Driving With Central Field Loss I

Effect of Central Scotomas on Responses to Hazards

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Objectives: To determine how central field loss (CFL) affects reaction time to pedestrians and to test the hypothesis that scotomas lateral to the preferred retinal locus will delay detection of hazards approaching from that side.

Methods: Participants with binocular CFL (scotoma diameter, 7°-25°; visual acuity, 0.3-1.0 logMAR) using lateral preferred retinal fixation loci and matched controls with normal vision drove in a simulator for approximately 1½ hours per session for 2 sessions a week apart. Participants responded to frequent virtual pedestrians who appeared on either the left or right sides and approached the participant's lane on a collision trajectory that, therefore, caused them to remain in approximately the same area of the visual field.

Results: The study included 11 individuals with CFL and 11 controls with normal vision. The CFL participants had more detection failures for pedestrians who appeared in areas of visual field loss than did controls in corresponding areas (6.4% vs 0.2%). Furthermore, the CFL participants reacted more slowly to pedestrians in blind than nonscotomatous areas (4.28 vs 2.43 seconds, $P < .001$) and overall had more late and missed responses than controls (29% vs 3%, $P < .001$). Scotoma size and contrast sensitivity predicted outcomes in blind and seeing areas, respectively. Visual acuity was not correlated with response measures.

Conclusions: In addition to causing visual acuity and contrast sensitivity loss, the central scotoma per se delayed hazard detection even though small eye movements could potentially compensate for the loss. Responses in nonscotomatous areas were also delayed, although to a lesser extent, possibly because of the eccentricity of fixation. Our findings will help practitioners advise patients with CFL about specific difficulties they may face when driving.

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CENTRAL FIELD LOSS (CFL) is a scotoma that encompasses the fovea and is commonly caused by age-related macular degeneration; however, many other causes are possible.[1,2] People with CFL almost always use a preferred retinal locus (PRL),[3,4] an extrafoveal location near the scotoma, to fixate targets that would normally be foveally fixated (we will refer to scotoma location/direction relative to the PRL in visual field space, not in retinal directions). The scotoma is lateral to the PRL in approximately 65% of cases but can be above or, rarely, below the PRL.[4,5] In addition, CFL reduces visual acuity (VA) and contrast sensitivity because these functions are normally poorer in the peripheral retina. In some countries (eg, the United Kingdom[6] and Canada[7]), driving regulations address central visual field integrity and peripheral field extent. In the United States, however, driving regulations do not explicitly address CFL but rather consider only acuity loss.[8] We hypothesize that vision loss due to CFL may have a greater effect on driving than simply acuity loss.

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People with age-related macular degeneration report difficulty driving.[9-13] However, many continue driving even when their VA falls below the legal limit and even when they have CFL.[13,14] Delayed responses to stop signs and traffic lights have been reported for people with CFL in driving simulator studies.[12,15] In an on-road study,[16] 25% of current drivers with age-related macular degeneration passed a driving test com-

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pared with 42% of people with peripheral field loss and 64% with other mild visual field impairments.

Although CFL is associated with driving difficulty, it is not known how the scotoma and its location affect driving skills. In a recent driving simulator study,[17] people with hemianopia frequently failed to detect pedestrians appearing in their blind side of the road. We therefore hypothesized that scotomas lateral to the PRL would cause difficulty in detecting pedestrians appearing on that side despite the smaller size of the scotomas.

Visual acuity is widely used in driving regulations, but it is a poor predictor of performance.[18] Contrast sensitivity is more predictive of driving outcomes in older adults with normal vision (NV)[18] and is correlated with driving skills in people with moderate peripheral field loss.[19] We therefore examined the relationship between pedestrian detection performance and a range of clinical vision measures, including scotoma size and location. We hypothesized that better contrast sensitivity and smaller scotoma size, but not better VA, would permit faster detection.

METHODS

The study followed the tenets of the Declaration of Helsinki and was approved by institutional review boards at the Schepens Eye Research Institute and the Veterans Administration Boston Healthcare System.

PARTICIPANTS

Participants had at least a 120° horizontal binocular field extent, measured with Goldmann kinetic perimetry (V4e target). Corrected binocular single-letter VA was 20/200 or better for the CFL participants and 20/25 or better for NV controls. Thus, all had vision sufficient for a restricted drivers' license or better in some states.[20] Each CFL participant had a binocular absolute central scotoma as measured with custom kinetic perimetry[21] (74 candela-per-square-meter [cd/m^2] bright 0.74° square target, gray background [24 cd/m^2], distance of 1 m). Binocular scotoma location was categorized left or right of the binocular PRL in visual field space (ie, equivalent to a right PRL or left PRL, respectively). Individuals with PRLs above or below the scotoma were not included. A similar classification, based on the relative location of the PRL and former fovea, shows moderate repeatability ($\kappa = 0.92$ for 20 eyes of 12 participants) (Russell Woods, PhD, written communication, May 24, 2012).

Scotoma size was quantified as the mean diameter of 4 main meridians passing through the center of the scotoma. For one participant who had several distinct scotomas, each scotoma was measured and summed. Letter contrast sensitivity (2.5° letters) was measured with a custom, computer-based test with single-letter scoring, sequential decreasing contrast, and a 2-incorrect response stopping rule.[22] The results are similar to those obtained with Pelli-Robson and Mars tests for patients with low vision.

Participants were recruited from the Veterans Administration, the Schepens Eye Research Institute, and the Harvard Cooperative Program on Aging. Participants with cognitive decline were excluded (>4 errors on the Short Portable Mental Status Questionnaire).[23] All had more than 15 years of driving experience. None had previously used our simulator.

DRIVING SIMULATOR

The simulator has been detailed previously.[17,24] It is a PP1000-x5 simulator (FAAC Corp) with five 60 × 45-cm cathode ray tube monitors (1024 × 768 pixels, 60 Hz), providing a 225° × 32° field of view.

PROCEDURE

Two driving assessments were conducted roughly 1 week apart. Because of fatigue or discomfort, 5 participants completed assessments across more than 2 visits. Participants completed a series of acclimation and practice drives during which they rated their physical comfort and vehicle control on 10-point scales ("lousy" to "great"). If vehicle control was below 7, they continued to practice before progressing. Mean (SD) acclimation time was 18 (7) minutes.

Each assessment consisted of 3 city and 2 rural undivided highway scenarios, each lasting 8 to 12 minutes. We encouraged participants to drive 30 mph in the city and 60 mph on highways and to obey all standard road rules. Participants drove different scenarios during their first and second assessments, and 6 different counterbalance orders were used. Mean (SD) driving time for each session was 84 (11) minutes.

Participants pressed the horn as soon as they detected pedestrians, who appeared every 15 to 60 seconds (8-12 per scenario, 52 per session) at 1 of 4 eccentricities (−14°, −4°, 4°, and 14°). Pedestrians walked or ran (exhibiting biological motion) toward the road at a speed that would result in a collision with the car[25,26] (eFigure 1; http://www.jamaophth.com). Thus, pedestrians stayed in approximately the same visual field location (eFigure 2), assuming the driver looked straight down the road. Although drivers may scan from side to side, even experienced drivers mainly look down the road in the direction of travel.[27] Pedestrians stopped before entering the participant's lane.

Pedestrians appeared 67 m/134 m (city/highway) from the participant's vehicle. These distances are double the 2.5-second perception-brake time used in the calculation of minimum recommended sight distances for safe roadway design.[28] At initial appearance, the pedestrians (2 m tall, light shirt, and dark pants) subtended 1.5° vertical and 0.5° horizontal in the city (half that on highways). Small eccentricities (−4° and 4°) represented pedestrians approaching from an adjacent lane (crossing the street) or the sidewalk. The larger eccentricities represented hazards approaching more quickly from a greater distance (eg, a bicyclist).

STATISTICAL ANALYSIS

Primary measures were pedestrian detection rates and reaction times (latency from pedestrian appearance to horn-press). We used logistic regression to predict whether participants detected each pedestrian. Factors included visual field area in which each pedestrian appeared (ie, blind or seeing), drive type (city or highway), and vision (CFL or control). For CFL participants, whether pedestrians appeared in blind or seeing areas was based on the position and size of the scotoma in the binocular visual field plot (**Figure 1**). Visual field area (blind or seeing) was defined for controls by their matched CFL participant.

We analyzed median reaction times separately for (1) blind and seeing visual field areas, (2) drive type (city vs highway), and (3) first or second assessment. Medians were used because reaction times were not normally distributed. Medians did not include detection failures; these were used in the untimely reaction analysis. The medians were normally distributed and

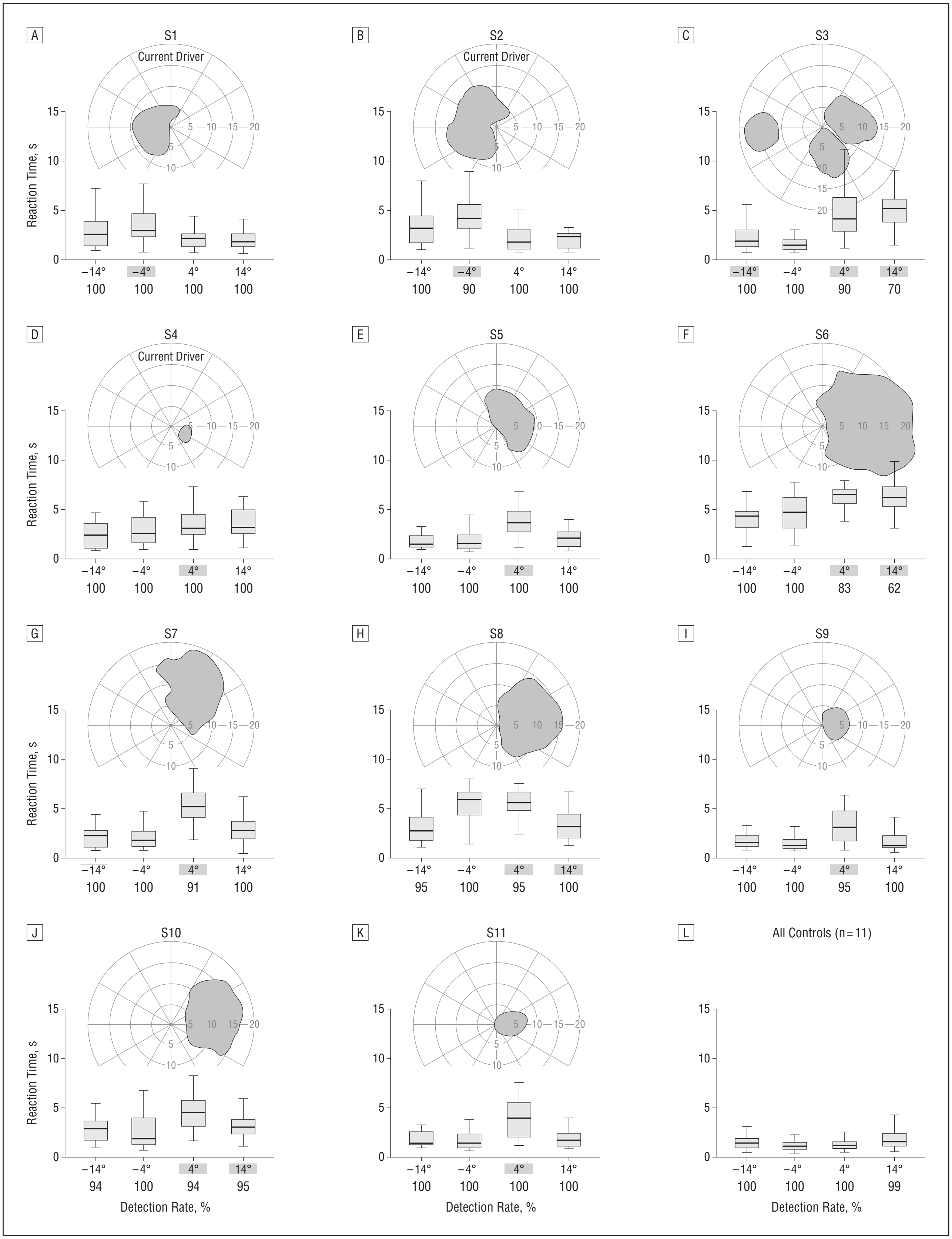

Figure 1. Binocular visual field plots for each participant and their individual reaction times for the 4 pedestrian eccentricities (8-26 appearances at each eccentricity; median, 22). A-K, Reaction times for each patient (S1-S11). L, Reaction times for the group of normally sighted control participants. The central field loss (CFL) patients S1 and S2 have scotomas to the left of their preferred retinal locus in visual field space and were predicted to have longer reaction times to the −4° pedestrians than to pedestrians at the other 3 eccentricities; predictions for each participant are shown with a gray highlight over the relevant eccentricities. Box lengths indicate the 25% to 75% extent; error bars, the maximum extent of cases that are not outliers. Percentages under each plot show detection rates.

Table 1. Participant Characteristics

Characteristic	Mean (SD) [Range][a] Central Field Loss (n = 11)	Mean (SD) [Range][a] Normal Vision (n = 11)	Test for Group Differences[b]
Current driver, No. (%)	3 (33)[c]	11 (100)	Mann-Whitney = 16.5, $P = .002$
Driving history, y	44 (17.5) [19 to 65]	48 (16.6) [23 to 70]	$t_{20} = 0.5$, $P = .61$
Stopped driving, y	7 (5) [0.5 to 13]	NA	NA
Male sex, No. (%)	7 (64)	7 (64)	$P > .99$
Age, y	65 (16.2) [42 to 87]	65 (15.1) [40 to 84]	$t_{20} = 0.06$, $P = .96$
SPMSQ score	10 (0.74) [9 to 11]	11 (0.85) [9 to 11]	$t_{16} = 0.33$, $P = .75$
Binocular VA, logMAR	0.66 (0.24) [0.32 to 1]	−0.05 (0.06) [−0.12 to 0.06]	$t_{11.3} = 9.8$, $P < .001$
Contrast sensitivity, log units	1.23 (0.21) [0.85 to 1.5]	1.81 (0.13) [1.55 to 1.95]	$t_{16.8} = 7.75$, $P < .001$
CFL cause, No.			
AMD	7	NA	NA
Stargardt disease	1		
Other[d]	3		

Abbreviations: AMD, age-related macular degeneration; CFL, central field loss; NA, not applicable; SPMSQ, Short Portable Mental Status Questionnaire; VA, visual acuity.
[a] Data are given as mean (SD) [range] unless otherwise indicated.
[b] Some degrees of freedom are fractional because they are adjusted for inequality of variances.
[c] One nondriver later resumed driving. In all, 4 participants with CFL were licensed to drive.
[d] Optic nerve atrophy, optic nerve degeneration, and presumed ocular histoplasmosis.

analyzed by repeated-measures analysis of variance, with area (blind or seeing), drive type, and assessment as within-subjects factors and vision (CFL or control) as a between-subjects factor (α=.05).

We calculated whether participants could have stopped in time, given their reaction time and vehicle speed, for each pedestrian appearance. A deceleration rate of 5 m/s^2 was used, representing a car and road both in good condition.[29] We classified each appearance as (1) timely, meaning the pedestrian was detected with enough time to stop if necessary, or (2) untimely, meaning the reaction was not quick enough to stop or the pedestrian was missed. Binary logistic regression was conducted with SPSS statistical software, version 11.5 (SPSS Inc), using backward stepwise entry based on significance of the Wald statistic.

RESULTS

SAMPLE CHARACTERISTICS

We screened 28 individuals with CFL; 11 completed the study. Eight did not meet vision criteria and 9 withdrew: 2 for health reasons, 2 for simulator sickness, and 5 for other reasons (eg, transportation difficulties). For each CFL participant, a current driver with NV of the same sex and age (within 3 years) was recruited. We screened 17; 11 completed testing and were matched to a CFL participant.

Eight CFL participants had binocular scotomas to the right of their PRL, 2 to the left, and 1 to both the left and right (Figure 1), with scotoma diameters ranging from 7° to 25°. The CFL participants had poorer VA and contrast sensitivity than the NV participants (**Table 1**), and the 2 groups were similar for sex and age (Table 1).

DETECTION RATES

Overall detection rates were high (Figure 1). The CFL participants had more detection failures than controls (2.7% vs 0.3%, Wald statistic = 14.8, *df* = 1, $P < .001$, Exp(β) = 10.3) and 2.1 times more misses for pedestrians in blind than seeing areas, which in turn was many times more than controls' corresponding areas (6.4% vs 0.2%, Wald statistic = 19.4, *df* = 1, $P < .001$, Exp(β) = 5.24). Drive type (city vs highway) was not significant ($P = .20$), and neither were any interactions.

REACTION TIMES

Participants reacted 0.16 second faster at the second assessment, but this difference was not significant ($P = .08$). Overall, the CFL participants reacted significantly slower than controls (3.35 vs 1.27 seconds, $F_{1,20} = 72.5$, $P < .001$) (**Figure 2**) in both seeing and blind areas. As expected, the CFL participants reacted faster in seeing than in blind areas (2.43 vs 4.28 seconds, $F_{1,21} = 50.4$, $P < .001$), whereas in controls, reaction times did not differ (1.29 vs 1.25 seconds). For the CFL participants, the difference between seeing and blind areas was greater for rural highway than city drives (interaction of *drive type* [city vs highway] by *area* within the CFL participants, $F_{1,21} = 9.3$, $P = .006$). Controls did not differ by drive type.

UNTIMELY REACTIONS

The CFL participants were more likely to have untimely reactions than controls (29% vs 3%, Wald statistic = 44.44, *df* = 1, $P < .001$, Exp(β) = 0.02) (**Figure 3**). These untimely reactions were more likely to involve pedestrians in blind than in seeing areas (50% vs 19%) for CFL participants but not controls (5% vs 5%) (vision by area interaction, Wald statistic = 7.37, *df* = 1, $P = .007$, Exp(β) = 7.1) (Figure 3). All participants had more untimely reactions in highway than in city drives (48% vs 21% for CFL participants and 8% vs 1% for controls, Wald statistic = 9.89, *df* = 1, $P = .002$, Exp(β) = 0.12).

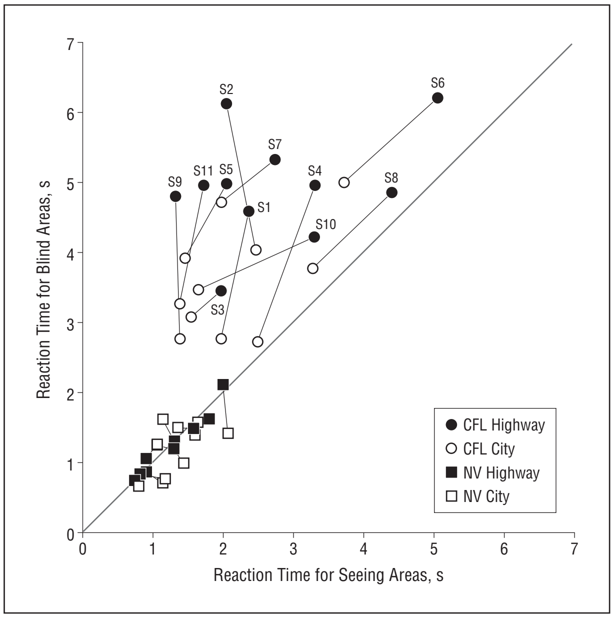

Figure 2. Median reaction times for seeing and blind areas. Data for each participant on city and highway drives are connected by straight lines. The central field loss (CFL) participants had reaction times longer than controls and longer to pedestrians in their blind than seeing areas (above diagonal). As expected, the normal vision (NV) group had similar reaction times in blind and seeing areas. The CFL medians were longer on rural highway drives (filled circles shifted up and right).

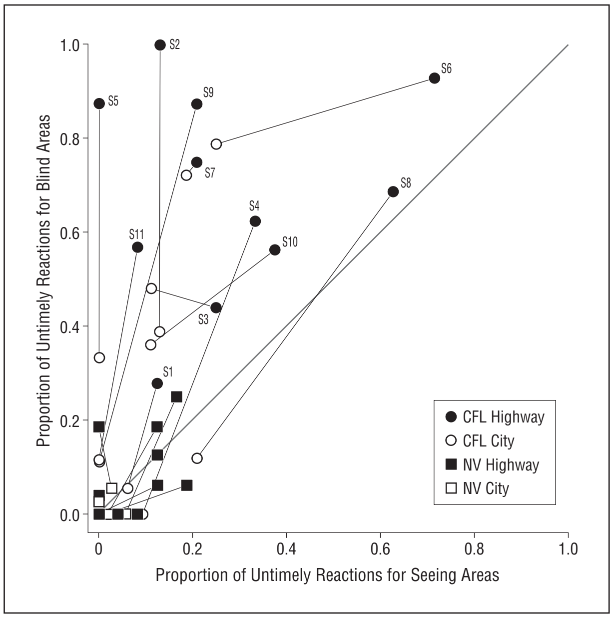

Figure 3. Proportion of untimely reactions for seeing vs blind areas. Data for each participant are connected by straight lines. Participants with central field loss (CFL) had much higher untimely reaction rates than normal vision (NV) controls, particularly in their blind areas and on rural highways. Controls also had more untimely reactions in rural highway than in city drives.

VISION MEASURES AND DETECTION PERFORMANCE

Larger scotomas were correlated with lower detection rates and more untimely reactions for pedestrians in blind areas on city drives (**Table 2**). Poorer contrast sensitivity significantly correlated with longer reaction times and more untimely reactions in seeing areas on highways and worse detection rates in blind areas on city and highway drives. Age and VA were not correlated with the response measures. The multiple planned comparisons were not corrected.[30,31]

COMMENT

Our hypothesis that lateral CFL delays reactions to pedestrian targets in scotoma areas was strongly supported. Participants with scotomas (regardless of right or left PRL) had longer reaction times to pedestrians appearing in their blind areas than in their seeing areas. One participant with scotomas on both sides had delays on both except for the −4° targets, where there was residual vision. Despite the relatively small sample, our repeated measures of hazards at multiple eccentricities were sufficiently powerful to produce significant large median reaction time differences. Although our sample is unbalanced (8 with right CFL and 2 with left CFL), the proportions are close to those reported in a larger sample.[4]

The longer reaction times in blind areas were due to the scotoma and not simply to the loss of acuity and contrast sensitivity. Such large scotoma effects might not be expected because small eye movements might be sufficient to compensate for obscuration by a scotoma. However, in our sample, such scanning, if it took place, was not sufficient for full compensation.

The effects of CFL have been anticipated[6] but have not been previously documented because of the difficulties of studying visually impaired driving. One on-road study of mild CFL[32] used a "stunt" pedestrian and cyclist and found no apparent differences between people with CFL and controls in reaction times. This finding may be because (1) the timing of the actors could not be precisely implemented and (2) the authors stated that actors only appeared in seeing areas of the participants' visual fields. Thus, in that study, there was no ex post facto reason to have expected differences except those due to acuity or contrast sensitivity.

The CFL participants also had longer reactions than controls in *seeing areas* of their visual field. This finding might occur because most seeing-area pedestrians appeared at larger absolute retinal eccentricities for participants with CFL because they used nonfoveal PRLs, whereas controls fixated foveally. For example, a 4° pedestrian to a participant with a 6° PRL will be projected to 10° from the former fovea where contrast sensitivity is lower. This reduction in sensitivity caused more substantial effects at highway speeds (because detection needed to be made at a greater distance).

By comparison, in a study[33] of drivers with paracentral scotomas who used foveal fixation and thus had VA and contrast sensitivity similar to that of NV drivers, no significant delays were found for pedestrian figures in seeing areas of their visual field using the same methods. Supporting the retinal eccentricity hypothesis, NV participants had longer reaction times to pedestrians at the larger (14°) eccentricities than the small (4°) by 0.3 second (paired $t_{10} = 5.9$, $P < .001$).

Table 2. Spearman Correlations Between Vision and Performance Measures for the 11 Participants With Central Field Loss[a]

Variable	Visual Acuity	Contrast Sensitivity	Scotoma Size	Age
Reaction times				
City, seeing	0.46	−0.59	0.27	−0.19
City, blind	0.37	−0.41	0.49	0.01
Highway, seeing	0.48	**−0.77**	0.31	−0.14
Highway, blind	0.39	−0.05	−0.08	−0.14
Detection rates				
City, seeing	0.31	0.27	−0.09	−0.13
City, blind	−0.01	**0.61**	**−0.76**	0.35
Highway, seeing	−0.48	0.20	0.00	−0.45
Highway, blind	−0.13	**0.61**	−0.54	0.38
Untimely reaction				
City, seeing	0.54	−0.51	0.34	0.22
City, blind	0.10	−0.47	**0.71**	−0.06
Highway, seeing	0.41	**−0.83**	0.39	0.06
Highway, blind	0.24	−0.10	0.19	0.10

[a] Significant correlations are set in bold type (2-tailed).

Despite deploying pedestrians at double the perception-brake sight distance in the American Association of State Highway and Transportation Officials guidelines[28] (2 × 2.5-second travel time), the CFL participants frequently did not react in a timely fashion, especially in rural highway drives (69% untimely in blind areas and 28% in seeing areas). Timely detections on highways were challenging even for normally sighted participants (8% untimely) because doubling speed quadruples stopping distance.

Our primary measure was how quickly the pedestrian was detected. We also derived the measure "untimely reactions," including vehicle speed and distance to the pedestrian, which imparts more real-world meaning to the measurement. We did not measure actual collisions, and we did not consider other possible maneuvers to avoid collisions. An advantage of simulator-based studies is that pedestrian challenges are safe, controlled, and more frequent than in on-road studies, enabling reliable measurement of response latencies. The greater frequency in the simulator should have primed the participants, making it easier for them to anticipate the events. In the real world, such occurrences would be unexpected and therefore would probably result in longer reaction times. It is not uncommon in mobility research to include events at a higher frequency or higher density than in the real world to have sufficient events for analysis.[34,35]

Larger scotomas were significantly correlated with poorer blind-area detection performance; larger blind areas should make it more difficult to detect pedestrians in that area. That contrast sensitivity correlated with worse detection rates in blind areas may be attributable to its correlation with scotoma size. For the acuity range of our CFL participants (20/40 to 20/200), VA was uncorrelated with performance measures despite being the primary vision screening measure for licensing in the United States. Higgins[36] has pointed out that VA should not be expected to correlate with outcome measures when there are range restrictions. We should note that within our CFL or NV group, VA was not correlated with performance measures. However, across all our participants, VA was correlated with most performance measures.

Our CFL participants had vision sufficient for a restricted driver's license in some states but not in the United Kingdom or Canada because of their CFL.[6,7] Although most had stopped driving, all had considerable driving experience, and the 3 who were current drivers had blind-area reaction times similar to the others.

In conclusion, people who fixate lateral to a binocular scotoma had relatively late reactions to potential hazards that appeared in scotoma locations. Vertical PRLs, more common in juvenile macular degeneration, may have a lesser effect on hazard detection, but confirmation is needed. Contrast sensitivity may also help differentiate those who are fit to drive. However, none of these measures is currently considered in driver licensing in the United States. We found that CFL may affect driving safety independent of its effect on acuity; thus, patients with CFL may be more vulnerable to hazards than other drivers with reduced acuity alone.

Our study was not designed to oppose or advocate for people with visual impairments as drivers. However, knowledge about how specific aspects of vision loss (CFL, VA, and contrast sensitivity) affect certain aspects of performance should help improve vision rehabilitation and the design of mobility aids. The results may help practitioners in advising patients with CFL about difficulties they may face when driving.

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Supplementary Online Content

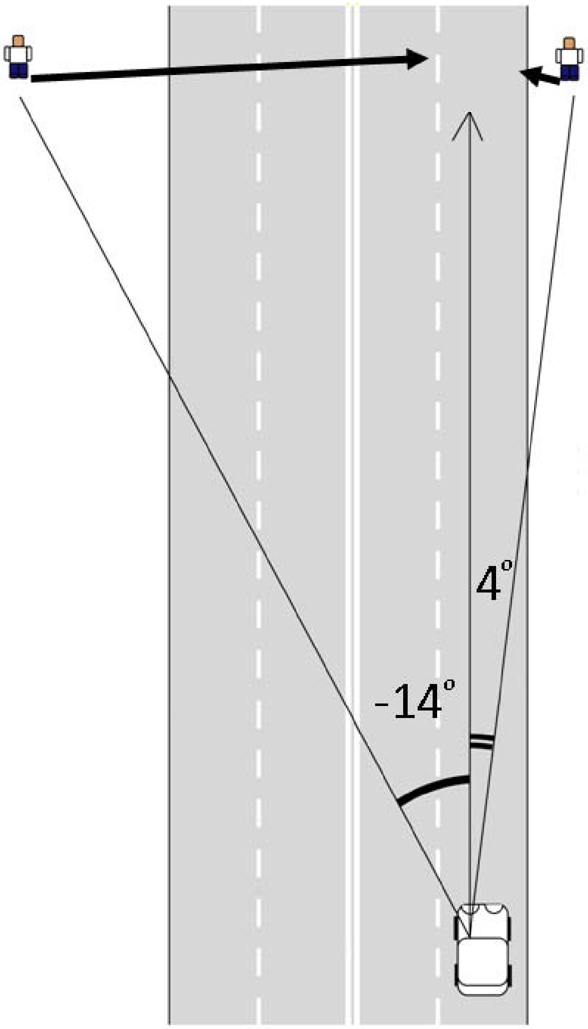
Bronstad PM, Bowers AR, Albu A, Goldstein R, Peli E. Driving with central visual field loss I: effective of central scotoma on response to hazards [published online January 14, 2013]. *JAMA Ophthalmol*. doi: 10.1001/jamaophthalmol.2013.1443.

eFigure 1. Overhead view of pedestrian appearance and motion. Dark arrows show approximate direction and start and end locations of pedestrians. Pedestrians at −4° and +14° are not shown but are similar.

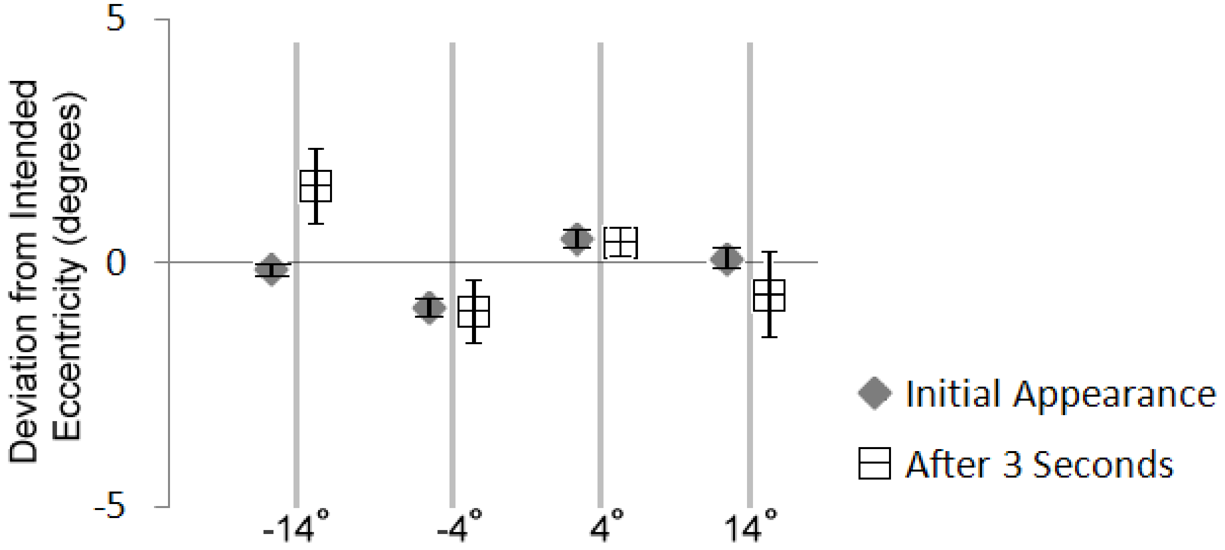
eFigure 2. Median reaction times for seeing and blind areas. Data for each participant on city and highway drives are connected by straight lines. The central field loss (CFL) participants had reaction times longer than controls and longer to pedestrians in their blind than seeing areas (above diagonal). As expected, the normal vision (NV) group had similar reaction times in blind and seeing areas. The CFL medians were longer on rural highway drives (filled circles shifted up and right).

This supplementary material has been provided by the authors to give readers additional information about their work.

eFigure 1



eFigure2


5
0
-5
Deviation from Intended Eccentricity (degrees)
-14°
-4°
4°
14°
Initial Appearance
After 3 Seconds

ONLINE FIRST

Driving With Central Field Loss

SHOULD PEOPLE WITH CENTRAL FIELD LOSS (CFL) be on the road driving? Independent travel is an important prerequisite for full participation in modern society. Reduced mobility and its associated social isolation and depression are among the most severe consequences of vision impairment. Research on mobility with vision impairment has focused primarily on pedestrian travel, but there is a growing interest in the impact of vision disorders on driving, including cataract,[1] retinitis pigmentosa,[2] hemianopia,[3] and macular degeneration.[4,5] In this issue of *JAMA Ophthalmology*, Bronstad et al[6] describe how specific characteristics of CFL affect driving performance.

See related article

With the aging of the American public, the number of people with macular degeneration is growing, expected to reach nearly 3 million by 2020.[7] A substantial number of these people will experience irreversible CFL. They will face life-changing questions: Should I continue to drive? Is it legal for me to drive? This population of aging drivers, their families, their eye care professionals, and the state authorities responsible for driving licensure will need to contend with the tension between protecting public safety and allowing people with impaired vision the freedom to drive.

Currently, acuity is the primary visual criterion used for determining licensure, typically requiring drivers to have 20/40 (6/12) letter acuity or better.[8,9] Remarkably, the evidence for an association between acuity and driving safety in the range of 20/40 to 20/200 is weak or absent.[9-11] We know that people with CFL have reduced acuity, but what additional consequences are there for driving from damage to the macula? We need research showing how specific characteristics of visual field loss impact driving performance, as well as how they interact with cognitive and health variables, environmental conditions, and the ergonomic demands of driving.

Bronstad et al[6] used a driving simulator to test 11 subjects with bilateral CFL (7 from age-related macular degeneration, 1 from Stargardt disease, and 3 from other disorders), and 11 normally sighted age-matched controls. During rural and city driving scenarios, the subjects were required to detect virtual pedestrians crossing the road ahead on a collision course with the driver's vehicle. Reaction times were measured and the number of "pedestrians" not detected (missed) were counted. Prior to the driving tests, each CFL subject's visual field was mapped to determine the size of the central scotoma and the location of the preferred retinal locus (PRL). The PRL is a region of retina, typically adjacent to the central scotoma, adopted by people with CFL for fixation and other visual functions.[12-14] Subjects with CFL were screened to include only those with PRLs located left or right of the central scotoma (rather than above or below the scotoma).

The goal of the study was to determine if the size of the scotoma and position of the PRL relative to the scotoma would influence detection of the virtual pedestrians. If drivers with CFL are assumed to use their PRLs for looking straight ahead down the road, it might be expected that virtual pedestrians on the side of the road corresponding to the direction of the scotoma in the visual field would be temporarily occluded, resulting in a prolonged reaction time or even a miss. But it is also possible that the relative locations of PRL and scotoma would have no effect; the individual with CFL may have learned compensatory eye or head movements to minimize the impact of an adjacent scotoma.

Bronstad et al[6] found that the subjects with CFL responded more slowly to and missed more virtual pedestrians than the controls. They also found that the detection performance of subjects with CFL was poorer for virtual pedestrians appearing on the scotomatous side of the PRL than on the seeing side. The slower reaction times of the subjects with CFL were not correlated with their acuities but were correlated with the size of their scotomas. These results are important in showing that the configurations of PRL and scotoma have more impact on driving performance than does acuity.

The Bronstad et al[6] findings are compelling and raise several additional questions. First, will their results generalize to on-road hazard detection outside the simulator? Simulators are limited in the fidelity and range of naturalistic lighting conditions they can produce and typically use scenarios in which subjects are primed to expect hazards (in this case, the virtual pedestrians). We might speculate that the differences in detection found by Bronstad et al[6] between their subjects with CFL and their normally sighted controls would be amplified in real driving.

Second, will people with PRLs above or below their central scotomas exhibit better hazard detection in driving? Bronstad et al[6] considered only PRLs lateral to the central scotoma and found that this configuration hindered the detection of hazards approaching from the left or right. Some subjects with central scotomas spontaneously adopt or are trained to adopt PRLs above or below the scotoma.[14] Preferred retinal loci below the scotoma in the visual field are thought to be more advantageous for reading than lateral PRLs because the scotoma is less likely to occlude text left or right of the PRL. But in driving, a scotoma above or below the PRL might occlude cars or other features on the road straight ahead.

Third, drivers with CFL must rely on their peripheral retina for visual input. Bronstad et al[6] focused on the configuration of PRL and scotoma, but what are the effects of other properties of peripheral vision on driving behavior? These properties include crowding,[15] deficiencies in eye-movement control,[16,17] and reduced accuracy in estimating time to contact.[18]

Since most people with CFL are older than 65 years, factors influencing aging vision more generally come into play, such as decreased contrast sensitivity (especially under scotopic conditions), slower light and dark adaptation, and slower visual processing overall.[19] In particular, aging vision seems less able to detect salient targets in a cluttered peripheral visual field, and this reduced useful field of view[20] is associated with greater risk for motor vehicle collisions.[10,21-23] A mitigating factor is the tendency for older drivers to self-restrict their driving exposure, especially at night.[24] DeCarlo et al[25] reported that some patients with age-related macular degeneration visiting a low-vision clinic were still licensed drivers, but most had drastically restricted their driving activity. For example, 80% reported not driving at night, and most drove only about 10 miles per week.

Most research on driving and low vision, like the work reported by Bronstad et al,[6] has focused on safety-related measures. But, from the driver's perspective, another important aspect of driving is wayfinding, following a route to a destination. Wayfinding in unfamiliar environments often puts a high demand on good acuity because of the need to read street signs and building addresses or watch for landmarks. Drivers with reduced acuity from macular degeneration or other eye disorders may minimize wayfinding problems by limiting their driving to familiar neighborhoods. Some may use bioptic telescopes—a small telescope (power typically in the range of ×2 to ×4) mounted on the upper portion of the driver's normal spectacle lens—for spotting and reading signs. For reasons that are not yet clear, few people with macular degeneration actually use bioptic telescopes.[26] A recent advance in technology for assisting wayfinding is the use of talking GPS systems for route following, now widely used by normally sighted drivers and potentially of great value to people with reduced acuity. The future development of intelligent systems in which cars communicate wirelessly with other vehicles and the transportation infrastructure, and provide spoken feedback to drivers, could be particularly beneficial for wayfinding with visual impairment. We can also look forward to the brave new world of Google's driverless cars, which might extend driving accessibility to everyone with visual impairment. Advocates of this technology point out that most traffic accidents are due to human error and propose that driverless cars will be safer and more economical while extending the benefits of driving to more people.[27]

In the near future, we should expect to find more drivers on the road with CFL and other forms of visual impairment. Findings such as those reported by Bronstad et al[6] begin to shed light on individual vision-related factors that can guide ophthalmologists, optometrists, vision rehabilitation specialists, and their patients in making driving decisions. The findings also offer opportunities for improved educational and intervention programs for driving safety and for the development of onboard technology to assist driving mobility.

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