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ORIGINAL ARTICLE

The Effects of Visual Field Loss from Optic Disc Drusen on Performance in a Driving Simulator

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ABSTRACT

The purpose of this study was to compare the driving simulator performance of participants with visual field loss (VFL) from optic disc drusen (ODD) with a normally sighted control group and a group of individuals with glaucoma. Data on performance and safety from a traffic simulator test for five participants with VFL from ODD were retrospectively compared with data from 49 male individuals without visual deficits in a cross-sectional study. VFL of the ODD group was also compared with a group of 20 male glaucoma participants who had failed the same simulator test. Four individuals with ODD regained their driving licences after a successful simulator test and were then followed in a national accident database. All participants with ODD passed the test. No significant differences in safety or performance measures were detected between the normally sighted participants and the ODD group despite severe concentric visual field constrictions. Compared with failed glaucoma male participants, the ODD group had even lower mean sensitivity in the peripheral and peripheral inferior field of vision. None of the four participants with a regained licence were involved in a motor vehicle accident during a 3-year follow-up period after the simulator test. Despite having severe VFL, participants with ODD had no worse performance or safety than controls. As even individuals with severe VFL might drive safely, there is a need for individual practical assessments on licencing issues.

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Introduction

Sufficient vision for driving

Driving a car is unarguably a highly visual task. Countries all over the world have therefore set visual requirements for holding a driver's licence that usually includes minimum visual acuity and visual field. In most countries, the visual acuity limit is 0.5. The visual field needs to be at least 120° within the European Union. In the United States of America, this limit varies from ≥140° in Iowa to non-existent in California.[1] Even if the Nordic countries use the same European juridical framework, Sweden and Norway have relatively stricter regulations compared with Denmark, Iceland and Finland, by defining not only the requirements but also the perimetric methods to test the requirements.[2] To hold a driver's licence in Sweden, all corresponding test points within a 10° radius must be at least 20 dB measured with Humphrey perimetry with an object size III, or equivalent static threshold perimetry. Only one corresponding test point between 10° and 20° is allowed to be less than 10 dB.[3] In addition, a Swedish physician is obliged to report to the Transport Agency if the requirements are not met.[4] However, the relationship between visual field loss (VFL) and driving is far from clear. Therefore, a project was initiated at the Swedish Road and Traffic Research Institute (VTI) in Linköping in 2014 with the aim of developing a simulator-based method to assess if individuals with VFL can drive in a safe manner.[5]

Previous studies of visual field loss and driving

Two major outcomes are used in research on driving, safety and performance. Safety is defined by adverse events, typically collisions that might be studied in accident reports. An early and often-cited study report showed that 196 drivers with severe VFL in both eyes had accident rates twice

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those of the general population.[6] Performance, on the other hand, refers to driver behaviour when manoeuvring the vehicle. For example, an on-road study including 75 drivers with glaucoma and 70 age-matched controls showed that the former group were rated as significantly less safe, despite the fact that these drivers self-reported their driving to be relatively good.[7] Performance could also be studied in simulators. In a recent study from Japan, 100 patients with advanced glaucoma had significantly more collisions than 43 controls.[8] Compared with on-road driving, simulators can only give an imitation of reality and might also give motion sickness (simulator sickness). On the other hand, they provide a method to test hazardous situations in a systematic way.[9] Several studies suggest that VFL could be compensated for central VFL, strategies include reduction of overall driving speed; for peripheral VFL, strategies include increased head and eye movements. However, a period of time must elapse in order for individuals to develop these compensatory strategies.[10]

Optic disc drusen and visual field loss

Optic disc drusen (ODD) are acellular deposits of unknown pathogenesis located in the optic nerve head. The prevalence is estimated to 0.3–2.0% of the population, and the majority of cases are bilateral.[11] Although often asymptomatic, ODD are associated with visual field defects in frequencies ranging from 11% to 87%. Studies suggest that ODD involve a transition phase in adolescence where visual field defects may rapidly progress with minimal worsening thereafter.[12] Individuals with visible ODD have more VFL than those with buried ODD. Arcuate field defects, enlarged blind spots, nasal steps and constricted visual fields are the most common abnormalities. Progression may occur over the years. As the prevalence does not differ between children and adults, ODD do not likely develop after the first decade of life. Even though several strategies have been explored, no effective treatment has yet been established.[13] As optic neuropathy is associated with VFL, the condition mirrors glaucoma and therefore poses a challenging diagnostic dilemma although diagnosis has been facilitated by advances in optical coherence tomography technology.[11] VFL from ODD may be severe. A study including 66 patients with documented ODD showed that three (4.5%) did not fulfil the German visual field requirements for driving.[14] As patients with ODD might develop visual field defects at a young age, which thereafter remain relatively stable, they might have better compensatory abilities for driving than individuals with VFL with onset in later life. However, despite the impact of ODD on visual function, no studies have yet evaluated its association with driving performance and safety. This study analyses the result from a driving simulator test for individuals with VFL due to ODD compared with a healthy control group and with drivers with VFL from glaucoma.

Materials and methods

Participants

Between November 2014 and January 2015, normally sighted individuals were recruited to perform a driving simulator test at the VTI in Linköping. They needed to state themselves as healthy, drive approximately 15,000 km/year and be between 55 and 75 years of age. This group was also asked to visit an optician to test that their visual acuity was normal before the test and to bring this result. All controls were screened for visual field defects with 24-2 Humphrey perimetry. A normal binocular visual field was defined as mean deviation >−2 dB in the better eye as this value might be even lower (average −2.9 dB) in first-time testing of normal subjects.[15] These 83 individuals were paid €100 for participation. The driving behaviour for the normally sighted was used to create reference values for critical behaviour that was used to define a passed test.

Thereafter, between June 2016 and August 2018, individuals with withdrawn licences due to VFL could apply for the test and use the result as a cause of dispensation (i.e. return of the driver's licence) if no other medical complications were present. The cost for the individual was about €2000. Despite the price, the interest was very high. More than 300 individuals with VFL for different reasons (334) completed the test until August 2018 when the activity was paused for evaluation. The most common reasons for VFL were stroke, glaucoma and diabetes mellitus. As all these drivers were aware of the possibility of a returned driver's licence, all were highly motivated. In a previously published study, the glaucoma group passed the test in 71% of the cases.[16] This study analyses the result from the subgroup of five individuals with VFL due to ODD. Ethical approval was given by Linköping University Committee (Dnr 2014/124-31).

Field of vision

All participants with VFL had withdrawn licences due to the visual requirements of the Swedish legislation. The participants were asked to attach medical journals and visual field charts when applying for the simulator test. Diagnosis and visual field examinations were therefore always done in advance in a clinical setting (i.e. at their local clinic when the question of visual field requirements for driving was raised). If medical information was missing, this was asked for from the Swedish Transport Agency, which archives all decisions for individuals with withdrawn licences. To be included in the analysis of visual field, an examination with 24-2 Humphrey perimetry or Octopus G standard was needed. Examinations performed with Octopus were converted into Humphrey Field Analyser (HFA) according to previously described algorithms.[17] The binocular integrated visual field (IVF) was calculated by merging the points from monocular HFA, using the point with higher sensitivity from each test.[18] The number of corresponding test points below 20 dB within 10° in the IVF and the mean dB for different visual field clusters were thereafter extracted for each participant for comparison (Figure 1). To evaluate the severity of VFL in the ODD group, the mean sensitivity in these clusters was compared with that in the participants with VFL from glaucoma that had failed the test.

The simulator, the scenario and the safety and performance parameters

The driving simulator Sim III consisted of a real truncated car body.[19] The driving scenario contained three types of roads with different speed limits: city driving (30–50 km/h); rural road (70 km/h); and motorway (110 km/h). The testing was preceded by a practice session for approximately 8 minutes, giving the participant a possibility to get acquainted

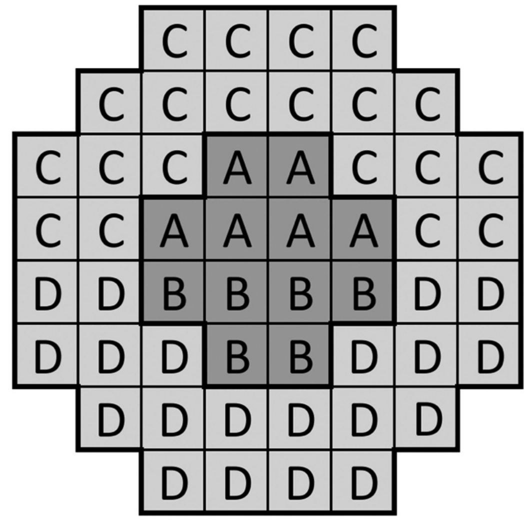

Figure 1. Test point clusters in a 20° integrated visual field. Boxes marked (A) show the superior test points located within the central 10°. Boxes marked (B) show the inferior test points located within the central 10°. Boxes marked (C) show the superior test points located between 10° and 20°. Boxes marked (D) show the inferior test points located between 10° and 20°.

with the equipment. The test drive then took approximately 50 minutes to complete, depending on the participant's chosen speed. The scenario did not include sharp turns, due to simulator sickness. The test included 33 possible collisions, including both with other cars and pedestrians. Failure to give way (FGW) was a specific situation when the test driver came too close to pedestrians. We used the minimum distance to the pedestrian and considered distances between 0 and 1 m as hazardous and 1 and 2 m as risky. This was measured 11 times and included only pedestrians. Time headway (THW) was the distance to different moving objects divided by the experimental vehicle speed.[20] THW was measured 29 times during the test. Values below 1 s were considered as critical, motivated by previous research on traffic safety.[21] Reaction time was measured 17 times during the test with objects that suddenly appeared and required braking. The simulator also recorded the average speed in all three different environments. Further details can be found in our previous publication.[16]

Assessment of passed versus failed

All test results from the 334 individuals with VFL for different reasons were digitally stored in protocols with a video recording of the full driving scenario. The data were retrospectively analysed by two independent traffic safety experts, one traffic inspector and one traffic safety researcher. In total, seven traffic inspectors and five traffic safety researchers were involved in the assessment. The instruction to the traffic inspector was to use his/her understanding of a normal on-road driving licence test session according to the Swedish guidelines.[22] The traffic safety researchers instead used a rating scale, based on 95% confidence intervals from the control group.[23] The classification into pass or fail was finally always based on subjective assessments. If the experts disagreed in their opinion, an additional traffic safety researcher performed a third assessment. However, this was rare as the inter-rater agreement was high with 93% overlap. None of the experts had any information about the side and degree of the driver's VFL when making pass/fail decisions.

Design and statistical considerations

The design was a between participant design with ODD versus normally sighted as one variable. The second step was to compare ODD participants with failed glaucoma participants. The dependent measures used in this study were a passed test but also several safety and performance parameters. The most important safety parameters were actual collisions and failure to give way, and the most important performance parameters were reaction time and THW. In addition, the extent of VFL was compared between passed ODD participants and failed glaucoma participants. Group comparisons were performed using t-tests and z-test of proportions. An alpha level of $p < .05$ was always used.

Car accidents among dispensation cases

One part of the evaluation of the simulator-based driving test was to conduct a follow-up of all individuals that had regained their driving licence after a successful performance in the simulator. The Swedish Traffic Accident Data Acquisition (STRADA) database was used that includes all road accidents with personal injuries in Sweden reported by the police or emergency hospitals.

Results

ODD versus normally sighted

All five participants in the ODD group passed the test. As the group with ODD consisted only of men, only men from the control group were used for comparison ($n = 49$). The two groups were matched by age. Statistical analysis of average speed, reaction times, lateral position (with independent two-sided t-tests), collisions, THW events and FGW events (with z-test of proportions) did not reveal any significant differences between the ODD and the normally sighted groups. However, the ODD group had their lateral position significantly dislocated to the right on the city road (Table 1). Compared with individuals that applied for the simulator test for other reasons, ODD participants had better success than most other groups, even if several other groups had lower mean age (Table 2).

ODD versus failed glaucoma participants

Compared with the ODD group, the failed male glaucoma group were significantly older (mean age 75 years), had a significantly higher mean number of critical THW events (5.4) and had their lateral position significantly dislocated to the right (0.1 m) on the motorway (all $p < .05$ with an independent two-sided t-tests). All participants with ODD had an available result from binocular Esterman perimetry, four from monocular 24-2 Humphrey perimetry

Table 1. Driving simulator data for male controls and patients with optic disc drusen.

	Controls	Optic disc drusen	p Value
Number	49	5	
Mean age (years)	66	64	.33
Mean speed when city driving (km/h)	41	39	.33
Mean speed on the rural road (km/h)	81	76	.05
Mean speed on the motorway (km/h)	108	103	.09
Drivers with collisions	12%	20%	.62
Drivers with hazardous (0–1 m) FGW	2%	0%	1.25
Drivers with risky (1–2 m) FGW	22%	0%	1.76
Average critical (<1 s) THW events	4.2	2.4	.07
Average RT (s)	0.67	0.65	.74
Average LP when city driving (m)	0.0	−0.2	<.05
Average LP on the rural road (m)	0.0	−0.1	.42
Average LP on the motorway (m)	0.0	0.3	.06

FGW: failed to give way; LP: lateral position compared with controls (- to the right, + to the left); THW: time headway; RT: reaction time.

Table 2. Results and mean age for 334 participants with visual field loss for different reasons that undertook a simulated driving test at the Swedish National Road and Transport Research Institute, Linköping, during 2016–2018.

Disease	n	Mean age	Percentage who passed
Stroke	153	62	65
Glaucoma	104	69	71
Diabetes	27	60	56
Brain lesions (except stroke)	22	46	68
Trauma	7	48	71
Tumours	7	43	57
Malformations	8	47	75
Optic nerve lesions (except glaucoma)	9	64	89
Optic disc drusen	5	64	100
Optic nerve infarction	3	60	100
Optic neuritis	1	72	0
Retinal lesions (except diabetes)	10	53	80
Dystrophy	5	51	100
Amotio	3	47	67
Age-related macular disease	2	66	50
Other	9	68	67
Total	334	63	67

and one from monocular Octopus G-standard. All had severe concentric constrictions in at least one eye. The average number of blind points within 120° width and 40° height with Esterman perimetry was 11 (Figure 2). Compared with the failed male glaucoma participants with available visual fields (n = 20), the ODD group had even lower mean sensitivity in the peripheral and peripheral inferior field of vision ($p < .05$ with independent one-sided t-tests) (Table 3).

Car accidents among dispensation cases with ODD

All individuals with a passed test applied for a renewed driver's licence. Among these, one was rejected because of other medical circumstances. The four individuals that regained their licence had to prove that their visual field defects had not deteriorated in a given interval (e.g. every second year). All of them still had a driver's licence 3 years after the test, and none of them were found involved in a motor vehicle accident according to the STRADA database.

Discussion

This study of simulator driving performance of individuals with severe VFL from ODD showed that this group did not have worse driver performance or safety margins than a normally sighted control group. In addition, all patients with ODD passed the simulator test even if their peripheral visual field was worse than failed patients with glaucoma.

The high success rate in this group could may be explained by the fact that patients with ODD usually develop VFL during the first decade of life,[12] which may facilitate the development of compensatory mechanisms. This also implies that central VFL is more crucial than peripheral VFL for safe driving. The ODD group also had lower mean sensitivity in the inferior visual field than the failed glaucoma group. This might also point to a higher degree of compensation as previous studies have shown that defects in the inferior visual field are more important for driving performance than those in the superior visual field.[8] The dislocated position to the right in the city section is rather contradictory as most hazards in city driving hazards are often coming from the right side (with right-hand sided traffic regulation). However, it should also be noted that the high cost for the testing (€2000) could affect the selection of participants. Individuals with less affected driving and higher economic resources were probably more disposed to apply for the test.

The individuals with renewed licences had no higher risk of on-road collisions on follow-up. The significance of this result, however, is not clear due to the low number of licence renewals (n = 4) and the short-time period of follow-up (2.9–4.5 years). Hence, it is not yet possible to conclude that our simulator assessment can discriminate between safe and unsafe drivers. However, the data support that the method is valid even if further evaluation is needed. Previous studies have shown that driving simulator testing seems to be a well-standardised method with good conformity to on-road driving, and it is appropriate for assessment of driving performance in individuals with binocular VFL.[24] Multivariate analysis of visual, attentional, perceptual, cognitive and psychomotor abilities combined with structured road testing might also distinguish safe from unsafe drivers among persons with other medical or psychological conditions.[25]

To the best of our knowledge, this is the only study so far of driving behaviour in simulator for individuals with VFL from ODD. Other strengths

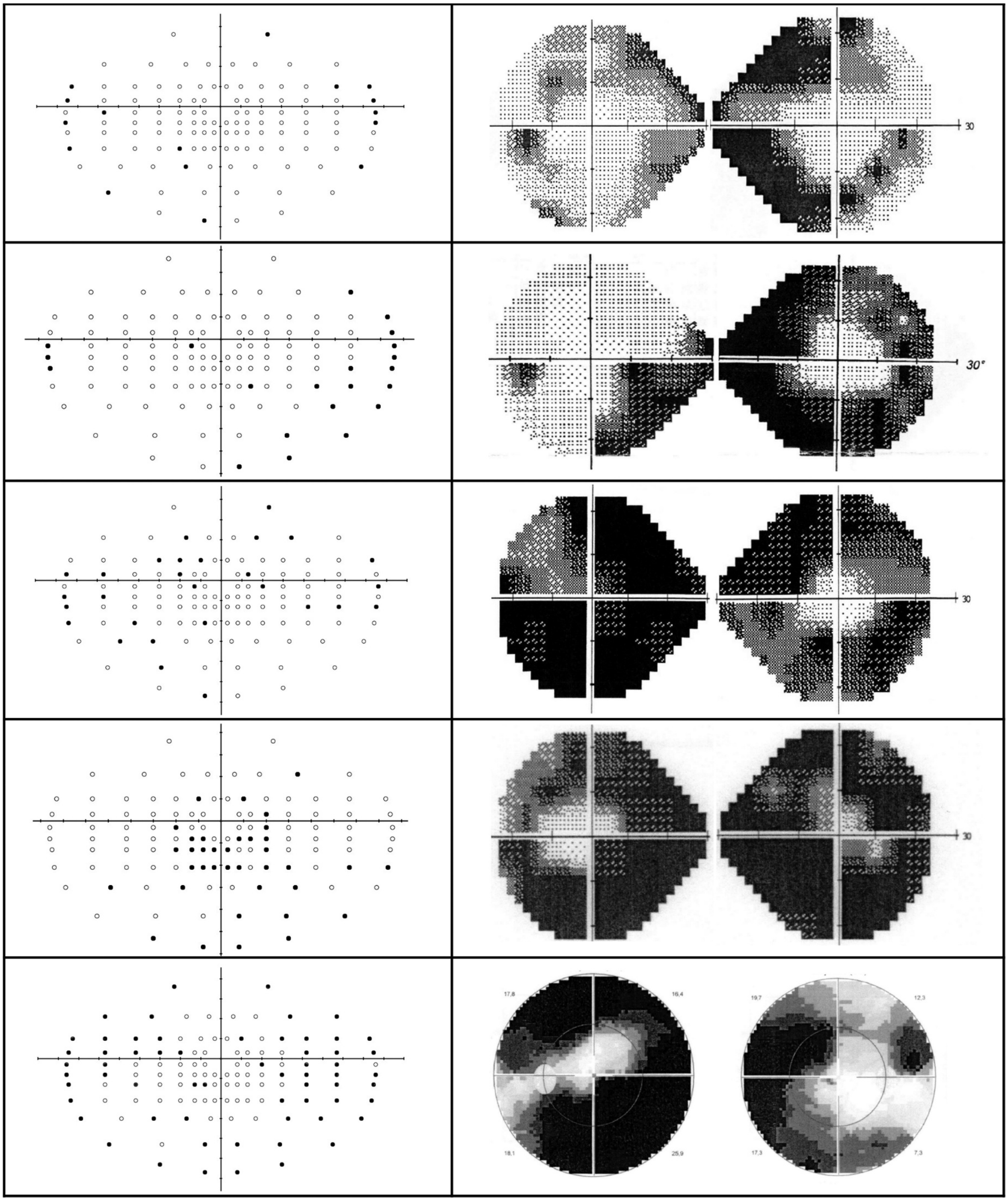

Figure 2. Perimetric examinations with binocular Esterman (left) and 24-2 Humphrey or Octopus G-standard (right) for the five participants with visual field loss from optic disc drusen.

of the study are the detailed simulator scenario and that the patients performed the test with the aim to regain their licences, which guarantees very good participation. In addition, both the control and the glaucoma group were sex-matched with the study group. This is an advantage as men and women may have different comfort with speed and willingness to take risk. A recent study of gender differences in simulated driving found that men drove more carefully than women.[26]

The study has, however, also important weaknesses. Due to the difficulty in recruiting patients with this diagnosis, the ODD cohort was very small ($n = 5$), and two of them had no central VFL on

Table 3. Comparison of mean sensitivity in different clusters of the integrated visual field for male participants with glaucoma who failed the simulator test and participants with optic disc drusen who passed the test.

	Failed glaucoma $n = 20$	Passed optic disc drusen $n = 5$	p Value
Mean age (years)	74	64	.00
IVF mean sensitivity (dB)			
Central (A + B)	19.8	22.1	.18
Peripheral (C + D)	19.4	14.7	<.05
Central superior (A)	18.1	21.6	.22
Central inferior (B)	19.0	16.2	.22
Peripheral superior (C)	21.4	22.7	.37
Peripheral inferior (D)	19.8	13.2	<.05

A-D: visual field clusters according to Figure 1; IVF: integrated visual field.

binocular Esterman testing. The result may therefore be questionable in a broader population and should not be overgeneralised. Sharp turns could not be used because of simulator illness, which made the simulator less like reality. Furthermore, a simulator test also always requires an amount of visual simplifications of the roadway. As head and ocular movements were not recorded, the importance of compensation could not be evaluated. The most important weakness, however, is that the normally sighted participants were not assessed in terms of having passed or failed the test due to resources (i.e. the availability of traffic inspectors), therefore, we do not know if all controls passed the test. An additional deficiency is that the failed glaucoma group had a significantly higher mean age than the ODD group. At the same time, the reference values for a passed test were created based on the results of the normally sighted control group. It should also be noted that the high cost for the testing (€2000) might have affected the selection of participants in two different ways. Participants with better economic resources and participants who believed that they would pass the test were probably overrepresented.

Even if the extent of central VFL may predict driver safety on a group level, drivers with severe VFL from ODD might also be safe drivers. It seems, therefore, reasonable to provide an opportunity for individualised assessments of practical fitness to drive in licencing issues. On-road testing by a certified driving examiner is currently considered the clinical gold standard. However, driving simulators may provide a useful adjunct to a road test for evaluation of responses to potential hazards under safe, controlled and repeatable conditions.

Disclosure statement

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