

VA is the most commonly measured visual function, but it might not be the best indicator of functional vision. Everyday living involves low contrast conditions, suboptimal lighting and sources of glare, so including CS measurement could provide a more comprehensive visual assessment. Individual variations in CS have direct implications for older adults in terms of environmental modifications (floor surfaces, lighting), behaviors (switching on lights especially at night) and treatment of conditions associated with poor CS (e.g. cataract). Although reduced vision does not affect the mobility of those with no FOF or FOF without activity

restriction, it does make those with FOF-related activity restriction more cautious, as evidenced by slower TUG. Reduced vision and FOF can lead to a self-imposed activity restriction, which can lead to social isolation, mobility limitations, loss of independence and increased fall risk. Therefore, the results of the present study suggest that clinicians should consider a comprehensive vision assessment including VA and CS, particularly in individuals with FOF, to prevent this transition to reduced activity.

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## Disclosure statement

The authors declare no conflict of interest.

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OA Donoghue *et al.*

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