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Hazard Detection by Drivers with Paracentral Homonymous Field Loss: A Small Case Series

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Abstract

Introduction: Stroke frequently causes homonymous visual field loss. We previously found in a driving simulator that patients with complete homonymous hemianopia had difficulty detecting potential hazards on the side of the field loss. Here we measured the effects of limited paracentral homonymous field loss on detection performance.

Methods: Three patients with paracentral homonymous scotomas, yet meeting vision requirements for driving in the United States, performed a pedestrian detection task while driving in a simulator. Pedestrians appeared in a variety of potentially hazardous situations on both sides of the road. Three age- and gender-matched control participants with normal vision participated for comparison purposes.

Results: Pedestrians appearing in the scotomatous side of the visual field were less likely to be detected, and when they were, reaction times were longer, frequently too late to respond safely.

Conclusions: Although legally permitted to drive in the USA, and possibly in other countries, patients with paracentral homonymous field loss may have impaired hazard detection and may benefit from education about their deficit and a fitness-to-drive evaluation.

Introduction

Homonymous visual field defects, commonly caused by brain injury due to stroke, affect the same half of the visual field of each eye [1]. Such visual deficits affect nearly 1% of people over 49, and 2-3% of people over 70 years of age [1]. The majority (at least 60%) of homonymous defects are incomplete with part of the vision in the affected hemifield spared [2].

In our prior driving simulator study, participants with complete homonymous hemianopia failed to detect 35-75% of pedestrian hazards in their blind hemi-field (depending on position relative to the driving lane) [3]. However the effect of incomplete homonymous field loss on potential hazard detection while driving has not been systematically evaluated. Here we report three cases with homonymous loss limited to the central area of the affected hemifield (paracentral scotomas). This type of field loss is not uncommon, accounting for at least 20% of incomplete homonymous defects [2]. Visual screening for driver licensing in the USA focuses on visual acuity and peripheral visual field extent, but not paracentral scotomas. By comparison, some other countries, including the UK and Canada [4,5], require screening for paracentral scotomas. As paracentral homonymous field loss is unlikely to be detected by visual screening tests for driver licensing in the USA, these patients are more likely to be on the road than patients with complete hemianopia who are restricted from driving in many states. Yet, they may also have detection deficiencies, as demonstrated by our three cases.

Methods

Three patients with paracentral homonymous scotomas and three control participants (normal full-field vision and VA 20/25 or better) were recruited. Controls were case-matched to each patient so they were the same gender, a similar age (on average, 3 years older than patients), and had a similar driving history (on average, driving 3 years longer, all were current drivers).

All six participants signed an informed consent form approved by the Schepens Institutional Review Board. We measured all participants' binocular peripheral visual fields using Goldmann perimetry (V4e target) and central visual fields with a custom-designed computerized perimeter [6] using kinetic perimetry (0.7° target, similar to the Goldmann IV3d target). Cognitive status was evaluated using the Short Portable Mental Status Questionnaire (SPMSQ) [7].

Driving was evaluated in a high-fidelity driving simulator Model PP-1000 (FAAC Inc., Ann Arbor, MI), over two 2-3 hour sessions conducted a week apart. The simulator has 5 screens that provide a 225° field of view, and an open cab with all controls typical of a car with automatic transmission. During each session all participants completed five test drives, three on city roads (30mph posted speed limit) and two on rural undivided highways (60mph). They were instructed to follow all the normal rules of the road.

Pedestrian models were 2m tall in the virtual world and appeared along the road at one of four locations relative to the car's heading (-14°, -4°, 4°, and 14°); Figure 1 D; [8]). 104 pedestrians were presented over the two sessions. Pedestrians were designed to represent a realistic hazard: they walked or ran toward the participant's travel lane. The participant's vehicle and the pedestrian were on a collision course; therefore the pedestrian maintained a relatively stable eccentricity

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with respect to vehicle heading for up to about 5 seconds after initial appearance [9,10]. Pedestrians stopped just before they reached the participant's travel lane to avoid collisions. More methodological details are available in Bronstad et al. [8].

Participants were instructed to press the horn as soon as they saw a pedestrian; we measured reaction times and detection rates. Given the distance to each pedestrian figure at horn-press time we calculated whether pedestrians were detected in sufficient time to avoid a potential collision (had the pedestrian continued walking into the participant's travel lane). The calculation was based on the participant's driving speed and an assumed deceleration of 5m/s² [11].

Case Reports

Case 1

A 76 year old woman suffered a hemorrhagic cerebrovascular accident 17 months earlier that caused an infarct in her right lateral geniculate nucleus, confirmed by CT scan. There was corresponding sectoranopia [2] in her left hemifield (Figure 1). She showed no evidence of neglect, had binocular visual acuity (VA) of 20/30 (decimal 0.67), and was mentally alert (SPMSQ score of 11/11). She reported driving five times a week to stores, appointments, and the gym, but avoided driving in high traffic and on highways. A family member had expressed concern about her driving performance. She is now deceased, cause unknown to us.

She detected all pedestrians on the non-scotoma right side of her visual field. Her response times on that side were 2 seconds (small eccentricity) to 2.8 seconds (large eccentricity), 0.7 to 1.1 seconds longer than control subjects, respectively (Figure 2). However, she failed to detect 10% of pedestrians that appeared on her scotoma (left) side. These failures were more than twice as likely to be on highway drives. Furthermore, when she detected pedestrians on the left side, her response times were very long, about 6 seconds, 4.7 seconds longer than the response times of age-matched control subjects (Figure 2). These scotoma-side deficits resulted in untimely responses (the pedestrian was not detected or was detected too late) for 23% and 31% of pedestrian appearances on the left side, at small and large eccentricities, respectively (Figure 3). She had untimely responses for 12% of pedestrian appearances at large eccentricities on the non-scotoma right side and none at the small eccentricity. She drove somewhat slowly on highway drives (40mph, rather than the posted 60mph), which would have reduced stopping distances and decreased the number of untimely responses, despite the long reaction times.

Case 2

A sixty year old man who had a stroke 8 months before driving in our simulator. His stroke caused an infarct in his right occipital lobe, suspected to be embolic in nature due to atrial fibrillation. The patient had a paracentral homonymous scotoma of about 30° in diameter in the left hemifield (Figure 1). His binocular VA was 20/15 (decimal 1.3) and he was mentally alert (SPMSQ of 11/11) with no sign of neglect. He was a current and confident driver and bicyclist, self-reported as driving "somewhat faster" than other drivers, travelling approximately three times a week to stores or restaurants. In a follow-up two years later he said that he increased his driving.

This patient also failed to detect about 10% of pedestrians that appeared on his scotoma left side. His response times were longer on his scotoma side by 0.45 (small eccentricity) to 2.3 seconds (large eccentricity) than those of normally-sighted controls (Figure 2). He
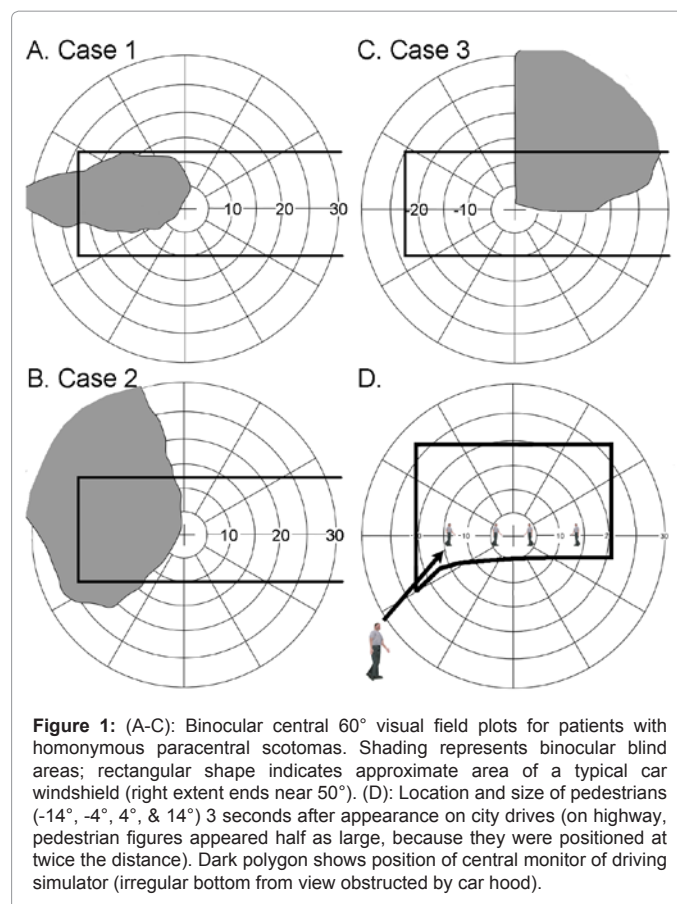

Figure 1: (A-C): Binocular central 60° visual field plots for patients with homonymous paracentral scotomas. Shading represents binocular blind areas; rectangular shape indicates approximate area of a typical car windshield (right extent ends near 50°). (D): Location and size of pedestrians (-14°, -4°, 4°, & 14°) 3 seconds after appearance on city drives (on highway, pedestrian figures appeared half as large, because they were positioned at twice the distance). Dark polygon shows position of central monitor of driving simulator (irregular bottom from view obstructed by car hood).

had untimely responses for 8% (small eccentricity) to 30% (large eccentricity) of pedestrian appearances on his scotoma side compared to 0% on his non-scotoma right side (Fig. 3). He drove at an average speed of 52mph on highway drives and 26mph on city drives.

Case 3

A thirty-eight year old man who suffered a presumed embolic left temporal stroke 9 months before our evaluation with corresponding right superior homonymous quadranopia that affected only the central 30° of the visual field (Figure 1). He had a history of patent foramen ovale, a congenital heart condition that increases risk of stroke in people under 55. Binocular visual acuity was 20/20 (decimal 1.0), and he was mentally alert (SPMSQ of 11/11) with no evidence of neglect. He stopped driving after his stroke but later resumed.

This patient failed to detect 5% to 20% of pedestrians (small and large eccentricity, respectively) that appeared in the scotomatous right side of his visual field. His response times were longer on the scotoma side by 0.4 (small eccentricity) to 1.3 seconds (large eccentricity) (Figure 2), and didn't differ from those of normally-sighted controls on the unaffected left side. Like case 2, he had untimely responses for 8% (small eccentricity) to 31% (large eccentricity) of pedestrian appearances on his scotoma side compared to 0% on his non-scotoma side (Figure 3). He drove at an average speed of 53mph on highway drives and 27mph on city drives.
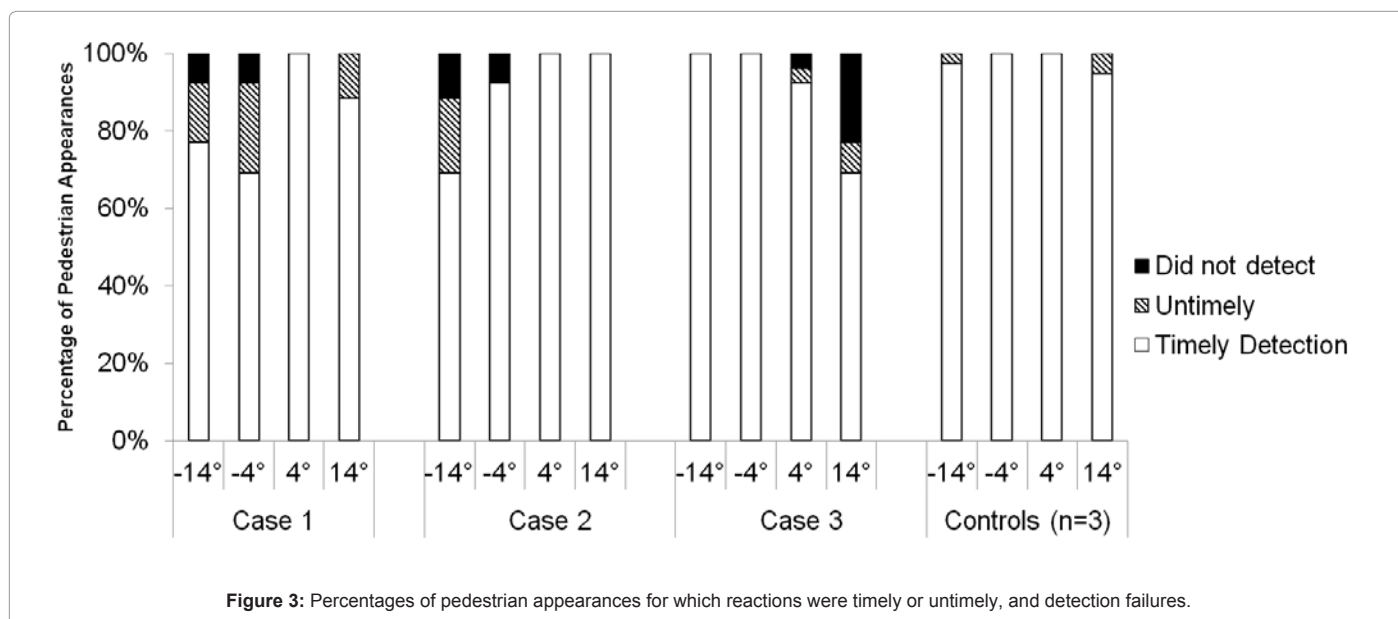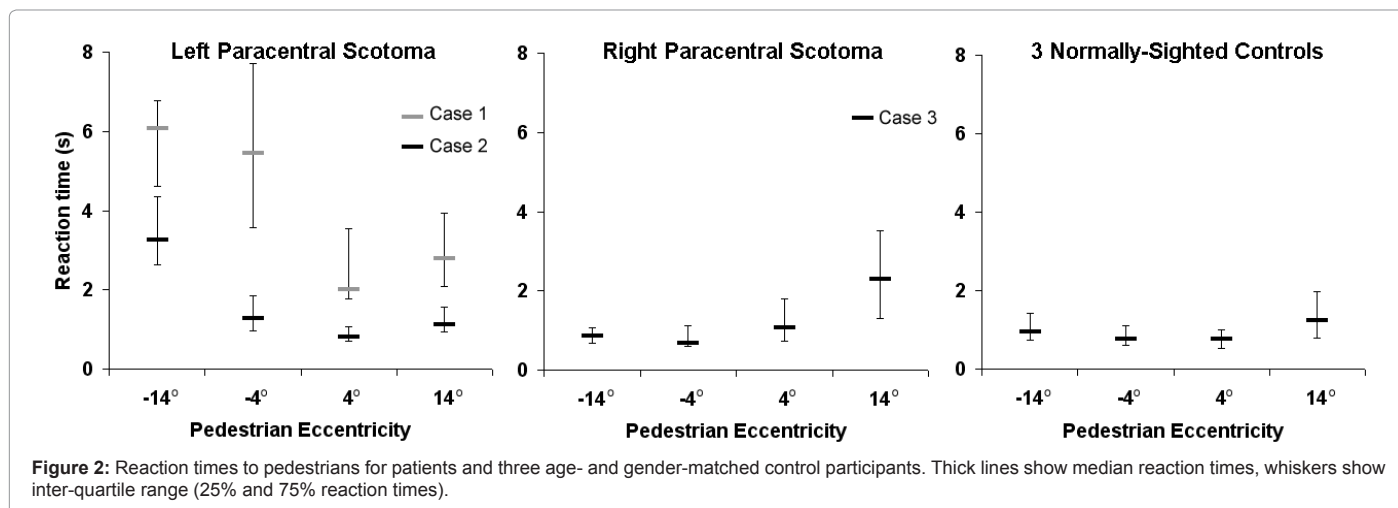
At the time of testing this patient, a 2-camera Smart Eye Pro (Smart Eye AB, Göteborg, Sweden) remote infra-red eye- and head-tracking system had been installed in the driving simulator. Thus, we were able
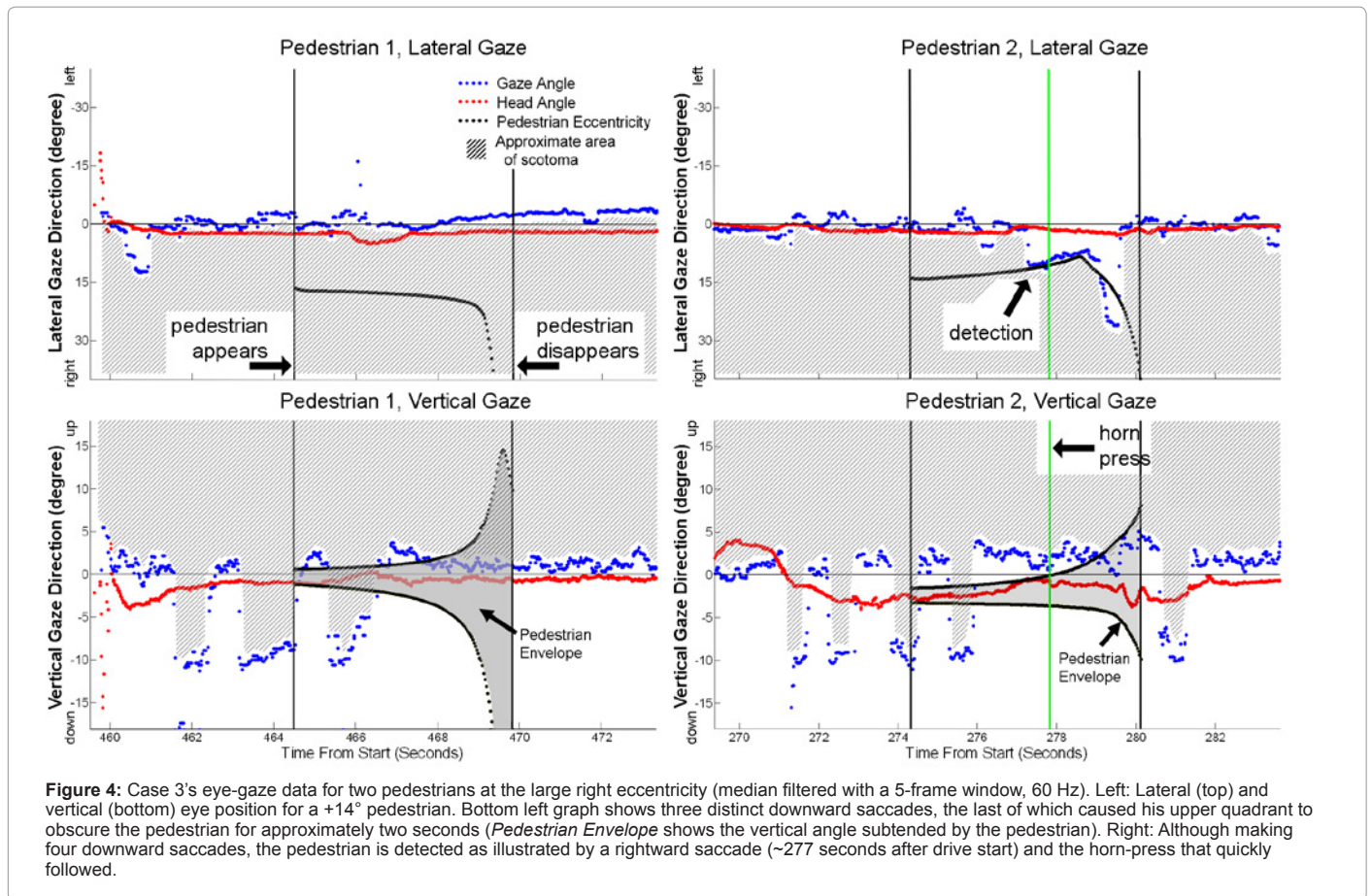
to examine the relationship between gaze behaviors and detection performance for pedestrians that appeared on the scotoma right side. Four of his six pedestrian detection failures on the right side happened when he was either following a lead car or there were other distracting objects in view (*e.g.*, an emergency vehicle with flashing lights); gaze data confirmed that in these situations, gaze was either fixed on the car ahead or the distracting object in the left field such that the pedestrian likely remained within the scotomatous area and was not detected. The two upper plots in Fig 4 show lateral gaze position for two different pedestrians at the large eccentricity on the scotoma right side. During the approach to pedestrian 1 (not detected), lateral gaze position was mostly straight ahead and there were no saccades to the right. By comparison on the approach to pedestrian 2 (detected), he made a rightward saccade of about 15° and the pedestrian was then fixated until the time point at which it disappeared. The horn-press indicated detection occurred soon after the rightward saccade.

Also of interest, the gaze data for this patient indicated that he made frequent downward saccades, presumably to examine the speedometer (Figure 4, lower plots). During approaches to pedestrians (~5 seconds before appearance), he made an average of 0.87 downward saccades (median = 1, range = 0 to 4). In comparison three normally-sighted participants (different from the control participants, for whom we unfortunately have no eye-tracking data) checked the speedometer using downward saccades on average 0.3, 0.45, and 0.74 times during similar time periods. Case 3 thus made more frequent downward saccades, and in doing so his upper quadranopic scotoma covered the entire right half of the road, including pedestrians appearing in the right hemifield (Figure 4, lower plots). Note that for normally-sighted participants such downward gaze movements would not obscure the pedestrians.

Case 3 wanted to resume driving. We informed him of the detection failures due to his field loss and the need to consider the risks apparent from our results. The patient subsequently had a fitness-to-drive evaluation by an independent driving instructor. He was rated safe and resumed driving.

Figure 2: Reaction times to pedestrians for patients and three age- and gender-matched control participants. Thick lines show median reaction times, whiskers show inter-quartile range (25% and 75% reaction times).

Figure 3: Percentages of pedestrian appearances for which reactions were timely or untimely, and detection failures.

Figure 4: Case 3's eye-gaze data for two pedestrians at the large right eccentricity (median filtered with a 5-frame window, 60 Hz). Left: Lateral (top) and vertical (bottom) eye position for a +14° pedestrian. Bottom left graph shows three distinct downward saccades, the last of which caused his upper quadrant to obscure the pedestrian for approximately two seconds (*Pedestrian Envelope* shows the vertical angle subtended by the pedestrian). Right: Although making four downward saccades, the pedestrian is detected as illustrated by a rightward saccade (~277 seconds after drive start) and the horn-press that quickly followed.

Discussion

Each patient in this case series had paracentral visual field loss but sufficient horizontal peripheral visual field extent and visual acuity to qualify for an unrestricted driver's license in the USA [12]. All of them would fail field screening requirements in some countries, including the UK and Canada [4,5]. Cases 1 and 2 were current drivers, and case 3 subsequently resumed driving after an on-road test. All had reaction time and detection deficits to potential pedestrian hazards that appeared on the scotoma side that might be considered unsafe.

Case 1 had the longest reaction times on both the non-scotoma and scotoma sides, and the highest proportion of untimely responses. Had she been driving faster she may have been at greater risk; stopping distance is 180 feet at 52mph, whereas it is 107 feet at 40mph. Case 1 had longer reaction times than case 2, despite the fact that case 2 had a more extensive left-sided scotoma (though both are similar once limited by a car windshield: Figure 1). The difference between cases 1 and 2 may result from case 1 being older (76 years old) than case 2 (60 years old). In our previous study of drivers with complete homonymous hemianopia, age was strongly correlated with blindside detection rates: older participants had poorer detection rates than younger participants [3]. It is also known that men speed more than women [13]; case 1 was female and case 2 male. In the control group, the slowest participant was also the oldest and female. In addition, case 1 had the poorest acuity of the three patients, which might account for the delay in detecting the pedestrians appearing on the highway due to their smaller visual angle at appearance.

Case 3 might not be expected to have detection failures or reaction time delay to pedestrians on his scotoma side, as his field loss did not extend below the horizontal midline (Figure 1C). However, his reaction times were longer to pedestrians on his scotoma side than his non-scotoma side, and he had poorer scotoma-side detection rates than the other two cases. This suggests that either 1) his gaze was directed low enough to keep the pedestrians in the scotoma for much of the time, or 2) the lower half of the pedestrians did not provide sufficient contrast against the road or sidewalk background to be detected. Gaze tracking data indicates that pedestrians on the right were indeed in the scotoma for much of the time, especially as he made frequent downward saccades to the speedometer such that his upper quadranopic scotoma covered the entire right half of the road (Figure 4.). Similar saccades to the speedometer would not be expected to reduce pedestrian detection much for normally sighted drivers, as was indeed found. Furthermore, when gaze was held either by a distracting object in the left field or by the instruction to follow the car ahead there were no scanning saccades into the scotoma right field and pedestrians on that side were less likely to be detected. These situations could easily occur in real-world driving.

Whether people with partial or complete hemianopia can drive safely is an important question, with public safety and patient quality of life in the balance. The findings of this and other recent studies [3,14] indicate the importance of individualized evaluations, as the functional abilities of two people with similar vision loss can differ widely. In recent years the UK [4] and Quebec, Canada [5] have permitted licensing following successful on-road driving evaluations for patients with hemianopia who do not meet minimum horizontal visual field

requirements. This policy is similar to that used for many years in The Netherlands [15], Switzerland, and Belgium.

With careful visual field measurements, clinicians can determine whether scotomata are present, whether they overlap (and thus affect the binocular field), and based on the extent of field loss decide whether patients meet the screening requirement for driver licensing. If there is complete hemianopia, the individual may not meet the minimum visual field extent for driving in his/her state in the USA [16] and will not meet the minimum 120° field extent in Europe. If the patient has partial hemianopia, however, the individual may meet the minimum visual field requirements in some jurisdictions. Whether the homonymous field loss is complete or incomplete, a fitness-to-drive examination, by an experienced examiner on a sufficiently challenging course, is required in jurisdictions that permit driving with hemianopia. A specific recommendation in the recent Driver Fitness Medical Guidelines produced by the USA National Highway and Traffic and Safety Administration [17] states "Drivers with hemianopia or quadrantanopia should be given the opportunity for a comprehensive on-road evaluation by a driving specialist, and if judged fit to drive, should be given the opportunity to take the jurisdiction's road test" (p. 46).

Findings from our previous study [3] and this case series, however, suggest indirectly that an on-road driving test (or actual driving) may not be sufficient to uncover deficits in detection and reaction times to hazardous situations as such events may not occur with sufficient frequency in a typical on-road test. Thus a driving simulator may be an appropriate tool for evaluating responses to blindside hazards as the normally uncommon hazardous situations may be programmed to occur multiple times within a test session. If patients fail to respond in a timely manner in the driving simulator, when they are primed and aware of the possibility and nature of the hazard, they may be even less likely to respond in a timely manner when such hazards appear unexpectedly during on-road driving [18].

Acknowledgements

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