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The effect of visual field defects on eye movements and practical fitness to drive

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Abstract

Eye movements of subjects with visual field defects due to ocular pathology were monitored while performing a dot counting task and a visual search task. Subjects with peripheral field defects required more fixations, longer search times, made more errors, and had shorter fixation durations than control subjects. Subjects with central field defects performed less well than control subjects although no specific impairment could be pinpointed. In both groups a monotonous relationship was observed between the visual field impairment and eye movement parameters. The use of eye movement parameters to predict viewing behavior in a complex task (e.g. driving) was limited. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Visual field defect; Eye movement; Visual search; Driving

1. Introduction

Central, paracentral and peripheral visual field defects pose differential difficulties on vision. It can, therefore, be expected that they lead to differential visual search strategies. Studies on eye movements in subjects with real or simulated visual field defects revealed that central scotomas resulted in increased search times (Bertera, 1988; Henderson, McClure, Pierce, & Schrock, 1997; Murphy & Foley-Fisher, 1988) but that saccadic amplitude was not affected (Bertera, 1988; Murphy & Foley-Fisher, 1989). Fixation duration was significantly increased in a visual search task requiring subjects to find a target in a matrix of squares (Bertera, 1988) but not when subjects were required to detect a stimulus of a particular luminance against a scene of another uniform luminance (Murphy & Foley-Fisher, 1988) or when

subjects were required to determine the identities of objects in an array (Henderson et al., 1997). Studies on peripheral visual field defects report increased search times and number of fixations. Zihl (1995) reported that 60% of subjects with homonymous hemianopia had impaired visual scanning patterns on a dot counting tasks. Scanning pattern was characterized by a nearly threefold longer search time and a substantial increase in number of fixations. Fixation durations and saccadic amplitudes were not increased. Henderson et al. (1997) reported data of less severe peripheral visual field defects. They reported a small increase in total fixation time and number of fixations in a group with a scotoma immediately to the right of the current fixated region (scotoma-offset condition). They also reported slightly longer gaze durations (the sum of all fixation durations) in this condition as compared to the control condition. Despite the differences between the two studies regarding subject sample (brain damaged patients versus simulated scotomas) and object encoding that was required, the studies by Zihl (1995) and Henderson et al. (1997) suggest a linear relationship between the degree of visual field impairment and the eye movement characteristics.

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Cornelissen and Kooijman (submitted for publication) have recently investigated the relationship between visual field impairment and eye movement characteristics in subjects with simulated visual field defects. They observed that when the size of a central scotoma was increased search time, fixation durations, and the number of return saccades increased too. In case of peripheral visual field defects, Cornelissen and Kooijman (submitted for publication) observed prolonged fixation durations as a function of visual field extent. Fixation durations decreased as the field of view enlarged. Enlarging the field of view also resulted in shorter search times and a more irregular scanning pattern.

In the present study, the effect of real visual field defects is studied in relation to a structured visual search task and an unstructured dot counting task. Eye movement characteristics of different visual field defect groups are compared and the relationship between the degree of visual impairment and eye movement behavior is investigated. It is then examined whether eye movement characteristics as assessed in the laboratory are related to viewing behavior in a real-life complex task, i.e. driving. It is assumed that subjects with visual field defects can use compensatory viewing strategies to overcome the negative effects of the visual field defect. The relationship between eye movement behavior and practical fitness to drive is determined and it is investigated whether eye movement characteristics can be used to predict at-risk drivers.

2. Methods

2.1. Subjects

Fifty volunteers participated in this experiment: 30 (60%) males and 20 (40%) females. They all had visual field defects due to ocular pathology such as (age-related) macular degeneration, glaucoma, or retinitis pigmentosa. They were recruited by short reports in newspapers, folders at ophthalmologists and rehabilitation centers and at patients' associations. All subjects were regular drivers, although most of them had been told they did not meet the vision requirements for driving anymore. Most of them (92%) held a valid driving license. Participation in the study had no impact on their driving license. Mean age was 60 years, age ranging from 34 to 86 years. When subjects volunteered to participate in the experiment, a letter fully explaining the nature of the experiment was sent to them. Subjects were asked to return a form, indicating whether they wished to participate or not. They were also sent a questionnaire related to the inclusion and exclusion criteria. To be included in the study, visual field defects had to be present, visual acuity had to be greater than 0.1 (decimal notation, equivalent to 20/200 or 1.0 logMAR) and

subjects had to have sufficient and recent driving experience, which was defined as a minimum of 2000 km during the last two years. Exclusion criteria were severe cognitive impairments, including hemi-spatial neglect. All subjects scored above a predefined cutoff point (22) on a cognitive screening test (MMSE (Folstein, Folstein, & McHugh, 1975), mean score = 26.6, range: 23–29). None of the subjects demonstrated clinical neglect. Hemi-spatial neglect was further screened by means of the Bells test (Vanier et al., 1990) (mean number of errors = 1.2, range: 0–6). Four subjects made more than four errors. However, the omitted targets were not lateralized and it was therefore assumed that the high number of omissions was caused by a visual scanning impairment rather than by hemi-spatial neglect. To gain insight in the effect of vision parameters on driving performance, subjects were classified in five groups. Groups were formed on the basis of the current vision requirements for driving. According to these guidelines, visual acuity has to be at least 0.5 (decimal notation, equivalent to 0.30 logMAR [1]) and the horizontal diameter of the binocular visual field has to extend for at least 120°. Group 1 ($n = 10$) had a central scotoma, resulting in reduced visual acuity (>0.3 logMAR) but intact visual fields ($>120°$). Group 2 ($n = 5$) had visual field defects that caused central vision loss (>0.3 logMAR) as well as restricted peripheral visual fields ($<120°$). Groups 3, 4, and 5 had good visual acuity (<0.3 logMAR) but varying degrees of peripheral visual field defects. Group 3 ($n = 8$) had a visual field constriction resulting in binocular visual fields of less than 80°. Group 4 ($n = 12$) had binocular visual fields between 80° and 120°. Group 5 ($n = 15$) had visual field defects that did not constrict the extent of the peripheral visual fields ($>120°$). Perimetry testing revealed scotomas in the paracentral or midperipheral area that did not impair visual acuity or constrict the horizontal diameter of the binocular visual field. Vision characteristics of the five groups are presented in Table 1. For the dot counting task (see Section 2.3), data of the visual field defect groups were compared to data of eight control subjects without visual field defects. Data of the control group were collected as part of a student research program. Visual acuity of the control group was higher than 1.0 (decimal notation, equivalent to 0.1 logMAR). Mean age of the control group was 60 years (range: 46–71). The research study was performed according to the Declaration of Helsinki and was approved by the ethical review committee of the University of Groningen (The Netherlands).

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[1] LogMAR is the logarithm of the minimum angle of resolution and refers to the angular size of the optotype which can just be discerned. LogMAR = 0 indicates standard acuity. Larger logMAR values indicate worse vision.

Table 1
Vision characteristics of the five groups with visual field defects

	Group 1: central VFD	Group 2: central and peripheral VFD	Group 3: peripheral VFD (<80°)	Group 4: peripheral VFD (80–120°)	Group 5: mild VFD (>120°)
n	10	5	8	12	15
Visual acuity[a]	0.65 (0.17)	0.66 (0.22)	0.15 (0.17)	0.16 (0.13)	0.10 (0.13)
Visual field[b]	148 (16)	82 (38)	34 (23)	101 (13)	148 (18)

[a] logMAR.
[b] horizontal diameter (in degrees) of the binocular Goldmann III4 isopters.

2.2. Procedure

This study was part of a larger research study on the effect of visual field defects on practical fitness to drive. Data reported here were collected during the first eight weeks of the study. Data regarding vision were collected in the first week. One week later, eye movements, visual attention, and viewing behavior were assessed (first session). During the third week practical fitness to drive was assessed. Eye movements, visual attention, viewing behavior, and practical fitness to drive were assessed again in weeks six to eight (second session).

2.3. Methods

2.3.1. Eye tracking
2.3.1.1. Eye movement recording. Subjects' eye movements were registered using an EyeLink Gaze Tracker (SensoMotoric Instruments (SMI), Teltow, Germany). The display generating computer received the 'real-time' gaze position data from the Eyelink through a high-speed Ethernet link. Stimuli were presented on a 20 inch monitor driven by a Power Macintosh computer. Saccades were detected off-line using a velocity criterion of $30° \text{ s}^{-1}$, an acceleration criterion of $8500° \text{ s}^{-1}$ squared and a displacement criterion of $1°$. Fixations were defined as the time between saccades. Prior to the statistical analysis, fixations shorter than 25 ms or longer than 1000 ms were excluded from analysis. To avoid onset and offset effects from affecting the results, the first and final two fixations (and saccades) were excluded too. Excluded were also those fixations that occurred during or immediately after an erroneous key press. The time at which the space bar was pressed was used as an indicator of visual search performance. Number of fixations, fixation duration, saccadic amplitude, change in direction of saccades (i.e., the difference in direction between two subsequent saccades), and the percentage of return saccades (i.e., the percentage (of total number of) saccades returning immediately to the previous fixation position) were used to characterize eye movement behavior during search.

2.3.1.2. Dot counting task. The dot counting task was based on the work by Zihl (1995). A random pattern of 19, 20, or 21 dots was presented on the screen. Subjects were instructed to count the number of dots. The test consisted of 15 trials. Subjects were sitting at a distance of 57 cm and viewed the display binocularly. The dots were white on a gray background (50% contrast). Diameter of the dots was 0.8° . The area in which the dots were presented extended for approximately 40° (diameter) horizontally and 30° (diameter) vertically. Subjects wore their own refractive correction.

2.3.1.3. Visual search task. The visual search task consisted of a hexagonal matrix containing 19 C's (distracters) and a single O (target). The matrix consisted of four rows and five columns. Size of distracters and target was 4.8° with a rim of 0.3°. Stimuli were white on a gray background (50% contrast). Orientation of the gap of the distracters was randomly determined to be left, right, up or down. Size of the gap was determined by a threshold detection program prior to the experiment. Gap size was 0.5 log units above threshold level for 25 trials and 1.0 log units above threshold for the remaining 25 trials. The subject was instructed to look for the target. When he had found the target, he was instructed to maintain his gaze on it while the experimenter pressed the space bar. Subjects were sitting at a viewing distance of 30 cm and viewed the screen binocularly. Subjects wore their own refractive correction for near vision.

2.3.1.4. Procedure. Prior to the eye movements recording, the threshold gap size to correctly detect the direction of the gap of one central target (e.g. C) was determined by a staircase procedure (quest method). No distracters were presented. Threshold values (in pixels) were log transformed. Subsequently, the log threshold value was increased with 0.5 log units (small gap) or 1 log unit (large gap). The reconverted pixel values were then entered into the visual search program to determine the gap sizes. Eye movement recording started with a calibration of the eye movement recording system. During the experiment, every trial started with a presentation of a central fixation spot (a rotating wheel). When subjects gazed at the fixation point, the experimenter pressed the space bar and a drift correction was carried out to correct for small deviations from the calibration settings. After pressing the space bar, the target display (either random dots or the visual search

display) was presented. Subjects practiced until they felt comfortable performing the test. The visual search task was always performed prior to the dot counting task.

2.3.2. Vision examination

The vision examination included refraction (if necessary), assessment of visual acuity (Bailey & Lovie, 1976), near visual acuity, visual field (Goldmann III4 and V4 isopters and HFA Central 10°), contrast sensitivity (Pelli, Robson, & Wilkins, 1988), dark adaptation, and eye motility.

2.3.3. Viewing behavior and visual attention

Viewing behavior was assessed by the AFOV test (Coeckelbergh, Cornelissen, Brouwer, & Kooijman, submitted for publication). The AFOV test is a visual search task which determines the (log) threshold presentation time that is needed to detect a target at various positions in the field of view. The target is an open circle (e.g. C) among 30 closed circles (O). Presentation times vary from 8 ms to 10 s.

Visual attention was assessed by a test similar to condition six of the UFOV test as developed by Ball, Beard, Roenker, Miller, and Griggs (1988). It consisted of four conditions: a peripheral task without distracters, a peripheral and central task without distracters, a peripheral task with distracters, and a peripheral and central task with distracters. The peripheral tasks involved the localization of a target whereas the central task required the identification of a central stimulus (i.e. a sad or happy face). Presentation times varied from 50 to 125 ms.

2.3.4. Practical fitness to drive

Practical fitness to drive refers to the ability of the driver to drive safely and smoothly despite a physical impairment, such as a visual field defect. It was assessed by means of a driving test on the road. Subjects were evaluated in their own car and their own neighborhood by an experienced driving examiner of the Dutch Central Bureau of Driving Licenses (CBR). This way of assessing practical fitness to drive is the official standard in the Netherlands to examine drivers who do not quite meet the (vision) requirements for driving. The driving examiner had knowledge of the visual acuity and visual field defect of the driver but was unaware of his performance on the driving simulator. The driver examiner determined whether the individual had adapted his behavior to minimize the negative effects of his impairment. To evaluate driving performance, he made use of a checklist. Items of the TRIP checklist included lateral position, steering control, choice of lane, car following, speed, viewing behavior, detection of traffic signals, mechanical operations, overtaking, anticipatory behavior, communication with other traffic participants, turning left, and merging into another driving lane. The

items were scored on a four-point scale (0–3). After the driving test, the examiner accredited a final score, which varied from 0 to 3. This final score was recoded to a pass/fail score and indicated whether the subject had failed (scores 0 and 1) or passed (scores 2 and 3) the driving test. The first driving test was regarded as a session to accustom the subjects to the assessment procedure. During the second session, the actual practical fitness to drive was assessed. Therefore, only the results of the second assessment are reported here.

2.4. Statistical analysis

Normality was assessed by means of the Shapiro–Wilk test. Data that were not normally distributed were transformed. The square root of number of errors in the dot counting task was used to obtain a normal distribution.

2.4.1. Dot counting task

Two analyses were computed to examine the effect of visual field defect on the dot counting task. Because of small sample size, data of Group 2 (central and peripheral visual field defects) were excluded from this analysis.

Results of subjects with peripheral visual field defects (Groups 3, 4, and 5) were compared to the results of the control group by a doubly multivariate repeated measurements analysis. The effect of visual field defect was analyzed as a between-subjects variable. Session was used as a within subjects variable. Dependent variables were search time, number of fixations, saccadic amplitude, change in direction of saccades, fixation duration and number of counting errors. Contrast testing compared the results of the visual field defect groups to the results of the control group. Polynomial contrasts were also used to determine the relationship between the eye movement parameters and the degree of visual impairment.

Results of subjects with central visual field defects (Group 1) were compared to results of the control group by a second analysis. The statistical analysis was similar to the analysis for the peripheral visual field defect groups.

2.4.2. Visual search task

Pearson correlation coefficients were computed between the visual field impairment and the eye movement parameters per gap size. Eye movement parameters are mean values of two sessions. For the peripheral field defect groups, the binocular horizontal diameter of the Goldmann III4 isopter was used as an index of visual field impairment. Data of 35 subjects were included with visual field extents ranging from 3° to 178°. For the central visual field defect group, visual acuity (logMAR) was used as an index of degree of central field impair-

ment. Data of 10 subjects were included with logMAR ranging from 0.90 to 0.42.

2.4.3. Predicting practical fitness to drive

Pearson correlations were computed between saccadic amplitude, fixation duration, saccadic change of direction, search time, number of fixations, number of errors, percentage return saccades and viewing behavior while performing an on-road driving test. Spearman's rho was computed between the same set of eye movement variables and the final score of the driving test. Significant correlations were added to two models to predict the pass/fail score of the on-road driving test by means of a logistic regression. The rationale for the models is described in more detail by Coeckelbergh, Brouwer, Cornelissen, and Kooijman, (submitted for publication). Model 1 consists of the current European vision requirements of driving and an index of viewing behavior. The predictor variables are visual acuity, visual field and AFOV threshold presentation times. Model 2 consists of predictor variables that have been described to be strong predictors of driving performance: visual attention score and contrast sensitivity. All subjects (n = 50) were included in this analysis.

3. Results

3.1. The effect of visual field defect on the dot counting task

3.1.1. Peripheral visual field defects

The multivariate effect of visual field defect was significant (Wilks' Lambda = 0.21, $F(18, 97) = 3.9$, $p < 0.01$), indicating that the visual field defect groups behaved differently on the combination of eye movement parameters. Univariate testing revealed that the multivariate effect was due to a difference between groups on the number of fixations ($F(3, 39) = 9.4$, $p < 0.01$) and the number of errors ($F(3, 39) = 6.0$, $p < 0.01$). The effects of visual field defect on search time ($F(3, 39) = 2.8$, $p = 0.05$) and fixation duration ($F(3, 39) = 2.8$, $p = 0.05$) were nearly significant. Differences between groups (contrast testing) are discussed for each dependent variable separately. Means are presented in Table 2.

3.1.1.1. Number of fixations. Subjects with peripheral visual field defects (Groups 3 and 4) made significantly more fixations than control subjects. In Fig. 1A, the relationship between groups and the number of fixations is depicted. It can be seen that smaller visual fields resulted in an increased number of fixations ($F(1, 39) = 25.0$, $p < 0.01$).

3.1.1.2. Number of errors. Subjects with severe peripheral field constrictions (Group 3) made significantly more errors than control subjects. The relationship between groups and number of errors is plotted in Fig. 1B. Polynomial contrast testing confirmed that subjects with smaller visual fields made more errors ($F(1, 39) = 11.6$, $p < 0.01$).

3.1.1.3. Search time. Subjects with severe peripheral field constrictions (Group 3) differed significantly from control subjects. Subjects with smaller visual fields needed longer search times (Fig. 1C), as confirmed by the polynomial contrast ($F(1, 39) = 7.6$, $p < 0.01$).

3.1.1.4. Fixation duration. The near significant effect of visual field defect on fixation duration is plotted in Fig. 1D and suggests that subjects with smaller visual fields had shorter fixation durations.

The multivariate effect of session was significant (Wilks' Lambda = 0.65, $F(6, 34) = 3.0$, $p < 0.05$). Univariate testing revealed that search time ($F(1, 39) = 7.8$,

Table 2
Eye movement parameters as a function of visual field defect group and session

|	Session	Group 1	Group 3	Group 4	Group 5	Controls
Search time (s)	1	10.1 (2.6)	14.1 (4.4)	10.7 (3.4)	10.8 (4.3)	9.7 (2.0)
	2	9.5 (2.7)	13.3 (3.9)	11.0 (3.8)	9.5 (3.3)	8.5 (1.7)
Fixations (#)	1	24.4 (9.5)	40.2 (13.9)	27.8 (8.4)	23.9 (8.2)	21.0 (4.2)
	2	22.4 (8.1)	37.5 (12.4)	27.0 (8.1)	21.0 (5.5)	17.9 (4.7)
Saccadic amplitude (°)	1	6.5 (1.3)	6.6 (0.8)	7.1 (1.8)	7.3 (1.8)	7.6 (3.7)
	2	6.9 (1.6)	6.7 (1.1)	6.9 (1.4)	7.0 (2.2)	7.1 (1.5)
Change direction (°)	1	78.6 (12.8)	80.9 (6.2)	81.9 (7.8)	81.4 (9.4)	85.7 (9.9)
	2	82.1 (10.3)	83.2 (5.8)	83.6 (8.4)	80.9 (9.9)	87.9 (9.1)
Fixation duration (ms)	1	441 (125)	338 (66)	386 (68)	446 (109)	381 (78)
	2	438 (98)	348 (54)	394 (83)	446 (109)	391 (102)
Errors (#)	1	1.8 (0.6)	3.4 (2.2)	2.5 (1.1)	1.3 (0.8)	1.5 (0.5)
	2	2.1 (0.6)	2.9 (1.5)	2.3 (1.0)	1.2 (1.3)	1.7 (1.0)
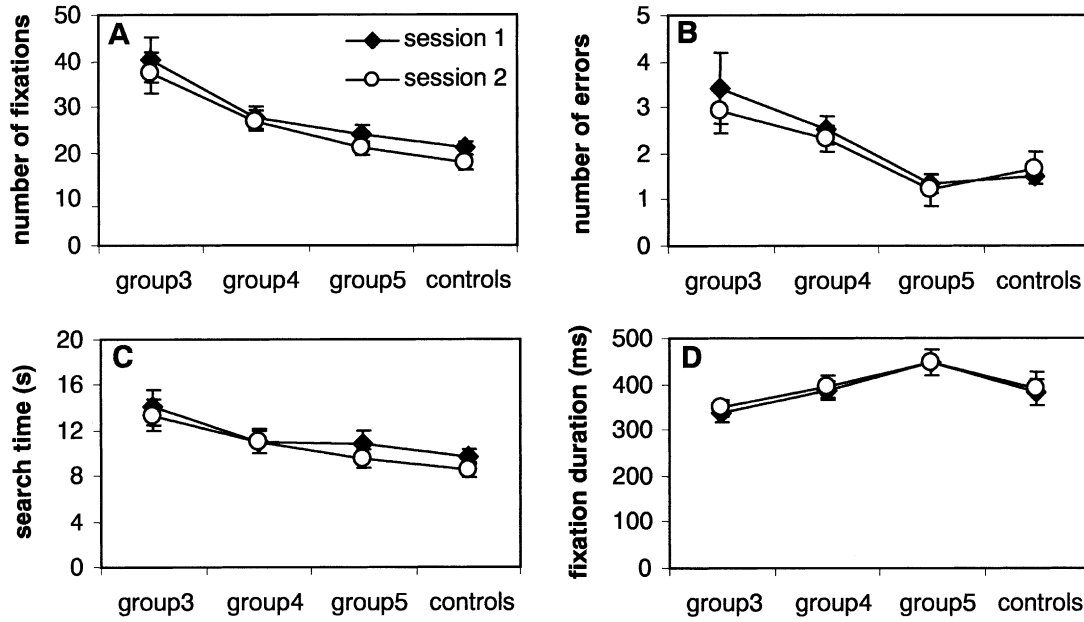
Fig. 1. Effect of peripheral visual field constriction on eye movement parameters.

$p < 0.01$) and number of fixations ($F(1, 39) = 12.2$, $p < 0.01$) decreased after the first assessment for all groups. The multivariate session by visual field defect-interaction was not significant (Wilks' Lambda = 0.76, $F(18, 97) = 0.76$, n.s.).

3.1.2. Central visual field defects

The multivariate effect of group (central visual field defect versus control group) was significant on the combination of dependent variables (Wilks' Lambda = 0.11, $F(6, 11) = 14.3$, $p < 0.001$), indicating that subjects with central visual field defects had eye movement characteristics that differed from those of control subjects. Univariate testing revealed that none of the dependent variables on its own reached significance ($p > 0.05$). Results of this group (Group 1) are presented in Table 2. The multivariate effect of session was significant (Wilks' Lambda = 0.24, $F(6, 11) = 5.9$, $p <$

0.01) and indicated that search times ($F(1, 16) = 8.4$, $p < 0.05$) and number of fixations ($F(1, 16) = 11.1$, $p < 0.01$) decreased after the first session for both groups. The multivariate interaction effect between session and groups was not significant (Wilks' Lambda = 0.79, $F(6, 11) = 0.49$, n.s.).

3.2. Relationship between visual field defect and performance on the visual search task

For the peripheral visual field defect groups, significant relationships between visual field extent and search time ($r = -0.34$, $p < 0.05$, Fig. 2A) and between visual field extent and number of fixations ($r = -0.37$, $p < 0.05$, Fig. 2B) were observed. Smaller visual fields were related to longer search times and higher number of fixations. Both relationships were observed for the large gap; the relationships for the small gap were not sig-
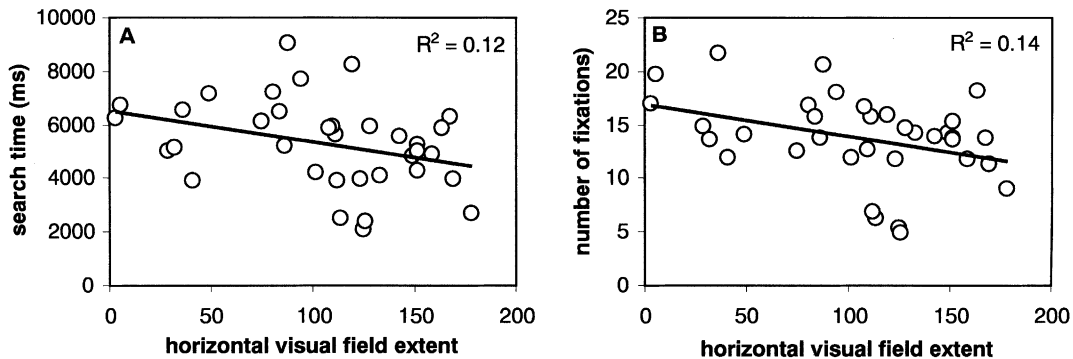

Fig. 2. Relationship between visual field extent, search time (A) and a number of fixations (B) on visual search task for subjects with peripheral visual field defects.
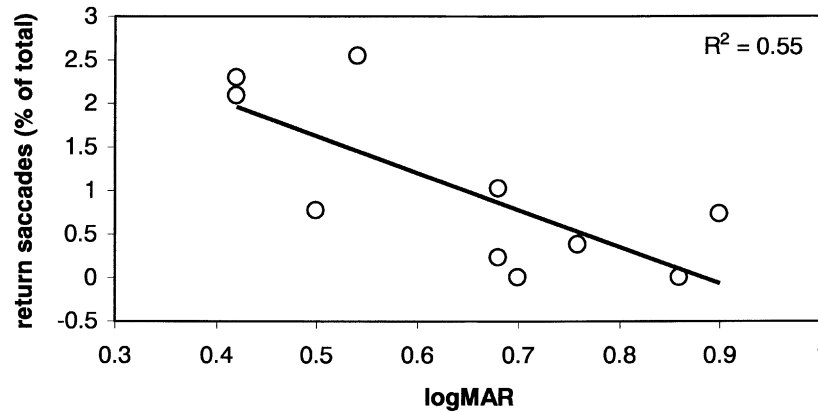
Fig. 3. Relationship between visual impairment and number of return saccades on the visual search task for subjects with central visual field defects.

nificant. The other eye movement parameters were not significantly correlated to the visual field extent.

For the central visual field defect group, a significant relationship between visual acuity and the percentage of return saccades ($r = -0.74$, $p < 0.05$, Fig. 3) was observed, again only for the large gap. Larger central scotomas (i.e., lower visual acuity) were related to a smaller percentage of return saccades. The other eye movement parameters were not significantly related to visual acuity.

3.3. Predicting practical fitness to drive

None of the eye movement parameters on the dot counting task was significantly related to viewing behavior while performing an on-road driving test ($p > 0.05$). Mean search time (rho $= -0.32$, $p < 0.05$) and number of errors (rho $= -0.33$, $p < 0.05$) of the dot counting task correlated significantly with the final score of the on-road driving test. These parameters were added to Model 1 on the basis of visual acuity, visual field, and viewing efficiency (AFOV) and to Model 2 on the basis of visual attention and contrast sensitivity. Model 1 explained 41% (Nagelkerke R^2) of the pass/fail score. Adding the eye movement parameters (search time and number of errors) to the model, did not improve predictive power ($\chi^2(2) = 0.95$, n.s.). Model 2 explained 38% (Nagelkerke R^2) of the variance of the pass/fail score. Entering the eye movement parameters to the model did not increase predictive power either ($\chi^2(2) = 2.52$, n.s.).

4. Discussion

Eye movement characteristics of subjects with central or peripheral visual field defects were examined on an unstructured dot counting task and on a structured visual search task. On the dot counting task, it was ob-

served that subjects with peripheral visual field defects needed longer search times, made more fixations, made more errors, and had shorter fixation durations than control subjects. The dot counting task and visual search task further revealed that gradually decreasing visual fields resulted in a gradual increase of number of fixations and search times. The data on search time and number of fixations are consistent with previous findings. Cornelissen and Kooijman (submitted for publication) reported that search times of subjects with simulated peripheral visual field defects significantly increased as the field of view became smaller. A similar (nearly significant) relationship was observed for the number of fixations. Zihl (1995) reported that impaired scanning pattern in patients with homonymous hemianopia was characterized by a nearly threefold longer search time and a substantial increase in number of fixations. Henderson et al. (1997) reported a small increase in search time and number of fixations in a group with a scotoma immediately to the right of the current fixated region (scotoma-offset condition). The present study supports a linear relationship between visual field extent and level of impairment on the eye movement analysis. It was observed that subjects with severe visual field constrictions (Group 3) needed 45% to 56% longer search times than control subjects. Subjects with mild visual field defects (Group 5) required on average only 12% longer search times than the control group. Data on the number of fixations revealed the same relationship. Subjects with severe peripheral field constrictions made on average 100% more fixations than control subjects whereas subjects with mild visual field defects made only 14% more fixations than control subjects. These data demonstrate that the degree of impairment increased with increasing constriction of the visual field.

A similar relationship between the constriction of the visual field and the number of errors was observed. Subjects with severe peripheral field constrictions made on average twice as many errors per trial than control subjects. Subjects with mild visual field defects, on the

other hand, made slightly less errors than the control subjects. Data of the mild visual field defect group are in accordance with the findings by Henderson et al. (1997) who reported no effect of the scotoma-offset condition (mild visual field impairment) on the accuracy data. In contrast to our results, Zihl (1995) reported that all subjects with homonymous hemianopia (severe visual field impairment) reported the right number of dots. However, the two studies should not be directly compared as Zihl (1995) assessed accuracy in only one trial (20 dots) whereas the present study consisted of 15 trials.

Although subjects with peripheral visual field defects required longer search times, more fixations and made more errors than control subjects, the amplitude of the saccades and the scanning pattern did not significantly differ from controls. These results are in accordance with the findings of Zihl (1995) and Cornelissen and Kooijman (submitted for publication). Results on fixation duration suggested that smaller visual fields were related to shorter fixation durations but this effect should be interpreted cautiously as it was only nearly significant ($p = 0.05$) and the relationship was not observed on the visual search task.

Performance of subjects with central visual field defects on the dot counting task differed significantly from that of control subjects as evidenced by the multivariate effect of visual field defect on the combination of eye movement parameters. Yet, none of the eye movement parameters on its own reached significance. On the visual search task, however, it was observed that the number of return saccades decreased with increasing impairment. Thus, larger central scotomas (i.e., lower visual acuity) resulted in a smaller number of return saccades. This finding is in contrast to the finding by Cornelissen and Kooijman (submitted for publication) who reported that the number of return saccades increased with increasing scotoma sizes. The authors interpreted their findings in terms of the theoretical model by Findlay and Walker (1999). They argued that the presence of distracters in the periphery in combination with the reduced central stimulation had caused early initiation of a next saccade. As the encoding time was too short, subjects had to make more return saccades. The discrepancy between the findings of subjects with real visual field defects in the present study and subjects with simulated visual field defects (Cornelissen & Kooijman, submitted for publication) may be caused by different search strategies that were adopted. Subjects with real visual field defects might have consciously suppressed the tendency to initiate a saccade before the central information has been acquired. The cognitive control of the subjects to voluntarily suppress saccades and maintain fixation is described in the model by Findlay and Walker (1999) too.

The lack of a significant effect of any of the eye movement parameters on its own and the inverse effect of visual field impairment on the number of return saccades suggest that subjects with real visual field defects have learned to adapt their viewing behavior. The ability to compensate for visual field defects has been an important theme of our research group. It was hypothesized that subjects with visual field defects who use compensatory viewing strategies may reduce the negative impact of their visual impairment. The effect of compensatory viewing strategies was previously investigated in relation to driving performance (Coeckelbergh, Brouwer, et al., submitted for publication). It was observed that subjects who passed the driving test made more use of compensatory viewing strategies than subjects who failed the test. It was then investigated whether taking these compensatory viewing strategies into account might improve the predictive power of the current vision requirements for driving to identify at-risk drivers. As was previously shown (Coeckelbergh, Brouwer, et al., submitted for publication), taking compensatory viewing behavior (AFOV) into account improved prediction but sensitivity and specificity remained quite low. In the present study, it was investigated whether adding eye movement parameters further improved the model. It was observed that none of the eye movement parameters was related to viewing behavior while performing an on-road driving test. Yet, the number of errors and search time correlated significantly to the final score of the driving test. Adding these parameters to the model, however, did not improve power to identify at-risk drivers.

In conclusion, subjects with peripheral visual field defects required more fixations, required longer search times, made more errors, and had shorter fixation durations than control subjects on the dot counting task. The visual field extent was related to the degree of impairment such that gradually decreasing the visual field resulted in a gradual increase of the number of fixations and search times. Subjects with central visual field defects performed less well than control subjects on the dot counting task although no specific impairment could be pinpointed. On the visual search task, an inverse relationship was observed between the degree of visual field impairment and the number of return saccades. Adaptation to the visual field defect may explain the finding that fewer effects of visual impairment on eye movement data were observed than in a study on simulated field defects (Cornelissen & Kooijman, submitted for publication). Finally, the use of eye movement parameters to predict viewing behavior in a complex task (e.g. driving) is limited. None of the eye movement parameters was significantly related to viewing behavior while performing an on-road driving test. Search time and number of errors were significantly related the final score of the on-road driving test but did not improve the ability to identify at-risk drivers.

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