The Decline in Attentional Visual Fields over Time among Older Participants in the Salisbury Eye Evaluation Driving Study

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Purpose. The loss of attentional visual field (AVF) has been linked to poor mobility and car crashes. We investigated the risk factors associated with a decrease in AVF over time among participants in the Salisbury Eye Evaluation Driving Study (SEEDS).

Methods. In a longitudinal cohort of 968 individuals ages 67 to 87, demographic, medical, visual, and cognitive factors were obtained at baseline (2005–2006) and follow-up (2007–2008) using structured medical questionnaires and onsite examinations. Using the standard deviation for the difference in AVF over 2 years of 4.3°, two subgroups were created: Those who lost 5° or more in two years and those who had no loss (i.e., loss of 5° or less, or no loss). Age-adjusted and multivariate odds ratios (OR) with 95% confidence intervals (95% CI) for each explanatory factor were determined using logistic regression.

Results. The overall change in AVF was –0.34° (SD = 4.32), which was a significant decline from baseline. Of the population, 14% lost 5° or more of AVF. The following determinants were associated with a minimum loss of 5° over 2 years: female sex (OR = 1.59, $P = 0.03$), history of stroke (OR = 1.90, $P = 0.03$), depression (OR = 1.07, $P = 0.02$), a lower baseline Trails A and B scores (OR = 1.09, $P = 0.003$ and OR = 1.02, $P = 0.02$, respectively), and lower baseline visual acuity (OR = 1.21, $P = 0.03$). In addition, decline was related to a lower baseline measure of auditory attention (OR = 1.14, $P = 0.007$) and lower baseline visual fields in the central 20° (OR = 1.24, $P = 0.01$).

Conclusions. Loss in AVF over time is related independently to decrements in cognition and vision. The higher odds of loss in female subjects, independent of these factors, deserves further research. (*Invest Ophthalmol Vis Sci.* 2013;54:1839–1844) DOI:10.1167/iovs.11-8874

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Attentional visual field (AVF), often called useful field of view (UFOV), measures the size of the visual field (VF) over which a person can detect and localize a peripheral target in the presence of a fixed central target (divided attention), with or without other distractors (selective attention).[1] The importance and relevance of the AVF lies in the fact that the ability to extract visual information within a glance requires higher order cognitive processing, rather than solely visual sensory input, an important feature in mobility and driving.[2] In fact, a lower AVF value, or poorer performance on tasks that comprise the AVF score, has been linked solidly to car crashes[3] and driving performance,[4–6] including state recorded accidents, on-road driving, and simulated driving performances.[1] On an even more basic functional level, a lower AVF score has been associated with an impact on everyday tasks, including activities of daily living[7] and decreased mobility.[8]

The original test was developed to assess processing speed at a fixed VF extent by Ball et al.[3] However, our test measures the extent of the attentional field by adjusting the eccentricity of the targets and testing performance at different locations using a given presentation time for the stimulus. Our previous study had analyzed the predictors of AVF size itself, using cross-sectional data.[9] According to Hassan et al. in 2008, the following characteristics were associated independently with a lower baseline AVF size in our older, driving population: older age, female sex, black race, fewer years of education, depression, lower score on an auditory test of attention (brief test of attention), lower score on a test of executive function (Trails B), lower visual acuity (VA), lower contrast sensitivity in the better eye, and VF loss in central 20° radius.[9] Whether these factors are predictive of a decline in AVF, or simply are characteristics associated with persons who have a lower baseline AVF size, is not known.

To our knowledge, no studies to date have documented the change in AVF over time, nor confirmed factors that are predictive of the loss in AVF over time. Thus, the purpose of our study was to analyze possible baseline determinants in predicting a decline in AVF size over time using the Salisbury Eye Evaluation Driving study (SEEDS), a 2-year prospective cohort study of drivers ages 67 to 87 living in the Greater Salisbury Metropolitan Area.

Methods

Population

The SEEDS is a prospective cohort study of vision, cognition, and driving behavior of 1425 registered drivers ages 67 to 87 living in the greater Salisbury Metropolitan area who were followed over a 2-year period. Details on recruitment have been reported previously[9,10] and are summarized here. Of the 1425 participants enrolled at baseline, 13 individuals were excluded due to missing ($n = 11$) or inaccurate measurements of baseline average AVF (coughing and touch screen

problems, $n = 2$). Based on our definition of decline in AVF, a further 169 participants were excluded due to baseline average AVF values of ≤5.0, already so low that they had no opportunity to decline further. As a result, 1243 eligible individuals remained. From this, 275 (22%) were not included because they did not return at 2 years, giving a final data sample of 968 individuals participants. All procedures and protocols were approved by the Johns Hopkins University Institutional Review Board and met with the requirements of the Declaration of Helsinki.

Data Collection

Data for this report were collected at baseline (July 2005–June 2006) and then again at 2-year follow-up (July 2007–June 2008). The details of obtaining specific demographic, lifestyle, medical, visual, and cognitive measures have been described previously,[9] but will be mentioned briefly.

Demographic, Lifestyle, and Medical Background Characteristics. Baseline demographic characteristics (age, sex, race, level of education) were obtained using structured questionnaires administered at the participant's home and were based on self-report. Medical comorbidities (diabetes, arthritis, stroke, Parkinson's disease, depression) at baseline on all individuals and again at 2-year follow-up were collected via structured medical history questionnaires and the Geriatric Depression Scale questionnaire.[11] Depression was graded as a continuous variable based on the number of reported depressive symptoms out of a 30 point scale.

Visual Indicators. The detailed protocols of each visual indicator have been reported previously.[9] Briefly, all vision assessments were performed using the participant's normal correction if worn for driving, with the exception of VFs and AVF, where participants were corrected optically to account for shorter distances used in a particular device.

Binocular VA was obtained using a high contrast Early Treatment Diabetic Retinopathy Stud (ETDRS) acuity chart[12] with both eyes open and with their habitual correction. A strict forced-choice procedure was used, which required participants to continue until they missed at least 4 to 5 letters in a row. Binocular VA scores were converted into LogMAR scores.

Monocular contrast sensitivities (CSs) were gathered using the Pelli-Robson letter contrast-sensitivity chart.[13] A forced-choice procedure was used; the participants were required to guess letters until two of the three letters in a triplet were identified incorrectly. We reported number of letters identified correctly, and CS in the better eye was used for the analysis.

Monocular VFs were assessed by using an 81-point, quantify defect screening test strategy on a field perimeter (Humphrey Field Analyzer [HFA]; Carl Zeiss Meditec, Inc., Dublin, CA). The VF results of both eyes were combined using the Nelson-Quigg et al.[14] algorithm to create a binocular VF plot that consisted of 96 points. The number of missed points in the binocular field within the central 20° VF was noted and then used in the analysis.

Attentional Visual Field (AVF). Binocular AVFs were determined by a custom-written program that was modeled after Sekuler and Bennett.[15] The program assessed AVF out to a 20° radius in a divided attention protocol. Individuals sat 35 cm from a touch screen monitor and were corrected optically for the distance. Participants were instructed to fixate a central fixation mark. At a randomly determined time, the fixation mark disappeared and two numbers (between 0 and 9) flashed on the screen, one centrally and one peripherally, in conjunction with seven filled circles (distractors). The participants were asked to identify the numbers orally and then locate the peripheral target via a touch on the touch screen. The peripheral target was presented in one particular area location out of the entire possible area points in each of the four quadrants, which were represented equally throughout the experiment consisting of 24 trials. The targets were not limited to the cardinal axis point only. A parameter estimation by sequential testing (PEST) procedure was used to determine the eccentricity of the peripheral target to be tested on each trial for each of the 4 peripherally located quadrants.[16] A correct response occurred when an individual identified properly both numbers and the location of the peripheral target. From these assessments, a horizontal, vertical, and average AVF score (average of horizontal and vertical scores) were computed, and used for the analysis.

Cognitive Measures. General cognitive status was determined using the standard Mini-Mental Status Exam (MMSE),[17] with a maximum score of 30. The Brief Test of Attention (BTA)[18] was used to assess the cognitive domain of auditory divided attention. Participants were required to listen to a list of 20 "strings" of a combination of numbers and letters that ranged from 4 to 18, and then state the number of letters. The number of correct answers was scored. The Trail-Making Test, Part A (Trails A) was used to measure visual search. Participants were required to connect circles of numbers 1 through 25 in ascending order. The Trail-Making Test, Part B (Trails B) was used to assess executive cognitive function requiring psychomotor speed, visual search, and attention. In this task, participants were asked to connect circles that alternated between numbers 1 and 13, and letters A through L. In both Trails tests, the number of seconds participants took to complete this task was recorded, with a maximum timeout score of 480 seconds.

Analysis

Background Characteristics of Eligible Participants versus Participants Lost to Follow-Up. Mean (for continuous variables) and percentages in each subgroup (for dichotomous variables) and 95% confidence intervals (CIs) of the baseline characteristics were compared between participants who followed up at 2 years versus participants who were lost to follow-up. We used *t*-tests for continuous variables and ANOVA analyses for dichotomous variables to assess significance.

Determination of Average AVF Difference Subgroups. We computed the mean difference and standard deviation (SD) of the average AVF between baseline and follow-up using paired *t*-tests. Based on these results, we defined a "decline" in AVF as a decline that was greater than 1 SD of degree loss in average AVF.

Age-Adjusted and Multivariate Model. An age-adjusted logistic regression analysis was conducted to determine potential relationships between background characteristics and decline in AVF. Predictors then were chosen for the multivariate model if the age-adjusted *P* value was ≤0.20.

Next, to control for potential confounding, a stepwise multivariate logistic regression model was constructed from strongest to weakest *P* values. If the *P* value of the odds ratio (OR) of a particular variable became insignificant after the addition into the model ($P < 0.05$), it then was removed to build the most parsimonious model. As a sensitivity analyses, all results were checked using the full model without a step-wise approach, and the results did not change. All data were analyzed using Stata Statistical Software: Release 11 (StataCorp LP, College Station, TX).

Results

Participants who did not return after 2 years were older, had a worse depression score, tended to score worse on the tests of cognition, had worse contrast sensitivity, and had smaller AVF at baseline (Table 1). In a model adjusting for each factor, nonparticipants were more likely to be older, depressed, and have lower baseline auditory attention. Nonparticipants were not more likely to have worse AVF or worse CS after adjustment for age and depression.

There was a statistically significant loss of horizontal and average AVF between baseline and follow-up after 2 years using a paired *t*-test (–0.62°, $P = 0.0002$ and –0.34°, $P = 0.015$, respectively, Table 2). There was no significant loss of vertical

Table 1. Background Characteristics of Eligible Participants with Follow-Up at 2 Years Compared to Those Who Did Not Follow-Up at 2 Years in the SEEDS

Variable	Eligible Participants, $N = 968$	Eligible Nonparticipants, $N = 275$	Age-Adjusted *P* Value
Demographics			
Age, mean (SD)	75.4 (5.06)	76.6 (5.47)	0.001
Sex, % (*n*)			
Males	48.6 (470)	48.4 (133)	0.98
Race, % (*n*)			
Black	10.0 (97)	12.4 (34)	0.10
Y of education, % (*n*)			
>12 y	53.8 (521)	46.5 (129)	0.07
Medical history, % (*n*)			
Diabetes	15.6 (151)	18.9 (52)	0.15
Arthritis	56.9 (551)	58.5 (161)	0.64
History of stroke	8.4 (81)	9.1 (25)	0.88
Depression score, mean (SD)	3.4 (3.43)	4.3 (4.07)	0.001
Cognition, mean (SD)			
MMSE score, points	28.6 (1.5)	28.3 (1.6)	0.06
Auditory attention, points	6.9 (2.3)	6.3 (2.5)	0.005
Trails A, s	45.9 (18.2), $n = 967$	49.4 (20.3), $n = 272$	0.04
Trails B, s	115.3 (60.4), $n = 963$	130.6 (71.7), $n = 272$	0.005
Vision indicators, mean (SD)			
Average AVF, deg	13.9 (4.2)	13.0 (4.4)	0.02
Contrast sensitivity in better eye	35.5 (2.0)	35.1 (2.0)	0.03
Log visual acuity	−0.02 (0.1)	−0.007 (0.1)	0.30
Degrees missed in visual field (centered at 20°)	0.20 (1.0)	0.34 (1.5)	0.15

AVF over the two years. The SD for the difference in average AVF between baseline and 2 years was 4.32. Therefore, to ensure that the change in average AVF between 2 years was reasonably robust, a loss of at least 5° was used to define a decline in AVF. A total of 14% of the population lost AVF, using this definition, in the 2-year period.

In the age-adjusted (Table 3) and final model (Table 4), those with a 5° or more decline in average AVF were more likely to be female (OR = 1.59, $P = 0.03$). Those who demonstrated a decline in 5° or more in AVF over 2 years were more likely to report a stroke history and to report depressive symptoms at baseline (per unit change in score) (OR = 2.39, $P = 0.001$ and OR = 1.08, $P = 0.002$ respectively). Lower scores at baseline in all the cognitive domains of attention, visual search, and executive function were associated with loss of AVF at 2 years. For visual characteristics, 5° or more loss of average AVF was associated significantly with worse VA per line lost and worse VFs per point missed in the central 20° at baseline (OR = 1.21, $P = 0.03$ and OR = 1.24, $P = 0.01$, respectively, Table 4).

We undertook a sensitivity analyses to determine if the factors were robust against the choice of different cut points to define loss of AVF (Table 5). The cognitive and visual indicators maintained their significant association with AVF loss, regardless of definition. The increased odds associated with depression, stroke, and female sex and AVF loss also persisted, although the confidence limits overlapped one when the cutoff was more than 4° lost.

Table 2. Difference in AVF between Baseline and 2-Year Follow-Up in 968 Participants in the SEEDS

Variable	Mean (SD)	*P* Value*
Horizontal AVF difference, deg	−0.62 (5.25)	0.0002
Vertical AVF difference, deg	−0.05 (5.33)	0.75
Average AVF difference, deg	−0.34 (4.32)	0.015

* paired *t*-test.

Discussion

The results of our study supported the role of AVF as a marker of higher order brain processing and sensory visual inputs involved in extracting visual information at a glance in the presence of distractors. Specifically, we found that a 5° or more decline in AVF score over a 2-year period was associated significantly with lower scores at baseline in tests of visual search and executive function, and lower baseline scores of VA and VF. We also found that a history of stroke and depression at baseline, and interestingly, being female were associated with a decline of 5° or more in the AVF score over two years.

The sensitivity analyses demonstrated the robustness of the association of the visual and cognitive indicators with loss of AVF. Notably, the odds that women would lose AVF doubled if the cutoff was at more than 6°. The increase went from an OR of 1.24 to 1.59 to 2.11, with a cutoff at more than 4°, 5°, and 6°, respectively. The finding implies that women were far more likely to experience more severe loss over the two years, adjusted for other factors. The association of loss of AVF with stroke and depression was significant for loss of AVF when defined as loss of more than 5° or more than 6°, but lost statistical significance when AVF loss was defined as more than 4°. The estimate of the OR also increased with the more severe definitions, suggesting these factors were responsible for more severe AVF loss and the effect was diluted when including more modest loss. An alternative explanation also could be that defining loss at the more modest cut point of 4° allows more noise in the association, although the absence of such an effect in the visual indicators argues against such an interpretation.

We expected that, because of the construct of the test, a lower baseline VF score and lower baseline auditory attention score would be associated with a decline in 5° or more in the AVF score over time. These components have been shown to be related to the AVF in our cross-sectional survey.[9] The exact mechanisms through which the other measures of cognitive

Table 3. Baseline Characteristics and Age-Adjusted ORs for a Decline of 5° or More in Average AVF over a 2-Year Period in the SEEDS

Variable	Loss of 5° or More, $n = 138$	No Loss (Less Than 5° Loss or Gain) $n = 830$ Base Outcome	Age–Adjusted OR (95% CI)	Age–Adjusted *P* Value
Demographics				
Age mean (SD)	76.47 (4.78)	75.24 (5.09)		
Sex, % (*n*)				
Male	43.5 (60)	49.4 (410)	0.79 (0.55–1.13)	0.20
Race, % (*n*)				
Black	12.3 (17)	9.6 (80)	1.49 (0.84–2.63)	0.17
Y of education, % (*n*)				
>12 y	48.6 (67)	54.7 (454)	0.82 (0.57–1.17)	0.27
Baseline medical history, % (*n*)				
Diabetes	16.7 (23)	15.4 (128)	1.12 (0.69–1.82)	0.653
Arthritis	54.4 (75)	57.4 (476)	0.89 (0.62–1.28)	0.54
History of stroke	15.9 (22)	7.1 (59)	2.39 (1.41–4.06)	0.001
Parkinson's disease	0.7 (1)	0.4 (3)		
Pain score, mean (SD)	0.85 (1.06)	0.85 (1.04)	1.00 (0.84–1.19)	0.98
Depression score, mean (SD)	4.37 (3.57)	3.27 (3.35)	1.08 (1.03–1.13)	0.002
Baseline cognitive indicators				
MMSE score, mean (SD)	28.29 (1.80)	28.62 (1.43)	0.89 (0.80–0.99)	0.04
Attention, mean (SD)	6.50 (2.28)	6.93 (2.29)	0.94 (0.87–1.02)	0.15
Trails A: per 5 s	52.14 (22.34)	44.89 (17.24)	1.09 (1.01–1.02)	<0.0001
Trails B: per 5 s	133.60 (70.27)	112.29 (58.06)	1.02 (1.01–1.03)	0.001
Baseline contrast sensitivity in better eye	35.28 (1.87)	35.52 (2.07)	0.97 (0.89–1.07)	0.56
Baseline log visual acuity per 1 line of visual loss	0.02 (−1.87–4.77)	−0.25 (−1.87–4.23)	1.19 (1.01–1.41)	0.03
Baseline visual field (center 20°)	0.44 (1.612)	0.16 (0.834)	1.19 (1.03–1.38)	0.02
Baseline average AVF, mean (SD)	15.33 (3.70)	13.65 (4.19)	1.13 (1.08–1.19)	<0.0001
Baseline horizontal AVF in degrees, mean (SD)	16.89 (3.79)	15.32 (4.65)		
Baseline vertical AVF, mean (SD)	13.77 (4.78)	11.98 (4.85)		

function affect AVF are unknown, but several studies have found potential links, which we describe below.

Clearly, the test of AVF is not strictly a vision test and requires several domains of cognitive processing to carry out successfully. According to the 2009 research of Van der Stigchel et al.,[19] the initial visual search occurs in a top-down manner, whereby the brain processes the information it receives, interprets, and translates it into a choice. Since the Trails A making test is a measure of the task of visual search, it may reflect the top-down control of the initial visual scan. Conversely, since the Trails B test requires a more complex set of brain functions in which one must identify scattered numbers and letters visually, and consciously reorganize them into a proper order, Trails B may mirror the top-down processing that the Trails A score encompasses, in addition to higher order executive organization functions that require switching between numbers and letters. Though it is not exactly clear why Trails A and Trails B would be associated independently with a decline of 5° or more in the AVF score, the independent significance of Trails B may reflect this high order functioning embodied in the test, which Trails A does not cover.

Table 4. Multivariate Model of Loss of 5° or More in Average AVF Compared to No Loss in Average AVF over a 2-Year Period in the SEEDS ($n = 968$)

Variable	Multivariate Odds Ratio (95% CI)*	Multivariate *P* Value for Trend*
Demographics		
Sex		
Female	1.59 (1.05–2.38)	0.03
Medical history		
History of stroke	1.89 (1.05–3.42)	0.03
Depression score per unit worse	1.07 (1.01–1.13)	0.02
Cognitive indicators		
Attention per unit score increase	0.88 (0.81–0.97)	0.007
Trails A per 5 s increase	1.09 (1.03–1.15)	0.003
Trails B per 5 s increase	1.02 (1.00–1.04)	0.02
Visual indicators		
Log visual acuity per 1 line loss	1.21 (1.02–1.45)	0.03
Visual field		0.01
(center 20°, per point missed)	1.24 (1.05–1.46)	

* In addition, adjusted for age and baseline average AVF.

The relationship between lower baseline scores on the auditory tests of attention and a decline of 5° or more in the AVF score deserves further discussion. The lower baseline scores in our population were not the result of hearing loss, but rather a deficit in attention. This demonstrates that AVF is a function of attention as a whole, that is higher order functioning, and not just vision itself. The precise nature of this relationship is unclear, whether the auditory test of attention is a marker for decline in the cognitive domain of attention itself or that a biologic interaction occurs. In an older population, as we are working with, it is more likely that the lower baseline auditory attention score is a marker for a decline in attentional processing in general, and mirrored in the decline of 5° or more in the AVF score as well.

Our study also found that VA and VFs were determinants of a decline in 5° or more in the AVF score. We previously found a cross-sectional link between VF and AVF,[3] and the finding from this study that lower baseline VFs also was predictive of a decline in 5° or more in the AVF score over two years confirms this link. The association between VA and a decline in AVF or

Table 5. Comparison of Risk Factors Associated with Loss of More than 4°, 5°, or 6° of AVF over a 2-Year Period

	Degrees of Loss		
	>4°	>5°	>6°
Variables	**OR (95% CI)***	**OR (95% CI)***	**OR (95% CI)***
Demographics			
Sex			
Female	1.26 (0.88–1.80)	1.59 (1.05–2.38)	2.11 (1.31–3.90)
Medical history			
History of stroke	1.25 (0.70–2.23)	1.89 (1.05–3.42)	2.04 (1.06–3.93)
Depression score per unit worse	1.04 (0.99–1.09)	1.07 (1.01–1.13)	1.07 (1.01–1.13)
Cognitive indicators			
Attention per unit score increase	0.92 (0.85–1.00)	0.88 (0.81–0.97)	0.90 (0.81–0.99)
Trails A per 5 s increase	1.07 (1.02–1.13)	1.09 (1.03–1.15)	1.05 (0.99–1.12)
Trails B per 5 s increase	1.03 (1.01–1.05)	1.02 (1.00–1.04)	1.02 (1.01–1.04)
Visual indicators			
Log visual acuity per 1 line loss	1.18 (1.00–1.38)	1.21 (1.02–1.45)	1.22 (1.00–1.49)
Visual field (center 20°, per point missed)	1.40 (1.17–1.69)	1.24 (1.05–1.46)	1.23 (1.03–1.45)

* From a multivariate model in addition, adjusted for age and baseline average AVF.

even a lower baseline AVF has been inconsistent. However, as detailed previously,[9] the protocol of this study used a smaller target size, whose identification may rely more heavily on VA than a larger target that has been reported by Owsley,[2] and Leat and Lovie-Kitchin.[20]

Lower baseline contrast sensitivity scores were not predictive of a decline of 5° or more in AVF score over two years. This finding is in contrast with our previously reported cross-sectional study in this population.[9] It is unlikely a function of our testing methods as the AVF protocol itself used a high contrast in the target objects, so we were surprised at the association in the first study. It could be that CS may not have a role in a decline of 5° or more in AVF. The few studies that have reported an association between contrast sensitivity and AVF have been case-control designs,[20] or have assessed CS and AVF at one time point without regard to temporality.[9] We did not find that a lower baseline CS predicted future decline of 5° or more in AVF, which casts some doubt on the association.

The significance of stroke as a determinant of a decline of 5° or more in AVF score confirms the role of AVF as a sensor of executive function and higher order processing. The 2007 LADIS study linked a history of stroke to poorer executive brain function and attention, which are associated with AVF.[21] However, since Trails A and B more specifically represent markers of executive functioning, the fact that a history of stroke remained significant after adjustment of the trail making tests suggests that stroke may affect areas of the brain critical to visual attention that are not merely explained by executive functioning and attention. However, the lack of specificity in our stroke variable with respect to the exact location of injury makes it difficult to address this hypothesis. Conversely, stroke also may have affected the person's ability to use the touch screen correctly, although the technicians were required specifically to watch for any physical limitation in taking the test properly.

Similarly, depression as a significant determinant of a decline of 5° or more in AVF also may be a marker of diminished executive function and/or lack of attention. In a 2004 study by Baudic et al., major unipolar depression in elderly individuals was associated with poorer executive performance, which worsened with the severity of depression.[22] The most consistent findings that have been reported in early studies show that depressed patients have decreased activity in their frontal and prefrontal cortices, which correspond to areas of cognitive and executive processing.[23,24] Interestingly, depression may even be a manifestation of silent strokes, which has been demonstrated recently by Lim et al. in a 2010 review.[25] However, the fact that depression remains a significant independent determinant of a decline AVF suggests that depression may have a more unique role beyond affecting executive function or attention, or other cognitive processes. Depression is known to affect performance on a number of tests, including vision tests, for example.[26,27]

We found that female subjects were more likely to have a decline of 5° or more over 2 years, independently of other risk factors. Our cross-sectional study found an association of female sex with a lower baseline average AVF, and we have now confirmed this in the longitudinal study. The exact reason for this association is unknown. Hormonal control may have a role in differential activation. Hollander et al. in a New Zealand study in 2005 demonstrated that attention blink, a measurement of target detection and lag time, differed during different phases of the menstrual cycle in 21 women, with the highest attentional blink (target probe identification) and hemispheric suppression occurring when estradiol levels were highest.[28] However, the variable in that study is different than AVF and our study included only postmenopausal women, so it is unlikely that cyclical hormones in of itself had a role in our findings.

Despite the robust nature of this longitudinal study, these results should be taken in context of this study's limitations. First, this is not a population-based sample, rather it is a sample of older drivers. In one sense, the fact that we used a sample of older drivers makes our findings even more meaningful because the decline in the AVF score over time is so important for risk of crashes in the older population. However, our findings of the magnitude of decline over time should not be generalized to a sample of all older persons. Second, 22% of our sample of older drivers were lost at follow-up, and these tended to be persons who were more ill and with lower AVF at baseline. We may have had an even greater percentage of the population that demonstrated a decline of 5° or more in AVF over time if these had been included. Also, this participant loss may have made it more difficult to detect associations with other diseases, for example Parkinson's disease. It is unlikely to have biased our positive findings from the longitudinal follow-up, but may have minimized our ability to detect other associations. It is unlikely that there was bias in the assessment of most of our risk factors for AVF decline or in the AVF test itself, as these were assessed automatically by machine. Where

assessed by interview, the interviewer was unaware of the value of AFV and in any case was certainly not aware at baseline of who would have progression two years later. Finally, the follow-up time (2 years) was short, which may not be enough time to capture modest declines in AVF. We chose a 5° or more loss, which is 25% of the width of the 20° field diameter that we tested and is clearly a significant decline. However, if some variables are associated with a more modest decline in AVF we were unlikely to detect that association. It may be that a decline in AVF is along a continuum and by choosing a cutoff we have missed other determinants. However, we chose a cut-off that identified a significant decline over the two years to ensure we were not studying factors associated with minor variations in AVF.

Though the specific cutoff value may not necessarily be used in other studies, the results stemming from this study have important implications. First, a significant fraction of our older driving population, 14%, had a decline of 5° of AVF or more in two years. This suggests a rapid decrease in a test that has been an important marker for poor driving performance and crash risk for this age group. The role of AVF as a marker of visual and higher order cognitive processing makes it a potentially useful tool for screening.

Our study also confirmed that sex is a predictor of a 5° or more loss in the AVF score, which is not readily intuitive and should be a potential area of further exploration. Future studies may want to explore the predictors of a decline in AVF over a longer period of time, while incorporating functional MRI scans to assess the potential role of sex and differential cognition on scores of the AVF task.

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