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# Training compensatory viewing strategies: feasibility and effect on practical fitness to drive in subjects with visual field defects

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**Abstract** Fifty-one subjects with visual field defects were trained to use compensatory viewing strategies. The subjects were referred to the training program by an official driving examiner of the Dutch Central Bureau of Driving Licenses. Three training programs were compared: laboratory training, mobility training, and motor traffic training. Viewing behavior, visual attention, and practical fitness to drive were assessed before and after training. Practical fitness to drive was assessed on the road as well as in a driving simulator. It was observed that compensatory viewing behavior and practical fitness to drive could be improved by training. Subjects in the motor traffic training showed a small advantage with regard to practical fitness to drive, suggesting that training is task-specific and that generalization is limited. The effect of visual field defect on viewing behavior and practical fitness to drive was analyzed separately for subjects with central or peripheral visual field defects. It was observed that none of the outcome measures differed between the central and peripheral visual field defect groups.

**Key words** Visual field defects; training; driving; compensatory viewing strategies

**Introduction** When fixating steadily, persons with central visual field defects cannot discern objects within the fixation area, while persons with peripheral visual field defects do not notice objects in the

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periphery. In traffic, the delayed detection of objects (cars, cyclists, pedestrians) in the scotomatous area may be hazardous. In order to detect objects on time, the use of compensatory viewing strategies is required. In the case of peripheral visual field defects, compensatory viewing strategies consist of scanning to enlarge the field of view. In the case of central visual field defects, compensatory viewing behavior consists of eccentric fixation as well as scanning to assure that no information is concealed by the scotoma. Studies on the training of scanning behavior in subjects with visual field defects due to brain damage have shown that efficient scanning techniques can be successfully trained. Moreover, most studies reported that patients mentioned a transfer effect of the trained skills to everyday activities.[1,2] Studies on the effective use of low vision devices while walking or driving have also reported positive training results. Szlyk et al.,[3] for example, trained subjects with central visual field defects to use a bioptic telescope. They observed that visual skills, such as the recognition of road signs, peripheral identification, and scanning while driving, significantly improved after training. Szlyk et al.[4] reported similar results on training with bioptic amorphic lenses in subjects with peripheral field constrictions. Huss[5] reported that 32 out of 47 patients with central visual field defects became legally licensed to drive after following a training program consisting of classroom driver education instruction, visual utilization training, and on-road driving. In subjects without visual field defects, Ball et al.[6] reported that the UFOV (useful field of view) could be enlarged by 10 degrees with practice. This practice effect was demonstrated for all age groups and all eccentricities and persisted for at least six months after training. Moreover, Ball[7] reported preliminary results suggesting that UFOV training transferred to driving tasks. The author also reported that expansion of the UFOV resulted in a significant reduction of the number of hazardous maneuvers. This effect was not observed in a simulator training program or in a control group.

In the present study, the effect of training in the use of compensatory viewing strategies was assessed in subjects with visual field defects due to ocular pathology. Optical devices, such as the bioptic telescope or bioptic amorphic lenses, were not used. The aim of the training was to improve practical fitness to drive by improving compensatory viewing strategies. Three training programs were distinguished: laboratory training, mobility training, and motor traffic training. In the laboratory training, compensatory viewing strategies were taught in the laboratory without any reference to a traffic situation. We examined whether the trained skills transferred to a complex driving situation. Studies by Ball et al.,[7] Zihl,[1] and Nelles et al.[2] suggest that the transfer of trained skills to a complex driving situation may be feasible. In the motor traffic training, compensatory viewing strategies were trained while driving a car. The studies by Szlyk et al.[3,4] and Huss[5] have reported positive results with this kind of training. The mobility training was an intermediate training program. Compensatory viewing strategies were taught in a real traffic situation, but while walking and cycling. The relationship to a traffic situation was more direct than in the laboratory training, but, in contrast to the motor traffic training, the subjects were given the opportunity to practice the newly acquired skills when time pressure was not as high. Since this kind of training is the standard training used in the Netherlands to teach orientation and mobility skills to visually impaired people, individuals with this kind of training were considered the control group.

## Materials and methods

SUBJECTS Thirty-one males and 20 females with visual field defects due to ocular pathology, e.g., (age-related) macular degeneration, glaucoma, or retinitis pigmentosa, participated in this study. They were recruited by means of short reports in newspapers and folders at ophthalmologists' offices and rehabilitation centers, and at patients' associations. All subjects were regular drivers, although most of them had been told they no longer met the vision requirements necessary for driving. Most of the subjects (92%) had a valid driver's license. Participation in the study had no impact on their driver's license. Mean age was 63 years, with age ranging from 37 to 86 years. When the subjects volunteered to participate in the study, a letter fully explaining the nature of the experiment was sent to them. The subjects were asked to return a form, indicating whether or not they wished to participate. They were also sent a questionnaire regarding the inclusion and exclusion criteria. To be included in the study, visual field defects had to be present, visual acuity had to be at least 0.1 (decimal notation, equivalent to 1.0 logMAR), and the 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 comprised severe cognitive impairments, including hemispatial neglect. All subjects scored above a predefined cutoff point (22) on a cognitive screening test before as well as after training (MMSE,[8] mean score before training: 27.1, range: 24–29; mean score after training: 26.9, range: 24–29). None of the subjects demonstrated hemispatial neglect. Hemispatial neglect was screened using the Bells test;[9] mean number of errors before training: 1.4, range: 0–7; mean number of errors after training: 1.2, range: 0–6). Three subjects made four or more errors during both the pre- and post-training assessment sessions. However, as the errors were not lateralized, it was assumed that the impaired score on the Bells test was due to visual impairment rather than the hemispatial neglect. All subjects had failed one or both driving tests on the road and were referred to the training program by an official driving examiner of the Dutch driving license authority.

The effect of the training program was analyzed for 51 subjects. In some cases, the total number of subjects in a statistical analysis was not equal to 51 due to missing data. The exact number of subjects in these analyses is reported in the Results section. Missing data were due to the refusal of subjects to perform an on-road driving test after training (n = 3) or because the headtracker in the driving simulator was not yet operational (n = 21).

TABLE 1. Number of subjects as a function of visual field defect and training program.

| | Training program | | |
|---|---|---|---|
| | *Laboratory* | *Mobility* | *Motor traffic* |
| Central visual field defect (Group 1) | 5 | 5 | 7 |
| Peripheral visual field defect (Group 2) | 6 | 8 | 7 |
| Central and peripheral visual field defect (Group 3) | 2 | 2 | 1 |
| Mild visual field defect (Group 4) | 3 | 1 | 4 |

Subjects were classified into four groups according to 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) and the horizontal diameter of the binocular visual field has to be at least 120 degrees. Subjects in the 'central field defect group' (group 1) did not fulfil the visual acuity requirements; however, their visual field outside the central 10 degree area was intact and extended for at least 120 degrees. Subjects in the 'peripheral field defect group' (group 2) met the visual acuity requirement, but failed to meet the visual field requirement. Subjects in the 'central and peripheral field defect group' (group 3) met neither of the requirements. Subjects in the 'mild visual field defect group' (group 4) had scotomas in the paracentral or midperipheral area that did not restrict the horizontal field extent and did not affect visual acuity. Subjects were randomly assigned to one of three training programs (see Methods), although care was taken to guarantee that the four groups were equally represented in the three training programs (Table 1).

This research study was performed according to the guidelines of the Declaration of Helsinki and was approved by the Ethical Review Committee of the University of Groningen (The Netherlands).

PROCEDURE The experiment consisted of five phases: two pre-training assessment phases, a training phase, and two post-training assessment phases. Frequency of testing and training was one session per week. Each assessment session lasted for two to three hours. Each training session lasted for 90 minutes.

The first pre-training assessment phase consisted of four sessions. An extensive visual examination was conducted during the first session and included refraction (if necessary) and assessment of visual acuity, near visual acuity, visual field, contrast sensitivity, dark adaptation, and eye motility. The second session consisted of an assessment of visual attention, compensatory viewing strategies, and a cognitive screening. Questionnaires regarding driving habits were presented to the subject. The third session consisted of a driving test in a driving simulator. The fourth session consisted of a driving test on the road.

Two weeks later, the second pre-training assessment started. It included a retest of the driving test on the road and in the driving simulator. Visual attention and compensatory viewing strategies were also reassessed. Ophthalmologic screening was performed to obtain a clear and recent diagnosis during the course of the two pre-training assessment phases.

Subjects were randomly allocated to one of the three training programs. Each training program consisted of 12 sessions conducted at a frequency of one session per week.

The first post-training assessment was carried out immediately after training. It consisted of four sessions and included a visual examination, an assessment of visual attention, an assessment of compensatory viewing strategies, a cognitive screening, an on-road driving test, and a driving test in a driving simulator. Three months after training, a second post-training assessment was carried out to investigate the long-term effects of training. It consisted of two sessions and involved an assessment of visual attention, compensatory viewing strategies, an on-road driving test, and a driving test in a driving simulator. The entire experiment lasted eight months for each subject.

### MATERIALS

*Vision* Visual acuity was assessed using a Bailey-Lovie Chart[10] and expressed as logMAR. Contrast sensitivity was assessed by means of the Pelli-Robson letter chart[11] and expressed as log contrast sensitivity.

Visual field was assessed by means of Goldmann perimetry with the III4 isopter. The central area was examined using the Humphrey Field Analyzer (Central 10 degrees, Sita Standard method) since it assesses the central area in more detail than Goldmann perimetry. The horizontal field extent was assessed by superimposing the Goldmann III4 isopters for both eyes separately. A functional field score (FFS[12]) was obtained using an overlay grid with 110 points, 50 of which were situated in the central 10 degrees. Sixty-six points were located in the lower half-field and 44 in the upper half-field. Grid points enclosed by the III4 isopter (10 dB) were counted. Grid points within scotomas were not counted. This procedure was conducted for each eye separately. The visual fields for the left and right eye were superimposed for the binocular field. The functional field score equaled (2 * binocular score + right score + left score)/4 and should be viewed as an ability scale where '100' indicates normal performance and '0' the absence of any ability to perform. Normal ability scores range from 110 to 92.5. The FFS was transformed[a] to obtain a normal distribution.

*Visual attention* Visual attention was assessed using a test based on condition six of the UFOV (Useful Field of View) by Ball et al.[6] The stimulus size, however, was adjusted so that low vision subjects could well discern the stimuli. A detailed description of the test is discussed by Coeckelbergh and colleagues (manuscript in preparation). Stimulus presentation and response recording were controlled by a 80486 PC and presented on a 20-inch computer screen. The program was written with the MEL 2.0 software. Stimuli were white (luminance: 50 $cd/m^2$) on a dim

[a] Deviation from the maximum was calculated and divided by 100 $\left(FFS' = \frac{110 - FFS}{100}\right)$. The score was then log-transformed $\left(\log\frac{FFS'}{1 - FFS'}\right)$, as described by Stevens.[20]

background (luminance: 8 cd/m$^2$). Line width of the stimuli was 0.4 degrees. The central stimulus was either a sad or a happy face with a diameter of 6 degrees (mouth width: 3 degrees; mouth heigth: 1 degree). The peripheral target consisted of a circle (diameter: 4 degrees) which could appear on one of 24 positions. The positions were arranged into eight evenly spaced radial spokes. The target could appear at three eccentricities (7, 14, or 21 degrees). Distraction consisted of 47 squares subtending 4 degrees by 4 degrees, evenly spaced on 16 spokes. The testing room was illuminated (500 lux). Subjects viewed the screen from a distance of 30 cm. The test was performed binocularly. Every trial started with a central fixation marker, followed by the stimulus display, a mask, and the response screen. The test consisted of four blocks. The first block involved a peripheral localization task. The subject viewed a stimulus display with a face in the center and one target on one of 24 positions in the periphery for 25, 50, 75, 100, or 125 ms, after which the image was masked. The subject was then instructed to indicate the position of the circle by naming the number of the spoke on which the target was positioned. The shortest presentation time at which a subject responded correctly in at least 90% of the trials was used as the presentation time for the subsequent conditions, with a minimum of 50 ms. Only those targets presented in the intact visual field were used to determine the presentation time for the subsequent parts. Block two consisted of a peripheral localization task and a concurrent central identification task. The subject was instructed to locate the circle and to indicate whether the central face was sad or happy. Presentation times depended on the scores of the first part and could vary from 50 to 125 ms. The short presentation times prohibited observers from making eye movements during the target display. Blocks three and four were similar to blocks one and two, respectively, except for the simultaneous presentation of distractions. The proportion of correct responses was recorded. There was an obvious dependence of the proportion of correct responses on the quality of the visual field, as was the case in studies on the UFOV.[7,13] In case a subject could not perform the test because the severity of his visual field defect prohibited him from detecting any peripheral target, empty cells were replaced by scores reflecting chance performance. The mean proportion of correct responses is the mean of proportions on parts two, three, and four. It was then transformed[b] to a visual attention score to obtain a normal distribution.[14]

*Compensatory viewing efficiency* Compensatory viewing efficiency was assessed by means of the Attended Field of View test (AFOV test), as described by Coeckelbergh et al. (manuscript in preparation). The AFOV test is based on a visual search paradigm. In each trial, 30 closed circles and one open circle were presented on a 20-inch screen (stimulus luminance: 40 cd/m$^2$; background luminance: 16 cd/m$^2$). The 31 stimuli were arranged in three elliptical rings around a central stimulus. The visual angle of this stimulus array was 60 degrees horizontally and 24 degrees vertically. No stimuli were presented on the vertical axis. The size of the stimulus elements was determined by eccentricity and

[b] Proportions were transformed to a visual attention score by an arcsine transformation (visual attention score = $\arcsin\sqrt{p}$) in order to obtain a normal distribution. The visual attention score ranged from 0 to 90. In text, the visual attention score was converted back to a percent correct score (% correct = $[\sin(\text{visual attention score})]^2 * 100$). The arcsine transformation is described by, for example, Sokal and Rohlf.[14]

could be adjusted in relation to visual acuity.[c] The testing room was illuminated (500 lux).

The subject sat in front of the screen at a viewing distance of 30 cm and was instructed to locate the open circle (e.g., C) among 30 closed circles (O) and subsequently indicate the direction of the gap (left, right, top, or bottom of the circle). Eye and head movements were allowed after the central fixation marker had disappeared (a diamond consisting of four red dots; luminance: 14 cd/m$^2$). The test was performed binocularly. The stimuli were presented with varying presentation times (range: 8 ms–10 s). The time that the subjects needed to recognize and localize the target to achieve criterion performance (which was set at 67% correct target identification) was measured. A separate and independent staircase was ran for 19 positions in the stimulus display in order to estimate the required presentation time at that position. The decision rule for increasing and decreasing the duration was as follows: when the participant made a correct response, the duration (for that position) was decreased; when the participant made an error, the duration was increased (one-down/one-up rule). The duration was never the same on any two subsequent trials. By using a weighted up-down method (i.e. having a larger increase during errors than (absolute) decrease during correct responses), the staircase converges on the 67% correct point (delta–/delta+ ratio of 1:2; Kaernbach[15]). Measuring threshold presentation time allowed us to evaluate the subjects at the same criterion level of performance such that the results were not affected by different subjects making different speed/accuracy trade-offs. Measuring threshold presentation times also eliminated the confounding effect of differences in motor response time since the response mode was not reaction time-based. Subjects

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[c] Size of stimuli in the AFOV test.

| | *Position* | *Target size (degrees)* | *Ring width (relative)* | *Gap width (relative)* |
|---|---|---|---|---|
| AFOV1 | Center + ellipse 1 | 1.4 | 0.2 | 0.2 |
| V.A. ≥ 1.0 | Ellipse 2 | 1.9 | 0.2 | 0.2 |
| | Ellipse3 | 2.4 | 0.2 | 0.2 |
| AFOV2 | Center + ellipse 1 | 1.4 | 0.2 | 0.3 |
| 1.0 > V.A. ≥ 0.46 | Ellipse 2 | 1.9 | 0.2 | 0.3 |
| | Ellipse3 | 2.4 | 0.2 | 0.3 |
| AFOV3 | Center + ellipse 1 | 1.9 | 0.2 | 0.5 |
| 0.46 > V.A. ≥ 0.22 | Ellipse 2 | 1.9 | 0.2 | 0.5 |
| | Ellipse3 | 2.4 | 0.2 | 0.5 |
| AFOV4 | Center + ellipse 1 | 3.4 | 0.2 | 0.6 |
| 0.22 > V.A. ≥ 0.1 | Ellipse 2 | 3.4 | 0.2 | 0.6 |
| | Ellipse3 | 3.4 | 0.2 | 0.6 |

The use of AFOV 1, 2, 3, or 4 depended on the visual acuity (V.A., decimal notation) of the subjects.

responded by indicating the direction of the gap. The reaction times of the responses were not monitored.

Analogous to contrast sensitivity, the results in this paper are (mainly) reported in terms of sensitivity, which we define as 1/(presentation time in seconds required to correctly identify the target). The data were log-transformed for statistical reasons (normal distribution and homogeneity of variances) and to account for a general slowing in the older age group (see Cornelissen & Kooijman[16] for a discussion). Linear threshold presentation times were corrected for different stimulus sizes using a linear transformation. Two measurements were related to AFOV performance: mean threshold presentation time and the percent deviation from the median (PDM[d]). The mean threshold presentation time is the mean of the threshold presentation times and is an estimate of the speed of visual search. PDM refers to the variation of threshold presentation times expressed on a 0 to 100 scale. A PDM score of 0 indicates a flat distribution (i.e., threshold presentation times are equal for all positions), while a PDM score of 100 indicates a distribution with maximum variation (i.e., half of the positions at the minimum threshold presentation time and half of the positions at maximum threshold presentation times). An efficient scanning strategy is defined here as a scanning strategy resulting in low threshold presentation times and/or a low PDM.

*Driving simulator* A detailed description of the driving simulator is presented by Coeckelbergh and coworkers (manuscript in preparation). The driving simulator car was a modified BMW 518 on a fixed base, containing all of its original controls, including steering wheel, accelerator, brake and clutch pedals, speedometer, switches, dashboard indicators, and a manual and an automatic gear shift. A head tracker monitored the head movements while driving. Three graphics-data projectors displayed the computer graphics on a 165 × 45 degrees wide projection screen.

The virtual route consisted of approximately three kilometers in a town center (speed limit: 50 km/h), 15 kilometers in a rural area (speed limit: 80 km/h), and 20 kilometers on a highway (speed limit: 120 km/h). The rural area consisted of straight roads, roads with left curves, and roads with right curves. The route entailed 14 intersections, 10 without a sign and four with a 'yield' sign. In the first case, the driver had to give way to vehicles that were approaching from his right. In the second case, the driver had to give way to all vehicles that traveled on the main road, whatever side they approached from.

The subjects were instructed to operate the simulator as they would normally drive their car and to respect all traffic signs and signals. They were allowed to practice for as long as they wished. Mean practice time was about 10 minutes. The actual driving test lasted approximately half an hour.

The simulator indexes analyzed included viewing angle (i.e., the absolute angle of head movement as assessed by the head tracker; looking straight forward corresponded to 0 degrees), number of head movements, and the distance to an intersection at which subjects started to make appropriate head movements.

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[d] Percent deviation from the median =

$$pdm = \frac{\left(\frac{\sum |x_i - median|}{n}\right)}{\max\ deviation} \times 100.$$

In the case of the AFOV test with 19 positions and presentation times ranging from 8 ms to 10 s, $n$ equals 19 and *max deviation* equals 4.733.

*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. The 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 determined whether the individual had adapted his behavior to minimize the negative effects of his impairment. He made use of a checklist (TRIP, Test Ride for Investigating Practical fitness to drive[17,18]) to evaluate different aspects of driving, such as lateral position, steering control, and viewing behavior. After the driving test, the examiner assigned a final score on a four-point scale (0: insufficient; 1: doubtful; 2: sufficient; 3: good). This final score was recoded to a pass/fail score and indicated whether the subject had failed (scores 0 or 1) or passed (scores 2 or 3) the driving test. The driving examiner had knowledge of the type of visual field defect of the driver, but was unaware of his performance on the driving simulator or the kind of training program to which the subject was allocated. The first driving test was regarded as a session to accustom the subjects to the assessment procedure rather than to an actual assessment of driving safety and smoothness. Therefore, the results of the first pre-training assessment were not included in the statistical analyses.

*Training* The aim of training was to teach subjects compensatory viewing mechanisms such as eccentric viewing and a continuous and efficient scanning technique. Training consisted of 12 weekly sessions of approximately 1.5 hours. Three training programs were distinguished:

- *Laboratory training* During 10 sessions, subjects were taught compensatory viewing mechanisms by means of tasks that did not appear to have any direct relationship to a driving or a traffic situation. Efficient search and scanning strategies were taught by means of visual search tasks on a computer. Eccentric viewing was mainly taught by means of reading tasks. Software programs that are commonly available in Dutch rehabilitation centers were selected. The AFOV test was also used as part of the training program. Subjects were given the opportunity to become accustomed to the instruction car (one session) and driving simulator car (one session), but no instructions were given regarding scanning behavior while driving. Sixteen subjects were allocated to this training.
- *Mobility training* During 10 sessions, subjects were instructed to make efficient head and eye movements in a real traffic situation. While walking and cycling, these individuals were instructed to continuously scan the environment around them in order to travel safely among other traffic participants. Scanning behavior was elicited by means of search tasks. The subjects had to look for targets, such as the name of a street. Since this kind of training is the standard training used in The Netherlands to teach orientation and mobility skills to visually impaired subjects, the individuals in this training program

were considered the control group. As in the laboratory training, the subjects obtained some general driving experience in the instruction car (one session) and driving simulator car (one session). Sixteen subjects were allocated to this training.

- *Motor traffic training* The first session consisted of a theoretical explanation of the nature and usefulness of compensatory viewing strategies. During the 10 subsequent sessions, the subjects were taught to scan the environment while driving a car. The complexity of a real traffic situation was similar to the mobility training, but the time pressure was much higher. Subjects learned to anticipate in order to give themselves sufficient time to make time-consuming head and eye movements. The last session consisted of a ride in a driving simulator car. Nineteen subjects were allocated to this training.

STATISTICAL ANALYSIS A crossed design to study the effects of training and visual field defect within one analysis was not possible due to the small sample sizes (Table 1). Therefore, two analyses were performed. The first analysis examined the effect of training on visual attention, viewing behavior, and practical fitness to drive. The second analysis examined the effect of visual field defect on the same set of variables. Only the results of the central visual field defect group (Group 1) and the peripheral visual field defect group (Group 2) are presented. The other groups were not analyzed as sample sizes were too small.

Normality was evaluated using the Shapiro-Wilk test. Whenever the data were not normally distributed, either data were transformed or a nonparametric test was used. If the sphericity assumption was not met, the Greenhouse-Geisser correction was used. Whenever a multivariate analysis was used, the multivariate test statistic (Wilks' Lambda) was inspected. If significant, the univariate test statistics were inspected to determine the dependent variables that caused the significant multivariate effect. Finally, contrast testing was used to reveal differences between the levels of the independent variables (e.g., session or training program). Repeated contrasts were used to interpret the significant univariate effect of the session (pre1-pre2, pre2-post1, post1-post2). Bonferroni multiple comparisons were used to determine pairwise differences between training programs.

## Results

VISION Vision remained constant throughout the study period (Table 2). None of the Wilcoxon's signed rank tests reached significance ($p > 0.05$).

### EFFECT OF TRAINING

*The effect of training on viewing behavior (AFOV)* A doubly multivariate repeated measures analysis was used to study the effect of the training program and session on the AFOV parameters (mean threshold presentation time and variation of threshold presentation times).

| | | *Group 1* | *Group 2* | *Group 3* | *Group 4* |
|---|---|---|---|---|---|
| Visual acuity [logMAR] | Before | 0.65 (0.16) | 0.15 (0.14) | 0.57 (0.16) | 0.16 (0.10) |
| | After | 0.66 (0.16) | 0.13 (0.12) | 0.57 (0.13) | 0.15 (0.10) |
| Log contrast sensitivity | Before | 1.04 (0.25) | 1.44 (0.24) | 0.99 (0.38) | 1.31 (0.28) |
| | After | 1.02 (0.30) | 1.40 (0.30) | 1.01 (0.63) | 1.27 (0.31) |
| Goldmann III4 extent (degree) | Before | 138.4 (13.2) | 79.4 (38.5) | 97.4 (46.0) | 140.1 (18.7) |
| | After | 138.1 (15.3) | 76.5 (41.8) | 89.6 (43.1) | 146.0 (16.7) |
| Functional visual field score (range: 0–110) | Before | 95.3 (5.2) | 63.0 (23.3) | 77.3 (23.1) | 88.5 (8.8) |
| | After | 94.2 (5.7) | 61.1 (5.4) | 75.1 (21.9) | 88.7 (9.6) |

TABLE 2. Mean (standard deviation in parentheses) vision characteristics.

Mean threshold presentation time ($F(3,144) = 6.7$; $p < 0.001$) and variation of threshold presentation times ($F(3,144) = 3.6$; $p < 0.05$) differed between the sessions (Figure 1). Mean threshold presentation time decreased significantly after training and remained at the same level at the second post-training assessment. Mean log threshold presentation time was 0.36 (SD = 0.36)(2.3 s) at the first pre-training assessment, 0.37 (SD = 0.38)(2.3 s) at the second pre-training assessment, 0.28 (SD = 0.39)(1.9 s) at the first post-training assessment, and 0.27 (SD = 0.36)(1.9 s) at the second post-training assessment.

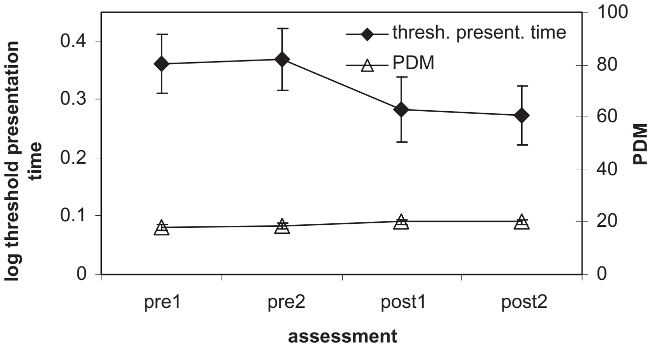
The variation of threshold presentation time showed a monotonic, though small, increase across the sessions. Mean variation was 18.0% (SD = 7.2) at the first pre-training assessment, 18.5% (SD = 7.3) at the second pre-training assessment, 20.0% (SD = 7.3) at the first post-training assessment, and 20.0% (SD = 6.8) at the second post-training assessment.

The effects of the training program ($F(4,94) = 1.5$; $p = 0.22$) and session by training program ($F(12,86) = 1.1$; $p = 0.38$) were not significant, indicating that there was no difference between the three training programs with regard to the AFOV.

*The effect of training on viewing behavior (on-road driving test)* A repeated measures design was used to study the effect of the training program and session on viewing behavior during the on-road driving test. Data from 48 subjects were included in the analysis, 15 of whom were allocated to the laboratory training, 14 to the mobility training, and 19 to the motor traffic training.

After training, the viewing behavior of the subjects who had had the motor traffic training received a higher mark than of those who had had the mobility or laboratory training ($F(5,113) = 2.8$; $p < 0.05$; Figure 2). Simple main effects indicated that the difference between the motor traffic training and the two other groups was significant immediately after training ($F(2,45) = 5.2$; $p < 0.01$), but not at the second post-training assessment ($F(2,45) = 1.2$; $p = 0.30$). The effects of the session ($F(3,113) = 1.3$; $p = 0.28$) and the training program ($F(2,45) = 1.3$; $p = 0.27$) were not significant.

*The effect of training on viewing behavior (driving simulator)* Viewing behavior while driving in the driving simulator was assessed in 30 subjects, nine of whom were allocated to the laboratory training, 11 to the



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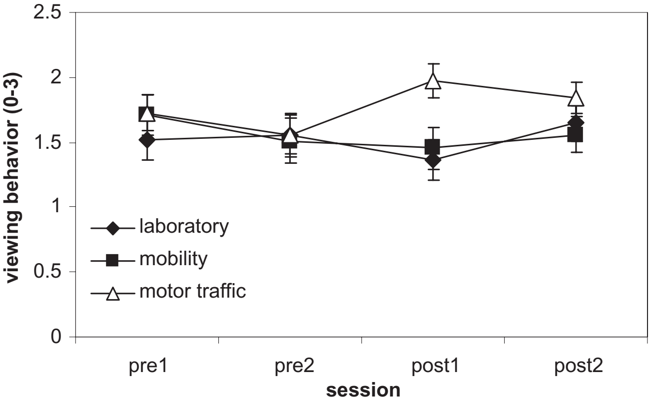

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*Fig. 1.* The effect of training on the AFOV test. The mean threshold presentation time decreased significantly after training and remained at the same level at the second post-training assessment. The variation of threshold presentation time (PDM) showed a monotonic, but small, increase across sessions. Error bars denote standard error of means.

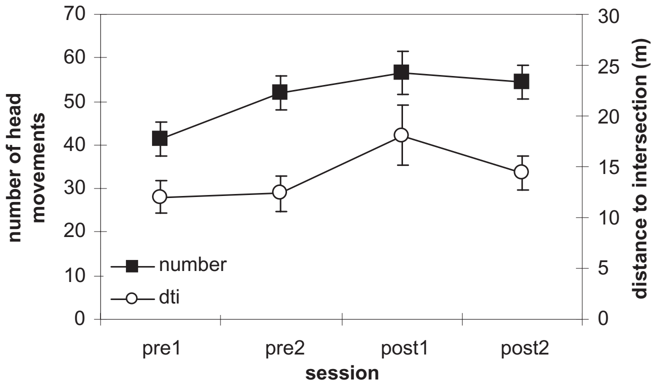
*Fig. 2.* The effect of training on viewing behavior during the on-road driving test. The viewing behavior of subjects who had had the motor traffic training was given a significantly higher mark immediately after training than that of subjects with either laboratory or mobility training. The difference between the groups was no longer significant three months later. Error bars denote standard error of means.

mobility training, and 10 to the motor traffic training. A doubly multivariate repeated measures design was used to study the effects of the training program and session on viewing angle, number of head movements, and distance to intersection at which subjects started to make head movements. The number of head movements varied across sections ($F(2,58) = 8.6$; $p < 0.01$; Figure 3). Contrast testing revealed that the number of head movements increased after the first pre-training assessment and remained at this level thereafter. The distance to the intersection at which subjects started to make head movements also varied across the sessions ($F(3,81) = 4.1$; $p < 0.01$; Figure 3). It remained constant across pre-training assessment sessions, increased immediately after training ($p = 0.01$), but then slightly decreased again ($p = 0.07$). The viewing angle did not differ across the sessions ($F(2,61) = 1.9$; $p = 0.16$). The effects of the training program ($F(6,50) = 1.4$; $p = 0.25$) and session by training program ($F(18,38) = 1.1$; $p = 0.38$) were not significant.

*Effect of training on visual attention* A repeated measures design was used to study the effect of the session and training program on the visual attention score. The visual attention score differed across sessions ($F(2,117) = 11.9$; $p < 0.01$; Figure 4). The mean visual attention score was 52.6 (SD = 11.1)(63% correct) at the first pre-training assessment, 55.7 (SD = 11.7)(68% correct) at the second pre-training assessment, 55.8 (SD = 11.0)(68% correct) at the first post-training assessment, and 57.3 (SD = 11.2)(71% correct) at the second post-training assessment. Repeated contrasts revealed that the differences between the two pre-training assessments and the two post-training assessments were significant ($p < 0.05$). The difference between the second pre-training assessment and the first post-training assessment was not significant ($p = 0.81$).

The effects of the training program ($F(2,48) = 0.52$; $p = 0.60$) and session by training program ($F(5,117) = 0.74$; $p = 0.60$) were not significant.

*The effect of training on practical fitness to drive (on-road driving test)* Across training programs, the percentage of the subjects who passed the on-road driving test equaled 13.7% for the second pre-training



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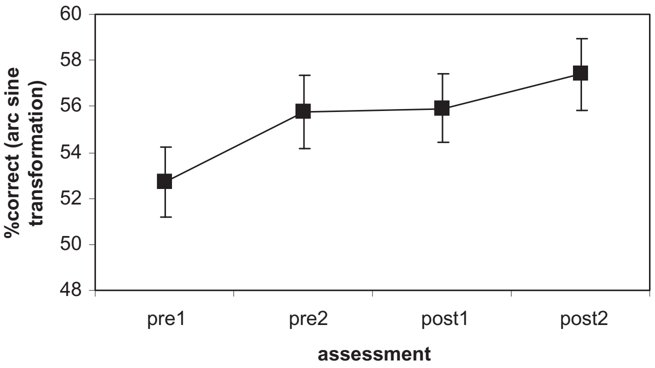

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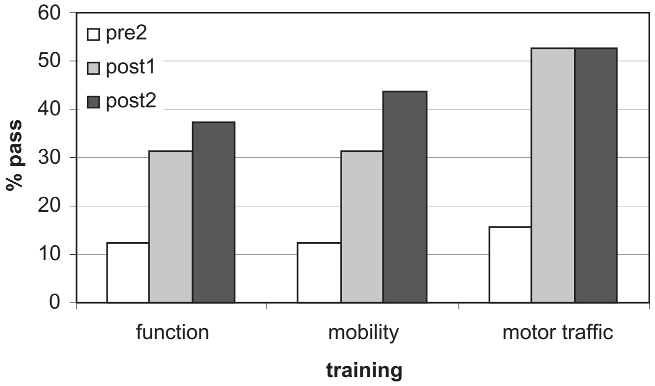

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*Fig. 3.* The effect of training on viewing behavior while driving in a driving simulator. The number of head movements significantly increased after the first assessment and remained at this level thereafter. The distance to the next intersection at which subjects started to make head movements increased significantly after training. Three months later, the effect was slightly reduced. Error bars denote standard error of means.

*Fig. 4.* Visual attention scores across sessions. The differences between the two pre-training assessments and between the two post-training assessments were larger than the difference between the second pre-training assessment and the first post-training assessment, suggesting a practice effect rather than a training effect. Error bars denote standard error of means.

*Fig. 5.* The percentage of subjects who passed the on-road driving test. Although the percentage increased in the function and mobility training groups, it was not statistically significant. Only with motor traffic training did the proportion of subjects who passed the on-road driving test significantly increase after training and remain at the same level thereafter.

assessment, 39.2% for the first post-training assessment, and 45.1% for the second post-training assessment. This increase across sessions was significant (Cochran's Q(3) = 24.12; $p < 0.01$). The results of the first pre-training assessment were not included in the analysis as the first driving test was considered to be a session to accustom the subject to a testing situation rather than an actual assessment.

For each training program, we tested the hypothesis that the proportion of subjects who passed the driving test remained the same across sessions using the Cochran's Q test. As three analyses were performed, alpha level was set at 0.01. Figure 5 shows the proportion of the subjects who passed the on-road driving test as a function of the training program. In the function and mobility training, the proportion of the subjects who passed the on-road driving test increased across sessions; however, this difference was not statistically significant (Cochran's Q(2) = 6.5; n.s. and Cochran's Q(2) = 6.3; n.s., respectively). In the strategy training, however, the proportion of subjects who passed the on-road driving test significantly increased after training and remained at the same level thereafter (Cochran's Q(2) = 12.3; $p < 0.01$).

EFFECT OF VISUAL FIELD DEFECT It was hypothesized that a central field defect (Group 1) might demonstrate a differential performance and training pattern than a peripheral visual field defect (Group 2). To test this hypothesis, the main effect of the visual field defect and the interaction effect of the visual field defect were inspected by session in the following analyses.

*The effect of visual field defect on viewing behavior (AFOV) and visual attention* A doubly multivariate repeated measured design was used to study the effects of the visual field defect and the session on AFOV (mean threshold presentation time and variation of threshold presentation time) and visual attention. Only the variation of threshold presentation time was affected by the type of visual field defect ($F(1,36) = 13.03$; $p < 0.01$). It was observed that the variation was larger for subjects with central visual field defects than for subjects with peripheral visual field defects. This result, however, is an artifact of the time limit of the AFOV test and is not further discussed.

The interaction effect of the session and the visual field defect on the AFOV threshold presentation time was not significant ($F(3,108) = 2.4$; $p = 0.07$).

*The effect of visual field defect on viewing behavior (on-road driving test)* Viewing behavior during the on-road driving test was analyzed using a repeated measures design. Scores on viewing behavior during the on-road driving test did not differ between the two visual field defect groups ($F(1,34) = 0.12$; $p = 0.73$). The effect of the session was also similar for both groups ($F(3,102) = 1.6$; $p = 0.19$).

*The effect of visual field defect on viewing behavior (driving simulator)* Viewing behavior while driving in the driving simulator was assessed by a doubly multivariate repeated measures design. Subjects with central or peripheral visual field defects did not behave differently in the driving simulator. Neither the main effect of the visual field defect ($F(3,18) = 1.8$; $p = 0.18$) nor the interaction effect of the visual field defect by session ($F(9,12) = 0.61$; $p = 0.77$) was significant.

*The effect of visual field defect on practical fitness to drive (on-road driving test)* The proportion of subjects with central visual field defects who passed the on-road driving test significantly increased across sessions: 18% passed the second pre-training assessment, 41% passed the first post-training assessment, and 47% passed the second post-training assessment (Cochran's $Q(2) = 8.4$; $p = 0.02$). Similarly, the proportion of subjects with peripheral visual field defects significantly increased across sessions: 14% passed the second pre-training assessment, 43% passed the first post-training assessment, and 52% passed the second post-training assessment (Cochran's $Q(2) = 10.4$; $p = 0.01$). The percentage of subjects passing the on-road driving test was not significantly related to the type of visual field defect for any of the assessments ($X^2(1) = 0.08$; n.s. for the second pre-training assessment, $X^2(1) = 0.01$; n.s. for the first post-training, and $X^2(1) = 0.11$; n.s. for the second post-training).

**Discussion** Subjects with visual field defects who failed an on-road driving test were trained to use compensatory viewing strategies. Three training programs were compared: laboratory training, mobility training, and motor traffic training. The study investigated whether compensatory viewing strategies could be enhanced by training and, if so, whether improved compensatory viewing behavior resulted in improved practical fitness to drive. It also investigated which training program was the most effective and whether the type of visual field defect (central versus peripheral) was related to training success.

Since mean threshold presentation times significantly improved across sessions, it was concluded that compensatory viewing strategies could be successfully trained. The visual attention score also improved, suggesting that a subject's field of view was enlarged. The improvement was comparable for all training groups and indicated that the type of training program did not matter. This latter finding was unexpected. Since the subjects in the laboratory training were assessed and trained with the AFOV test, it was expected that this group would demonstrate a clear advantage on the test after training. This advantage was not observed: all training groups improved equally. Inspection of the results indicated that a floor effect cannot account for the absence of an advantage effect in the laboratory training. Instead, the data suggest that training compensatory viewing strategies in a real traffic environment (mobility and motor traffic training) was as effective as training the task at hand (laboratory training) to demonstrate an improvement on the AFOV test. In other words, the data suggest that compensatory viewing strategies that were trained outside the laboratory transferred to a laboratory test.

Training also had a positive effect on viewing behavior while driving a car. Driving simulator results demonstrated that subjects learned to make more head movements and to scan earlier when approaching a crossroads. Viewing behavior during the on-road driving test improved too, but only for subjects in the motor traffic training and only for the first post-training assessment. With regard to practical fitness to drive, it was observed that 39% of the subjects passed the on-road driving test immediately after training compared to 14% before the training. Three months after training, this percentage had increased to 45%. The proportion of subjects who passed the driving test increased in all training groups, but reached significance in the motor traffic training. This advantage of the motor traffic training on the pass/fail score, combined with the results of viewing behavior during the on-road driving test, suggests that training is task-specific and that generalization to more complex tasks is limited. The limited transfer of training success in the mobility and laboratory training is in contrast to the results reported by Zihl[1] and Nelles et al.,[2] who described subjectively reported transfer of the trained skills to everyday activities. A weak transfer effect of computer-based tasks to real and complex everyday tasks was demonstrated earlier by Ross.[19] Ross examined the effect of a computer-based visual scanning program on a functional task in three subjects with closed-head injury. He observed that learning occurred throughout the study on both the functional tasks and computer visual scanning task, but that training did not affect performance in scanning time on the functional task more than could be expected from the naturally occurring practice effect.

To determine whether the observed improvements were caused by a training effect in contrast to a mere practice effect, the difference between the two assessments before training was compared to the difference between the second pre-training assessment and the first post-training assessment. With regard to the AFOV (mean threshold presentation time), the on-road viewing behavior of subjects in the motor traffic training, and the distance to the intersection at which the subjects in the driving simulator started to scan, the observed effects were most likely caused by the training itself. The difference between the second pre-training assessment and the first post-training assessment was significant, whereas the scores of the two pre-training assessments did not differ. The improvements on the visual attention task and the increased number of head movements in the driving simulator, in contrast, were most likely caused by practice effects and not by the training. In both cases, improvement after the first pre-training assessment was larger than improvement after training.

With regard to the long-term effect of training, it was observed that the effect of training on the AFOV test remained constant for at least three months. Viewing behavior during the on-road driving test of subjects in the motor traffic training, however, slightly decreased after three months. Similarly, the distance to the intersection at which subjects started to make head movements slightly decreased three months after training.

The effect of the visual field defect was examined for the AFOV task, on-road viewing behavior, viewing behavior in the driving simulator, and the pass/fail score of the on-road driving test. It was observed that none of the outcome measures differed between the central and peripheral visual field defect group.

In summary, compensatory viewing behavior could be improved by training. Enhancing compensatory viewing behavior did have a positive effect on the practical fitness to drive. The effect of training was strongest for subjects who had had the motor traffic training, suggesting that training is task-specific and that generalization to more complex tasks is limited. Finally, effect of training did not differ between subjects with central visual field defects and those with peripheral visual field defects. Therefore, it can be concluded that practical fitness to drive can be improved by training compensatory viewing strategies in subjects with visual field defects. With regard to driving, the best results are obtained by motor traffic training.

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