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.


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. People with CFL almost always use a preferred retinal locus (PRL), 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. 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 Kingdom6 and Canada7), 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. 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. However, many continue driving even when their VA falls below the legal limit and even when they have CFL. Delayed responses to stop signs and traffic lights have been reported for people with CFL in driving simulator studies. In an on-road study, 25% of current drivers with age-related macular degeneration passed a driving test com-
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.39 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.32 Each CFL participant had a binocular absolute central scotoma as measured with custom kinetic perimetry31 (74 candela-per-square-meter [cd/m²] bright 0.74° square target, gray background [24 cd/m²], 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 (κ=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°) was measured with a custom, computer-based test with a square target, gray background (24 cd/m²), 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 (κ=0.92 for 20 eyes of 12 participants) (Russell Woods, PhD, written communication, May 24, 2012).

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).33 All had more than 15 years of driving experience. None had previously used our simulator.

DRIVING SIMULATOR

The simulator has been described 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 car15,20 (eFigure 1; http://www.jamaophth.com). Thus, participants 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 untimed 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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Central Field Loss (n = 11)</th>
<th>Normal Vision (n = 11)</th>
<th>Test for Group Differencesb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current driver, No. (%)</td>
<td>3 (33)c</td>
<td>11 (100)</td>
<td>Mann-Whitney = 16.5, P = .002</td>
</tr>
<tr>
<td>Driving history, y</td>
<td>44 (17.5) [19 to 65]</td>
<td>48 (16.6) [23 to 70]</td>
<td>t6 = 0.5, P = .61</td>
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<tr>
<td>Stopped driving, y</td>
<td>7 (5) [0.5 to 13]</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Male sex, No. (%)</td>
<td>7 (64)</td>
<td>7 (64)</td>
<td>P &gt; .99</td>
</tr>
<tr>
<td>Age, y</td>
<td>65 (16.2) [42 to 87]</td>
<td>65 (15.1) [40 to 84]</td>
<td>t6 = 0.06, P = .96</td>
</tr>
<tr>
<td>SPMSQ score</td>
<td>10 (0.74) [9 to 11]</td>
<td>11 (0.85) [9 to 11]</td>
<td>t6 = 0.33, P = .75</td>
</tr>
<tr>
<td>Binocular VA, logMAR</td>
<td>0.66 (0.24) [0.32 to 1]</td>
<td>−0.05 (0.06) [−0.12 to 0.06]</td>
<td>t13,3 = 9.8, P &lt; .001</td>
</tr>
<tr>
<td>Contrast sensitivity, log units</td>
<td>1.23 (0.21) [0.85 to 1.5]</td>
<td>1.81 (0.13) [1.55 to 1.95]</td>
<td>t13,3 = 7.75, P &lt; .001</td>
</tr>
<tr>
<td>CFL cause, No.</td>
<td>7</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>AMD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stargardt disease</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Otherd</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: AMD, age-related macular degeneration; CFL, central field loss; NA, not applicable; SPMSQ, Short Portable Mental Status Questionnaire; VA, visual acuity.

aData are given as mean (SD) [range] unless otherwise indicated.
bSome degrees of freedom are fractional because they are adjusted for inequality of variances.
cOne nondriver later resumed driving. In all, 4 participants with CFL were licensed to drive.
dOptic 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/s² 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 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 7º to 25º. 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, F1,20 = 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, F1,21 = 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, F1,21 = 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 = 0.007, 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).
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 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 anticipated6 but have not been previously documented because of the difficulties of studying visually impaired driving. One on-road study of mild CFL32 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 study33 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 \( t_{10} = 5.9, P < .001 \)).
Despite deploying pedestrians at double the perception-brake sight distance in the American Association of State Highway and Transportation Officials guidelines\(^2\) (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.\(^3,3\)

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\(^3\) 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.\(^5,7\) 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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Online-Only Material: The eFigures are available at http:\/\slash\slashwww.jamaophth.com.

### Table 2. Spearman Correlations Between Vision and Performance Measures for the 11 Participants With Central Field Lossa

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reaction times</th>
<th>Visual Acuity</th>
<th>Contrast Sensitivity</th>
<th>Scotoma Size</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>City, seeing</td>
<td>0.46</td>
<td>-0.59</td>
<td>0.27</td>
<td>-0.19</td>
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</tr>
<tr>
<td>City, blind</td>
<td>0.37</td>
<td>-0.41</td>
<td>0.49</td>
<td>0.01</td>
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<tr>
<td>Highway, seeing</td>
<td>0.48</td>
<td>-0.77</td>
<td>0.31</td>
<td>-0.14</td>
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<tr>
<td>Highway, blind</td>
<td>0.39</td>
<td>-0.05</td>
<td>-0.08</td>
<td>-0.14</td>
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</tr>
<tr>
<td>Detection rates</td>
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<tr>
<td>City, seeing</td>
<td>0.31</td>
<td>0.27</td>
<td>-0.09</td>
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<td>City, blind</td>
<td>-0.01</td>
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<tr>
<td>Highway, seeing</td>
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<td>0.20</td>
<td>0.00</td>
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<tr>
<td>Highway, blind</td>
<td>-0.13</td>
<td>0.61</td>
<td>-0.54</td>
<td>0.38</td>
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<tr>
<td>Untimely reaction</td>
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<td>City, seeing</td>
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<td>-0.51</td>
<td>0.34</td>
<td>0.22</td>
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<tr>
<td>City, blind</td>
<td>0.10</td>
<td>-0.47</td>
<td>0.71</td>
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<tr>
<td>Highway, seeing</td>
<td>0.41</td>
<td>-0.83</td>
<td>0.39</td>
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<tr>
<td>Highway, blind</td>
<td>0.24</td>
<td>-0.10</td>
<td>0.19</td>
<td>0.10</td>
<td></td>
</tr>
</tbody>
</table>

\(^{a}\)Significant correlations are set in bold type (2-tailed).
Additional Contributions: Christina Gambacorta, BA, Egor Ananev, BS, and Alex Hwang, PhD, made helpful comments on the manuscript. Joseph Rizzo, MD (Center for Innovative Visual Rehabilitation, Veterans Administration Boston Healthcare System), provided the simulator. The Harvard Cooperative Program on Aging assisted in recruitment.

REFERENCES


