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Compensatory viewing training improves practical fitness to drive of subjects with impaired vision

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Abstract In many countries strict legal requirements for obtaining a driver's license are in effect for visual acuity and visual field. We studied the relationship between these characteristics and driving safety and driving proficiency in an on-the-road test of practical fitness to drive in subjects with visual disorders, including many subjects scoring below current criteria. We further studied how far the relationship between the on-the-road test and visual measures improved if compensatory eye movements and visual attention were included in the criteria. Lastly, we studied the effects of training compensatory viewing strategies

METHODS: In two studies subjects with visual field defects due to retinal pathology (n = 100) and post-chiasmal damage (n = 28) per-

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formed the on-the-road test before and after training. Training consisted of laboratory and mobility training, including driving instruction. Visual function assessment included acuity, visual field, contrast sensitivity, visual attention, compensatory viewing efficiency, and visuo-spatial tests. In one study an advanced driving simulator was used besides the on-the-road assessment. Two models were compared to predict the on-the-road score.

RESULTS: 13–62% of the subjects passed the on-the-road test before training. After training, an additional 15–45% passed. The power of both models to predict the on-the-road score rose to about 45% by adding viewing behavior in the driving simulator.

DISCUSSION: A considerable percentage of the subjects, legally not allowed to drive, passed the on-the-road test. Sensitivity and specificity of vision tests and driving simulator tests are still too low to decide upon unfitness to drive. Training of compensatory viewing improved the performance in the on-the-road test.

Key words Driving, field defects, brain injury, retinal degeneration, compensation, training

Introduction Vision is the most important source of information while driving and minimal requirements for visual functions seem relatively easy to define. Many countries set firm minimal requirements for some visual functions for driving licensing, for example, requiring a binocular visual acuity of at least 0.5 (20/40) and a horizontal visual field extent of at least 120 degrees.

Ideally, individuals who fail to meet the criteria should demonstrate unsafe driving performance. A priori however, the chances to be able to indicate a level that separates safe and unsafe drivers with a high sensitivity and specificity can be expected to be rather low. In the International Classification of Functioning (ICF), Disability and Health¹ human performance on the level of every day activities (activity limitation) is viewed as the outcome of an interaction between a person's physical and mental condition and the social and physical environment.² From the literature on skill development it can be further added that driving experience and compensatory strategies play a modulating role.³

In spite of these theoretical considerations it is standard practice to base legal decisions of individual fitness to drive on basic visual functions like visual acuity and the extent of the visual field.

Using further ICF terminology and conceptualization, an interaction of lower-order impairment (medico) and environmental factors (legal) results in a participation restriction, namely being refused to drive a car or obtaining a driving license and hence being deprived from this popular and socially important type of mobility. This is an example of the presence of a participation restriction, without touching upon the activity construct. Medico-legal unfitness to drive restricts driving without taking into account evidence about individual performance at the activity level.

Previous studies⁴⁻¹⁴ demonstrated significant relationships between vision parameters and driving safety, but these relationships are generally weak and it must be seriously questioned whether these parameters used in isolation could be used as a basis for the decision on individual unfitness to drive.

It is quite likely that the association between vision impairment and driving safety is weakened by intermediate variables such as compensatory behavior at tactical and strategic levels of the driving task resulting in lower risk taking^{3,5,9} and the use of technical aids. For example, a bioptic telescope system, a small telescope in the carrier lens of the spectacles, has proven in many patients to offer successful compensation for a low visual acuity.¹⁵⁻¹⁸

Particularly in the case of visual field defects, compensatory viewing strategies such as an efficient scanning technique or eccentric viewing, are thought to be useful to reduce the negative effect of the visual impairment.^{19,20} Therefore, it's hypothesized that drivers who apply effective compensatory viewing strategies will have a safer driving performance than drivers who do not and that, as a consequence, taking compensatory viewing efficiency into account may improve the predictive power of a model based on visual acuity and visual field extent.

Because of the expected interaction between functional visual limitations and driving skill-related individual characteristics, including the use of visual aids, the need has been felt for an assessment of fitness to drive that takes the use of this compensatory potential into account. For this purpose the Netherlands Bureau of Driving Skills Certificates (CBR) makes use of the concept 'practical fitness to drive' which is defined as a driver's ability to drive safely and smoothly despite a physical impairment, allowing the use of compensatory strategies and technical aids.²¹ It is assessed in a test ride in actual traffic, focusing on situations that are often problematic for the impairment in question. In the Netherlands, the outcome of this assessment procedure is legally defined as the standard for deciding on legal fitness to drive in subjects with binocular visual field defects²² (slightly) below the limit of 140 degrees for the horizontal meridian, including homonymous hemianopia. In our studies we have based our on-the-road assessment of driving performance on this standard.

We have used this standard to assess the sensitivity and specificity of vision parameters (visual acuity and visual field) and also to assess how these might be improved, taking into account a test score indicating compensatory viewing efficiency (model 1).

Furthermore, we compared the outcome of this model to a model based on an assessment of visual attention and contrast sensitivity, which have been frequently reported to be strong predictors of driving safety²³⁻²⁵ (model 2). In this context visual attention refers to a measurement procedure focusing on visual speed in central and near peripheral vision, and not allowing the use of compensatory eye and head movements.

As soon as compensatory viewing strategies are considered important to reduce the negative effect of visual impairment on the activity level, it's of interest to study the opportunity to develop and to improve the efficiency of the viewing strategy by some sort of training

program.^{19,20,26} The second main subject of this paper is concerned with this question.

In summary, this paper describes the improvement of the power to predict the practical fitness to drive taking into account compensatory viewing efficiency, visual attention, the effect of training on the compensatory viewing efficiency, and the driving performance on the road and in a driving simulator. We compiled the results, which we obtained in two large studies on the effect of compensatory viewing strategies, before and after a training program in subjects with major visual field defects, either caused by retinal pathology or by post-chiasmal brain damage.^{27,28} The results of the various parts of these studies are extensively and completely described in a number of articles.²⁹⁻⁴¹ In this article we provide for a general overview of the results and an overall conclusion concerning the practical-fitness-to-drive of subjects with impaired vision.

Material and methods

SUBJECTS

Study A: Visual field defects due to retinal causes Sixty-three males and 37 females with visual field defects due to ocular pathology such as (age-related) macular degeneration (n = 42), glaucoma (n = 31), retinitis pigmentosa or choroideremia (n = 13), or other (n = 14) participated in this study.^{29,30,34,40} They were recruited by short reports in newspapers and folders at ophthalmologists, rehabilitation centers, and 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 (94%) had a valid driver's license. Mean age was 64 years, ranging from 37 to 86 years. To be included in the study, visual field defects had to be present, visual acuity had to be better than 0.1 (20/200), and subjects had to have sufficient and recent driving experience, which was defined as a minimum of 2000 km during the last two years.

Subjects were classified in four groups based on the European requirements for drivers of vehicles of category A (motorcycle) and B (car < 3500 kg): binocular visual acuity should be at least 0.5 and the binocular* horizontal field should extend for at least 120 degrees.^{22**} Subjects in the 'central field defect group' (group 1) did not fulfill the visual acuity requirements but the 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. As this group met the standard vision requirements for driving, this group was considered as a reference group for further analyses (Table 1).

Fifty-one subjects, who failed the practical fitness to drive test (see description further on), were trained to use compensatory viewing

*In this manuscript visual acuity and visual field are always the binocular visual acuity and the binocular visual field.

**Apart from exceptional cases duly justified by a favorable medical opinion and a positive practical test.

TABLE 1. Study A. Subject Characteristics, Pre-Training group.

	<i>Visual Field Defect</i>			
	<i>Central</i> (n = 24)	<i>Peripheral</i> (n = 36)	<i>Central and Peripheral</i> (n = 7)	<i>Mild</i> (n = 33)
Visual acuity (logMAR)	0.23 (0.64)	0.74 (0.14)	0.19 (0.72)	0.77 (0.11)
Horizontal Field Diameter* [deg]	142	84	91	141
Male/Female	16/8	29/7	4/3	14/19
Age [y] (SD)	65 (13)	60 (12)	63 (15)	67 (9)
Driving license [y] (SD)	38 (11)	37 (10)	39 (17)	38 (8)

*Goldmann III4 isopter.

TABLE 2. Study A. Subject Characteristics, Trained group.

	<i>Training</i>	
	<i>Before (n = 51)</i>	<i>After (n = 51)</i>
Visual acuity [logMAR] (SD)	0.36 (0.28)	0.35 (0.29)
Log Contrast Sensitivity (SD)	1.23 (0.32)	1.23 (0.37)
Horizontal Field Diameter* [deg] (SD)	110 (41)	109 (44)
Functional Visual Field Score [range 0-110] (SD)	79 (22)	78 (23)
Male/Female	31/20	31/20
Age [y] (SD)	63 (12)	64 (12)

*Goldmann III4 isopter.

strategies (Table 2). Subjects were randomly allocated to one of the three training programs. Sixteen participated in the laboratory training, 16 in the mobility training and 19 in the on-the-road training³² (see description of Study A further on).

Study B: Homonymous Hemianopia Thirty-two brain-damaged patients were referred to us by either ophthalmologists, neurologists, or neuropsychologists because either the caretakers or the patient had expressed the desire for the patient to be assessed on fitness to drive. All patients had a binocular best corrected acuity of 0.8 or better and contrast sensitivity within normal ranges. All had complete or incomplete Homonymous Hemianopia (HH) as confirmed by automated perimetry using the Humphrey Field Analyzer (Full Field 246 screening program, age corrected, 3-zone strategy). One patient, with left HH, only had (right) monocular vision. Four patients were excluded, three on the basis of severe hemi-spatial neglect and one who suffered severe object-agnosia. Hence, twenty-eight patients participated in this study³⁹ (Table 3).

TABLE 3. Study B, Subject characteristics, Pre-training group.

<i>Characteristics</i>	<i>Hemianopia</i>			
	<i>Value</i>	<i>Left</i>	<i>Right</i>	<i>Total</i>
Subjects [number]		15	13	28
Age [y]	Mean	53	53	53
	Range	29–76	24–68	24–76
Male/Female		13/2	9/4	22/6
Time since injury [months]	Mean	34	45	39
	Range	6–157	3–142	3–157
Aetiology [number]	CVA	12	11	23
	TBI	1	2	3
	Tumour	2	0	2
	Mean	2.8	2.9	2.9
Macular sparing [deg]	Range	0–10	0–8	0–10
	Mean	27	25	26
Driving Experience before injury [y]	Range	5–47	0–44	0–47
	Mean	4/15	3/13	7/28
Continued driving since injury				

TABLE 4. Study 2, Subject characteristics, Training group.

<i>Characteristics</i>	<i>Hemianopia</i>			
	<i>Value</i>	<i>Left</i>	<i>Right</i>	<i>Total</i>
Subjects [number]		9	8	17
Age [y]	Mean	57	59	58
	Range	29–76	50–68	29–76
Male/Female		8/1	6/2	14/3
Time since injury [months]	Mean	34	37	35
	Range	6–157	6–123	6–157
Aetiology [number]	CVA	6	7	13
	TBI	2	1	3
	Tumor	1	0	1
	Mean	2.0	3.0	2.5
Macular sparing [deg]	Range	0–3	0–5	0–5
	Mean	30	25	30
Driving Experience before injury [y]	Range	5–47	18–44	5–47
	Mean	2/9	1/8	3/17
Continued driving since injury				

Seventeen patients, who failed the practical fitness to drive test, entered the training program to use compensatory viewing strategies³³ (Table 4).

PRACTICAL FITNESS TO DRIVE Practical fitness to drive refers to the ability of the driver to drive safely and smoothly despite a physical or cognitive impairment, such as a visual field defect. This 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 expert* of the CBR. This way of assessing practical fitness to drive is the official standard in The Netherlands to examine drivers who do not quite

*‘Expert on practical fitness to drive,’ for shortness we will use ‘driving expert.’

meet the visual field requirements. The driving expert determined whether the individual had adapted his behavior to compensate for the negative effects of his impairment. The driving expert made use of a checklist (Test Ride for Investigating Practical [TRIP] fitness to drive).^{42,43} Items on the TRIP checklist included lateral position on the road, 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). The visual factor (VIS) joins all items in which predominantly visuo-perceptual behavior is reflected. This includes visual scanning, visuo-spatial, and visuo-integrative aspects like assessment of eye and head movements in different situations, perception of traffic signals, visual communication with other traffic participants, etc. This factor holds 25 different items. The operational factor (OPER) joins eight items and reflects fluency of instrumental and psycho-motor aspects of driving like handling the brakes and shifting gears. The tactical factor (TACT) reflects all aspects in which (tactical) choices, anticipation, and adaptation are represented. This factor is comprised of 15 items. Some items are represented in more than one factor. The global impression (GLOB) is the combination of three items (a global impression of practical fitness to drive, technical execution, and traffic insight), each scored on the same four-point scale.

After the driving test, the driving expert assigned 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.

DRIVING SIMULATOR The driving simulator car was a modified BMW 518 on a fixed base, containing all its original controls communicating with the computer system.³⁸ Three computer-driven projectors displayed roads, intersections, traffic lights and signs, buildings, objects, and road participants on a 165 × 45 degrees wide projection screen. Essentially each simulated vehicle perceived its environment, evaluated behavioral rules, and responded appropriately⁴⁴ to the driving of the subject.

The route consisted of approximately three kilometers in a town center (speed limit of 50 km/h), 15 kilometers in a rural area (speed limit of 80 km/h) and 20 kilometers on a highway (speed limit of 120 km/h). The rural area consisted of straight roads, roads with left curves, and roads with right curves. The route included 14 intersections, 10 intersections without a sign and four intersections with the sign 'give way.' At the start of the route, traffic density was low, increasing to very busy intersections at the final parts of the driving test. During the route, the subject was instructed four times to follow a car. Speed of the lead car was 40 km/h, 60 km/h, 80 km/h, or at a variable speed between 60 and 80 km/h. Dependent variables of this test are speed, mean lateral position, standard deviation of lateral position, distance to intersection at which the subject released the accelerator, activated the brake, started to make head movements to the right or left, time lead behind

a leading car (THW), mean THW and minimum THW, time to collision into a leading car (TTC), minimum TTC, head viewing angle, number of overtaking, number of crashes, and number of near crashes.

VISUAL ATTENTION Visual attention was assessed by a test similar to the Useful Field of View (UFOV) as described by Ball et al.^{30,37,41} that had been adapted for use in patients with low visual acuity. The peripheral target consisted of a circle (diameter = 4°), which could appear on one of 24 positions at three eccentricities (at 7°, 14°, or 21°) on eight evenly spaced radial spokes. Distraction consisted of 47 squares (4°) evenly spaced on 16 spokes. The test was performed binocularly. Prior to the test presentation time (25–125 ms) and target size (4°) were adapted to the performance of the subject. The test score is the mean percentage of correctly located targets.

COMPENSATORY VIEWING EFFICIENCY Compensatory viewing efficiency was assessed by means of the Attended Field of View (AFOV) test.^{31,41} Subjects could move their eyes and head during a peripheral localization task. It was hypothesized that eye and head movements should be taken into account when predicting practical fitness to drive in subjects with visual field defects. Subjects with visual field defects can use compensatory eye and head movements to eliminate the negative effects of their visual impairment. In each trial, 30 closed circles and one open circle (the target) were presented. The visual angle of this stimulus array was 60 degrees horizontally and 24 degrees vertically. The size of the stimulus elements was determined by eccentricity and could be adjusted in relation to visual acuity. The test was performed binocularly. By means of a staircase procedure the threshold presentation time (range: 8 ms–10 s) was determined for 19 positions. Two measurements were based on AFOV performance: mean threshold presentation time and the variation of the threshold presentation time over the field expressed in percentage deviation from the median (PDM).^{45,46} An efficient scanning strategy is defined here as a scanning strategy resulting in low threshold presentation times and/or a low PDM.

CEREBRAL VISUAL DISORDERS (CVD) QUESTIONNAIRE We used a (translated) Cerebral Visual Disorder questionnaire, originally developed and described by Kerkhoff et al.⁴⁷ and modified by Dittrich (1996, version E1.1, personal communication) to obtain subjective reports of the visual (field) impairment.⁴⁸ This questionnaire assesses visual disabilities, quantitatively as well as qualitatively, by way of specific descriptions as bumping into or avoiding people or obstacles, judging the height of the next step when climbing stairs, getting dazzled by bright lights, etc.

We scored eight visual disabilities as absent or present (0–1) and 12 specific situations on a five-point scale, ranging from ‘no problem’ (0) to ‘usually a problem’ (4). For each part, the scores are summed and divided by the maximum score, resulting in a proportion disability score. The reported subjective disability score is the average of the proportion of both parts.

VISUO-SPATIAL NEUROPSYCHOLOGICAL TESTS We chose a battery of visuo-spatial tests, which are extensively described elsewhere.⁴⁹ We classified the tests into four factors on an a priori basis, namely basic visual scanning and search (BVSS), a visuo-constructive and organisational factor (VCO), a visuo-integrative factor (VI) and a dynamic factor (Dy). From these factors, multiple components can be evaluated, namely performance in terms of lateralization, speed, and accuracy. The speed and accuracy components are traditional aspects for evaluating general test performance. Lateralization, expressed as an asymmetry index, qualifies and quantifies the nature and degree of differential lateral performance, independently of general performance.

The BVSS factor is constructed of 16 different visuo-spatial tasks. The speed, accuracy and lateralization components of this factor are combinations of respectively 12, 11, and 13 different measurements. The VCO factor is constructed by combining four tests. One test results in a speed component, all four tests lead to an accuracy measurement, and two tests result in a lateralization measure. Also four tests are part of the VI factor. One test leads to a speed evaluation, all four tests lead to an accuracy evaluation, and one test results in a lateralization score. The Dy factor is the evaluation of different aspects of the tracking task on a monitor screen. The speed component is a combination of reaction time (RT) and sidewind factor. The lateralization index is a combination of differential RTs and an evaluation of the lateral position. There is no accuracy component in this factor.

Visuo-spatial test performance is hereby operationally defined. It comprises the four different visuo-spatial factors, each of which is evaluated in terms of lateralization, speed, and accuracy. These respective factor component scores will be entered into a model, according to our a priori considerations, to predict visual performance during driving.

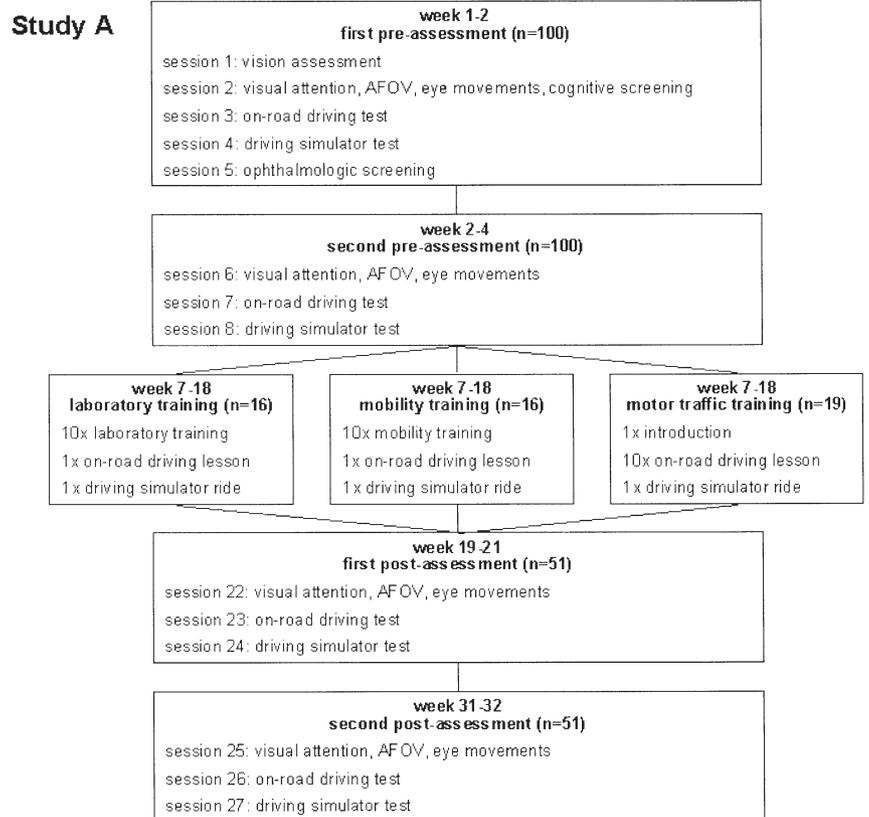
STUDY PROTOCOLS Study A consisted of five major phases: a first preassessment, a second preassessment, a training phase, a first postassessment, and a second postassessment (Fig. 1).

Pretests included extensive vision examination, ophthalmologic screening, assessment of visual attention and compensatory viewing strategies, cognitive screening, and questionnaires. Driving tests were performed on the road and in a driving simulator.

The second preassessment (three weeks later) included a retest of the practical driving test on the road, on the driving simulator, as well as an assessment of visual attention and compensatory viewing strategies.

Subjects were allocated to one of three training programs.³² Each training program consisted of 12 sessions at a frequency of one per week. Laboratory training in which subjects were taught compensatory viewing mechanisms by means of tasks that did not appear to bear any direct relationship to a driving or a traffic situation. In the mobility training, subjects were instructed to make efficient head and eye movements in a real traffic situation: while walking and cycling. As in the laboratory training, subjects obtained some general driving experience in the instruction car and driving simulator. In the on-the-road training, subjects were taught to scan the environment while driving a car.

Fig. 1. Study protocol of study A.



The complexity of a real traffic situation was similar to the mobility training but time pressure is much higher.

The first postassessment was performed in the week after the training period, the second postassessment was three months later.

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 was also investigated which training program was the most effective. Finally, it was examined whether the type of visual field defect was related to training success.

Study B consisted of three major phases: a preassessment, an integrated saccadic compensation training program, and a postassessment (Fig.2).

The preassessment comprised vision examination, neuropsychological screening, a Practical Driving Test on the road, the Cerebral Visual Disorder questionnaire, and the Visuo-Spatial Tests.⁴⁹

The Integrated Saccadic Compensation Training Program consists of three phases.³⁵ It starts with structured saccadic eye movement training in front of a large projection screen (Fig. 3), followed by application and integration of eye movements into the scanning pattern (Fig. 4), and subsequently into an activity of daily living: driving a car (Fig. 5). Each phase consisted of six sessions or less in case maximum performance was obtained earlier.

The postassessment consisted of the Practical Fitness to Drive Test on the road and the Visuo-Spatial Test.³³

Study B

Fig. 2. Study protocol of study B.

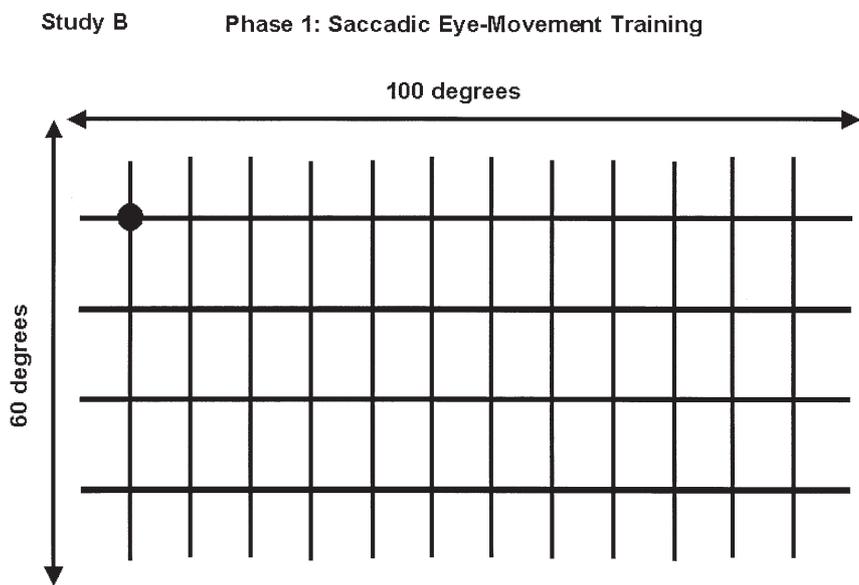
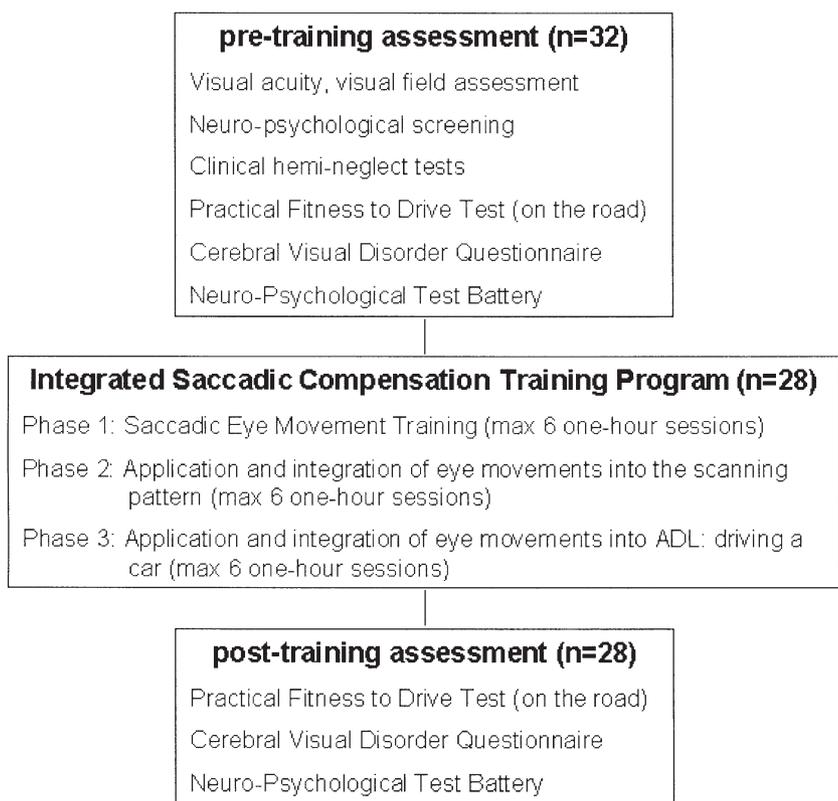


Fig. 3. Example of a task of phase 1 in study B: Saccadic Eye-Movement Training in study B. The pattern is displayed on a 100° × 60° screen. The Homonymous Hemianopic subject has to fixate the black dot, which jumps along a horizontal line from intersection to intersection.

Fig. 4. Four examples of phase 2 in study B: Application Tasks. (A) Copy the connection lines of the left figure into the right one. (B) Describe all details in the figure. (C) Recognize the displayed figure. (D) Tracking task on a desktop driving simulator.

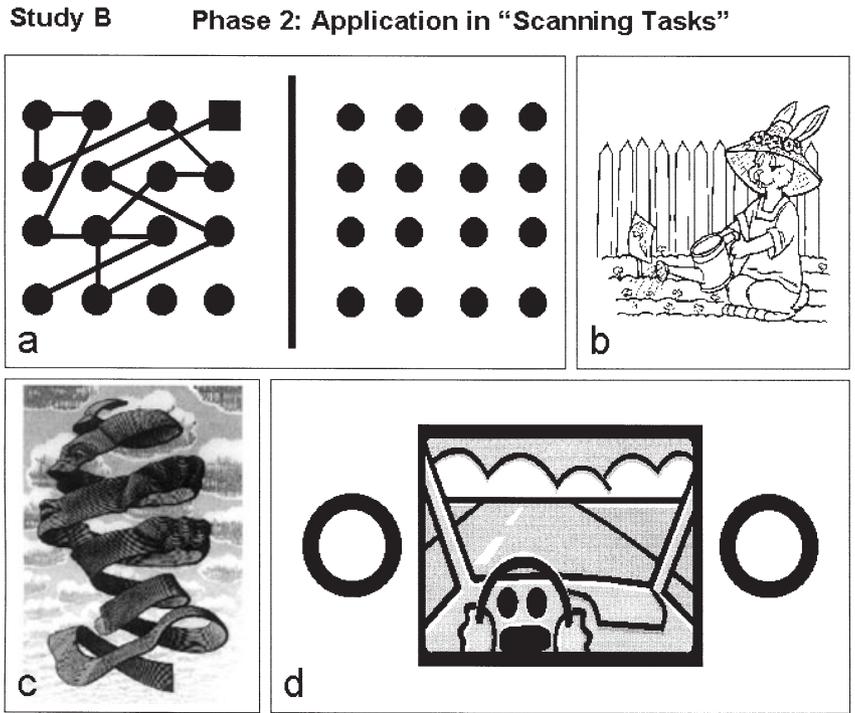


Fig. 5. Phase 3 in study B: ADL, driving instruction by a professional driving instructor.



STATISTICAL ANALYSIS Statistical analyses of the data are extensively accounted for in the published articles²⁷⁻⁴¹ of these two studies and only the resulting conclusions will be presented in this paper.

Results

STUDY A

*Practical fitness to drive*⁴⁰ Applying the current European guidelines, subjects with a binocular visual acuity less than 0.5 (decimal notation) and/or a horizontal field extent of less than 120 degrees are considered unfit to drive.³⁹ In our sample, 67 subjects were classified as unfit to

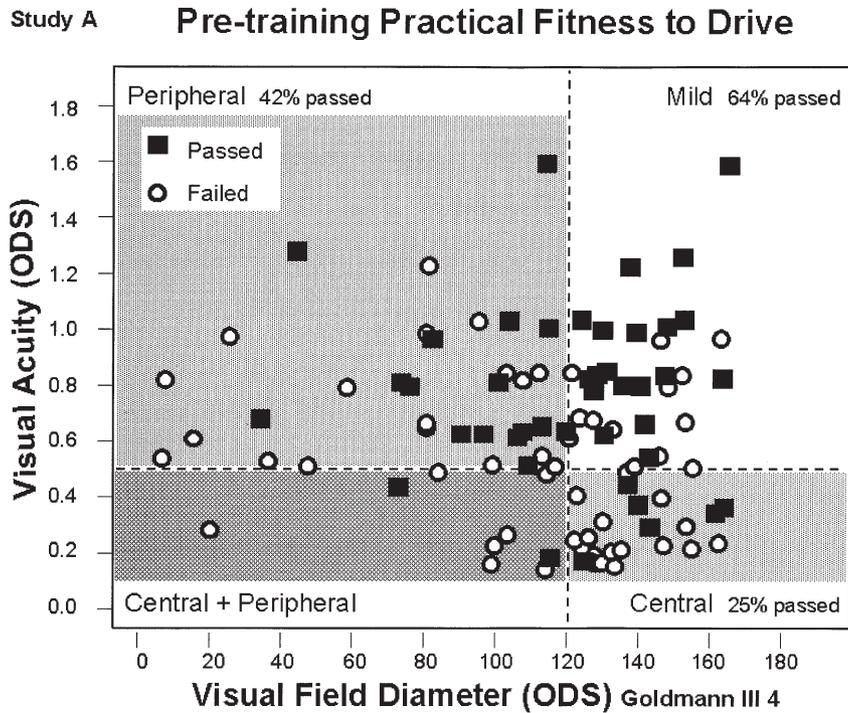


Fig. 6. Failing and passing the practical fitness to drive test in study A in relation to visual acuity and binocular visual field diameter.

drive. Forty-four of them failed the driving test whereas 23 passed. Of the 33 subjects who were considered to be fit to drive on the basis of the current guidelines, 12 failed and 21 passed the test on the road. These figures resulted in a sensitivity of 79% and a specificity of 48%.

Effect of visual field defect and diagnosis on practical fitness to drive⁴⁰ Sixty-four percent of subjects with mild visual field defects passed the driving test, as compared to 42% of subjects with peripheral field defects and 25% of subjects with central field defects (Fig. 6). The relationship between type of visual field defect and the pass/fail score was statistically significant. Results of the subjects with central and peripheral visual field defects (group 3) were not included in the analysis as the sample size was too small. In this group two subjects out of seven passed the driving test.

The type of ocular pathology (macular degeneration, glaucoma, RP, or choroidemia) was not significantly related to passing the driving test.

Correlation matrix⁴⁰ Visual acuity, log contrast sensitivity, AFOV (presentation time) and visual attention correlated significantly (between 0.47 and 0.52, $p < .01$) with the final driving test score.

Compensatory viewing behavior and practical fitness to drive⁴⁰ It was hypothesized that efficient compensatory viewing strategies, such as increased scanning and eccentric viewing, might reduce the negative impact of the visual field defect. An efficient compensatory viewing strategy was here defined as a strategy resulting in low threshold presentation times and/or a low PDM on the AFOV test. The mean thresh-

old presentation time of the AFOV test was highly correlated with the final score ($r = -0.52$) of the driving test. On average, subjects who failed the driving test needed twice as long presentation times (2.5 s) to detect targets than subjects who passed the driving test (1.2 s). The PDM score of the AFOV did not correlate significantly with the driving test scores.

*Driving simulator and practical fitness to drive*³⁸ In the driving simulator we measured a significant influence of the type of visual field defect on driving. Subjects with central visual field defects drove slower (67 km/h) than subjects with peripheral (70 km/h) or mild (74 km/h) visual field defects. Subjects with central field defects showed a different behavior on road curvatures than the subjects of the other two groups. Subjects in these two groups shifted in right and left curves more to the left or right side of the lane respectively, where central field defect subjects maintained a more central position. Subjects in the peripheral visual field defect group drove a less stable course in the lane than the subjects in the central and mild visual field defect groups. Following a lead car, which drove with a variable speed, seemed to be more difficult for subjects in the central field defect group. Minimum time to collision if both cars maintained their actual speed and minimum difference of passage time between the two cars was smaller in subjects with central field defects (4.1 s, respectively 0.9 s) than in the other two groups (5.0/5.4 s, respectively 1.1/1.2 s).

The number of subjects causing at least one accident did not differ between the visual field defect groups.

Subjects in the peripheral field defect group who passed the practical fitness to drive test, started at a larger distance to intersection (14 versus 7 meters) to make head movements (scanning DTI) and made more head movements (33 versus 23) than subjects who failed the test.

*Predicting practical fitness to drive*⁴⁰ Logistic regression was used to predict the pass/fail score on the basis of the vision requirements for driving (model 1). Visual acuity (logMAR) and visual field (functional field score) accounted for approximately 24% of the variation (Table 5). Sensitivity (to detect an at-risk driver) was 80% and specificity was 43%. The model improved significantly to 32% explained variance by adding the AFOV results. Sensitivity was 80% and specificity increased to 64%. This model was compared to a model on the basis of variables that have been reported previously to be good predictors: visual attention, contrast sensitivity, and age (model 2). The percentage variation that was accounted for by visual attention was approximately 23%. Adding contrast sensitivity to the model increased the explained variation to 34%. Age did not further improve the model. Sensitivity and specificity of the model based on visual attention and contrast sensitivity were 80% and 64%, respectively.

Analysis of the driving simulator data indicated that only the scanning DTI improved the predictive power of the two models. Adding scanning DTI to model 1 (VA, VF, AFOV) increased the explained

TABLE 5. Predictive power of (combined) tests for pass the Practical Fitness to Drive test.

<i>Number of subjects</i>	100		87 [†]	
<i>Predictor</i>	<i>Explained variance (%)</i>	<i>Sensitivity (%)</i>	<i>Specificity (%)</i>	
<i>Model 1</i>				
Visual acuity (log MAR)	20			
Visual Field (FFS)	24			
AFOV, threshold presentation time	32	38 [‡]	80	64
Scanning DTI*		47	90	74
<i>Model 2</i>				
Visual attention	23			
Contrast sensitivity (log CS)	34			
Age	34	35 [‡]	80	64
Scanning DTI*		45	90	61

*Scanning DTI: distance to intersection on the Driving Simulator at which a subject started head movements to left or right.

[†]Not all subjects participated in the driving simulator tests.

variance of the pass/fail score of the practical fitness to drive test from 38%* to 47% and improved the sensitivity and specificity to 90% and 74%. Adding scanning DTI to model 2 (CS and visual attention) increased the explained variance from 35% to 45% and the sensitivity and specificity to 90% and 61%.

*Explained variances differed from the above paragraph, because not all subjects performed the driving simulator test.

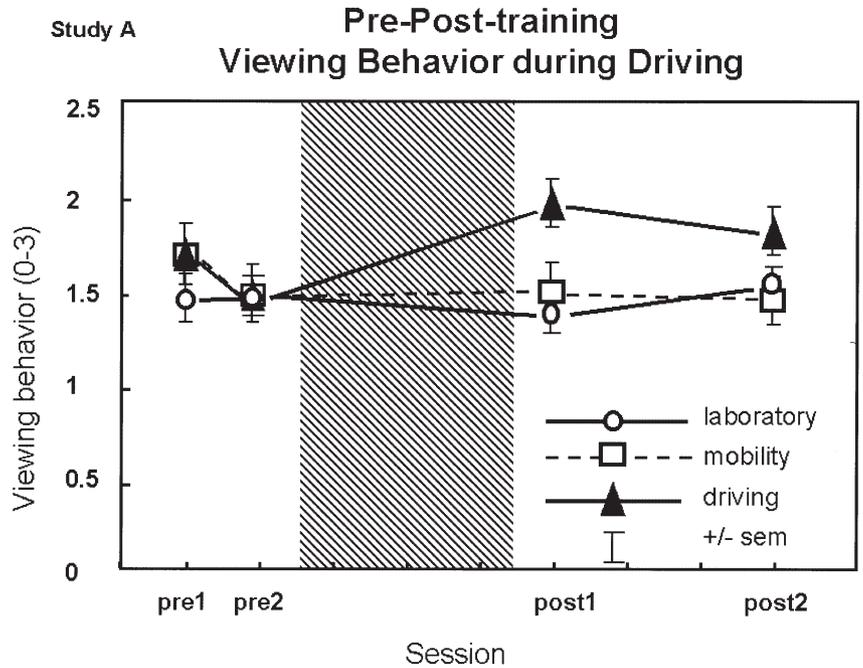
*The effect of training*³² Mean visual acuity (logMAR), mean log contrast sensitivity, and mean binocular horizontal extent of the visual field remained constant throughout the study period (eight months for each subject; Table 2).

*The effect of training on viewing behavior (AFOV)*³² Mean threshold presentation time decreased significantly from 2.3 s before the training to 1.9 s after training and remained at the same level at the second post-assessment.

*The effect of training on visual attention*³² Visual attention scores differed significantly between the first and second preassessment and between the first and second postassessment, but not between pre- and postassessment. The subjects scored 63% correct at the first preassessment, 68% at the second preassessment, 68% at the first postassessment, and 71% at the second postassessment.

*The effect of training on viewing behavior on-the-road*³² Data of 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 on-road training. After training, viewing behavior of subjects in the on-the-road training rated significantly higher than in the mobility or laboratory training. At the second postassessment, the difference was

Fig. 7. Influence of training program in study A on the viewing behavior of subjects during the practical fitness to drive test on the road. Viewing behavior of the subjects receiving driving training was significantly improved only directly after the training period. Shading indicates the training period.



not significant anymore as scores of the on-the-road training group decreased slightly (Fig. 7).

The effect of training on viewing behavior in the driving simulator^{32,40} Viewing behavior while driving in the driving simulator was assessed in 30 subjects of whom nine were allocated to the laboratory training, 11 to the mobility training and 10 to the on-road training. The number of head movements increased significantly after the first preassessment and remained at this level thereafter (Fig. 8). Distance to intersection at which the subject started to make head movements remained constant across preassessment sessions, were significantly increased immediately after training and slightly decreased at the last session (Fig. 8).

The effect of training on practical fitness to drive³² The percentage of subjects that passed the on-road driving test varied significantly across sessions. The percentage of subjects passing the driving test equaled 26% for the first preassessment, 14% for the second preassessment, 39% for the first postassessment and 45% for the second postassessment. The percentage of subjects that passed the on-the-road driving test did not vary significantly as a function of training program (Fig. 9). The percentage of subjects in the on-the-road training program passing the on-the-road driving test was, although not significantly, larger after on-the-road training than after laboratory or mobility training.

Type of visual field defect³² It was hypothesized that subjects in the central visual field defect group might demonstrate another training effect pattern than subjects in the peripheral visual field defect group, but no differences between these two groups were observed.

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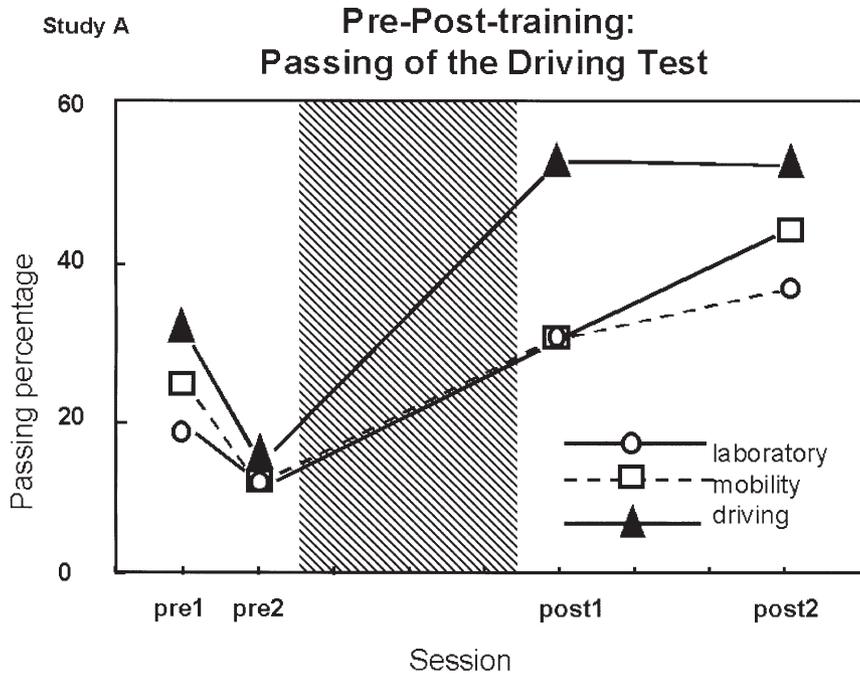


Fig. 8. Influence of training in study A on viewing behavior during driving on the driving simulator. The number of head movements increased before the training period, while the distance to intersection at which head movements started increased during the training period.

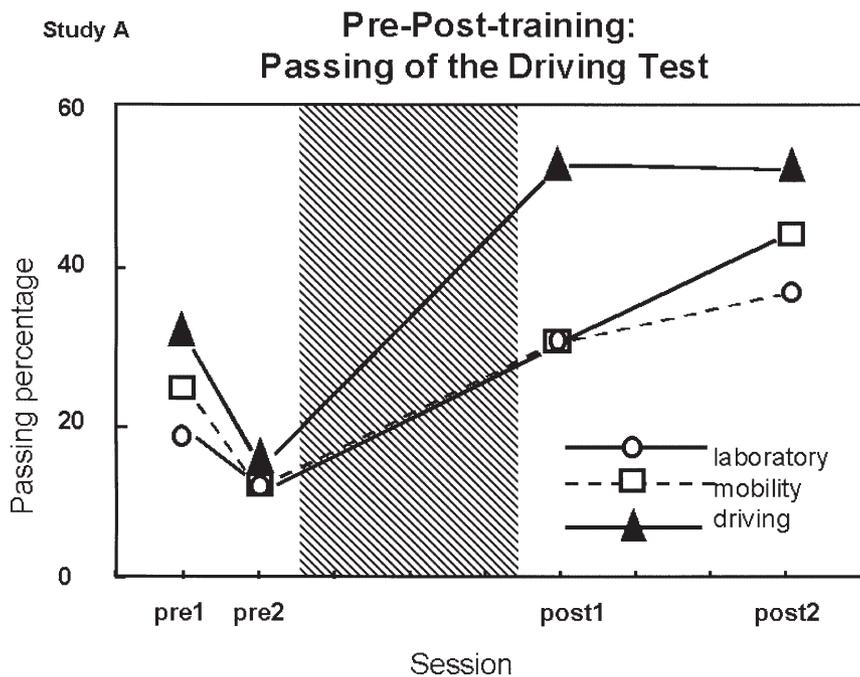
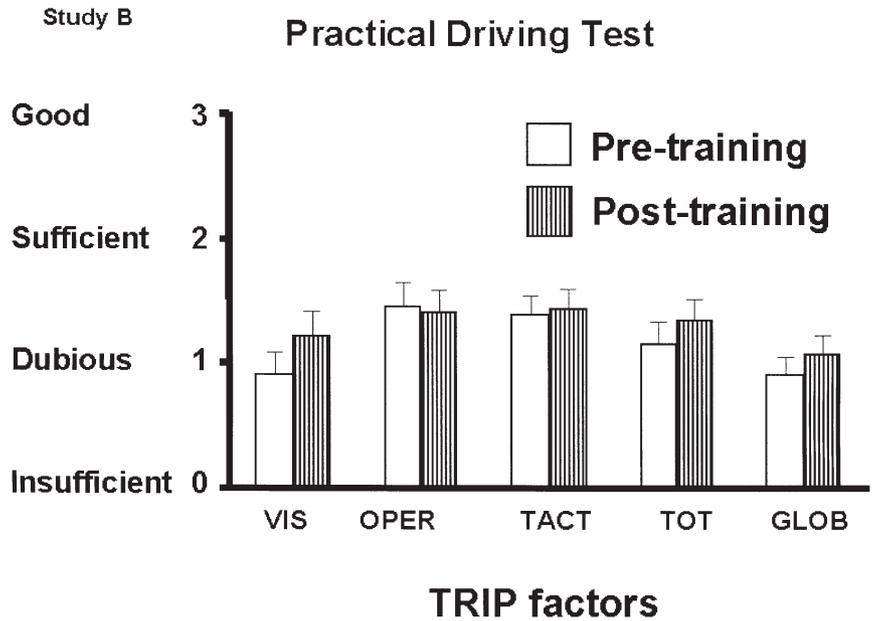


Fig. 9. Fitness to drive in study A as a function of training program. Subjects in all training groups improved during the training period; the subjects in the driving training improved most, but not significantly different from the other two groups.

STUDY B

*Practical fitness to drive*³⁹ Twenty-eight HH patients performed the practical test-ride, after which the TRIP protocol was completed by the driving expert. After quantitatively scoring the items, the driving expert had the opportunity to comment on salient and unacceptable aspects during the driving test for the items which he had rated as insufficient or doubtful. This showed that lack of stability in steering is the most

Fig. 10. The scores of the practical fitness to drive test in study B showed a significant improvement of the VIS after the training.



reoccurring comment (11 subjects). This deficiency is especially evident in complex situations. Complex situations could be busy traffic, difficult road design, distraction by conversation, or an upcoming maneuver. Unacceptable lateral deviations, either to the left or to the right, were observed in eight subjects. Surprisingly, there was no relationship between the side of the lateral deviation and the side of the HH. These large lateral deviations (and their corrections) led to unacceptable swinging on the road. Only four of the 28 subjects passed the on the road test.

Due to the nature of the visual impairment, visuo-spatial limitations can be expected in HH. Macular sparing didn't show any significant relationship with VIS, either at pre- or posttraining assessment.

The effect of training on practical fitness to drive^{33,35} After the rehabilitation program, two of the seventeen subjects (one left- and one right-sided HH) passed the practical driving test. Further analyses of driving performance is done on the TRIP factor scores (VIS, OPER, TACT, TOT and GLOB; Fig. 10).

The TRIP factor scores showed no difference in performance between left- and right-sided HH. After the training period only a significant improvement of the VIS factor was measured. On average, none of the TRIP scores (pre- and postassessment) reached level 2, which indicates 'sufficient performance'. However, in both patients who passed, all TRIP factors were at a 'sufficient' level (range: 2.00–2.12) after the rehabilitation program, while the pretraining levels ranged from 1.32 to 2.08. For those who did not pass, mean TRIP factor scores didn't change much. Pretraining scores ranged from 0.76 to 1.40 and posttraining from 0.88 to 1.36.

The effect of training on Visuo-spatial Neuropsychological tests^{33,35} Visuo-spatial Neuropsychological test performance was a priori classi-

fied into four factors, which were evaluated on different components (lateralization, speed, and accuracy).

In contrast to the significant improvement of the above-mentioned VIS factor after the training, we did not observe any effect of the training on the performance on the Visuo-spatial Neuropsychological test.

Discussion A number of questions were investigated in these studies. First, will the inclusion of a variable that accounts for compensatory viewing efficiency improve sensitivity and specificity of the current vision requirements for driving? Second, are subjects with peripheral field defects more impaired with regard to practical fitness to drive than subjects with a central field defect? Third, are subjects with Homonymous Hemianopia unfit to drive?

If compensatory behavior is important for practical fitness to drive, for the rehabilitation of visually impaired people, the next question is very important: Is it possible to improve compensatory viewing efficiency and practical fitness to drive by a training program? Practical fitness to drive is assessed in an on-the-road test, which is the official standard in The Netherlands for drivers who do not quite meet the visual field requirements for driving.

The first research question relates to the predictive power of the current European vision requirements for driving. The vision requirements for driving a motorcycle or a passenger car are a binocular visual acuity of at least 0.5 (decimal notation) and a horizontal field extent of at least 120 degrees.²² Previous studies have demonstrated that, although the relationships between vision requirements and driving safety are significant, they are not conclusive with regard to the identification of individual at-risk drivers.⁵⁰ Visual acuity is often reported to be a weak predictor for mobility in general⁵¹⁻⁵⁵ and for driving in particular.^{8,24} Measures of the visual field (such as horizontal extent, mean sensitivity, and percentage remaining visual field) have been reported to be better predictors for mobility.^{50,51,53,56-58} Johnson and Keltner,⁴ for example, reported that accident and conviction rates of subjects with visual field loss in both eyes were more than twice as high as for a control group. Szlyk and colleagues⁵⁹ evaluated driving performance of subjects with retinitis pigmentosa (RP), resulting in a visual field restriction that varied from partial restriction (binocular visual field extent: $77^\circ \pm 36^\circ$) to severe concentric peripheral restriction (binocular visual field extent: $6.3^\circ \pm 2.6^\circ$). The proportion of individuals who had one or more accidents was significantly greater for these subjects with RP than for control subjects. However, for less severe visual field defects, the effect on driving performance was much smaller. The effect of behavioral modifications, such as speed reduction and compensatory viewing strategies, has often been suggested as an intermediate variable between vision and driving safety. On the basis of these results and suggestions in the literature, it was hypothesized that subjects with visual field defects who compensate will have better driving performance than subjects not using compensatory viewing strategies. Results of the present studies corroborated this hypothesis. The mean threshold presentation time of the AFOV test was highly correlated with the final score of the practical fitness to drive test. Sub-

jects who failed the practical fitness to drive test needed twice as long presentation times to detect the target as subjects who passed the practical fitness to drive test. The capacity of visual acuity and visual field to discriminate between practically fit and unfit drivers was low. Adding the mean threshold presentation time of the AFOV improved the model significantly. Sensitivity to detect an at-risk driver was 80% and specificity was 64% in our sample. Ball and Owsley²⁴ argued that the low predictive power of the visual field could be due to the difference in complexity between a visual field assessment by means of perimetry and the use of the visual field while driving. They therefore suggested to assess the UFOV with the use of supra-threshold stimuli in a cluttered scene under varying attentional demands. Inclusion of this complex capacity improved prediction in their studies. Ball and Owsley²⁴ reported that sensitivity and specificity of the UFOV test alone were 92% and 65% respectively. Ball and colleagues⁶⁰ reported a sensitivity of 89% and a specificity of 81% in predicting crash frequency in a group of 294 drivers. On the basis of these results, a visual attention score similar to the UFOV, but adapted for application in low visual acuity subjects, was included in our model. Contrast sensitivity was also included in our model since contrast sensitivity has been reported to be a better predictor than visual acuity in mobility studies.^{50-53,57,58,61} In our study the visual attention score accounted for approximately 23% of the variance to distinguish practically fit and unfit drivers. Adding contrast sensitivity further improved the model. The model based on visual attention and contrast sensitivity resulted in a sensitivity to identify an at-risk driver of 80% and a specificity of 64%. These results were identical to the results of the VA, VF, and AFOV model.

Adding the scanning DTI parameter of the driving simulator test improved both models. Explained variances increased to 45-47%, and at sensitivity levels of 90% the specificity's of model 1 and 2 increased to 74% and 61%, respectively.

Even at these high sensitivity and specificity levels these tests have a limited value as a tool to distinguish between fit and unfit drivers, because large numbers of subjects might falsely be considered as unfit to drive. An alternative might be to use two criteria: a criterion with a high specificity to decide that a subject is unfit to drive and a criterion with a high sensitivity to indicate that a subject is fit to drive. Subjects scoring in between these two criteria have to pass the Practical Fitness to Drive Test to obtain a drivers license. The final score of the practical fitness to drive test is a subjective and overall score and incorporates other aspects of driving too, such as routine and a personal driving style.

The second research question related to the type of visual field defect and its effect on driving performance. Previous studies are concurrent with the hypothesis in mobility studies that subjects with central field defects are less impaired than subjects with peripheral visual field defects.^{6,9,59} Age-related macular degeneration, for example, was not associated with increased accident involvement.⁹ However the same subjects performed poorer on driving simulator parameters such as the number of accidents, lane boundary crossings, braking response times

to stop signs, and driving speed than a control group of comparable age. In accordance with the hypothesis that subjects with peripheral field defects are more impaired with regard to driving, Szlyk et al.⁵⁹ reported that a greater proportion of subjects with RP had accidents than a control group. Owsley et al.⁶² reported that subjects involved in injurious crashes were 3.6 times more likely to report a diagnosis of glaucoma than controls and emphasized that glaucoma per se, not visual field sensitivity, was a predictor of crash involvement. In the present study, no effect of diagnosis on driving performance was observed. Within diagnostic categories, vision parameters varied widely and showed a large overlap between categories. Making use of a diagnosis to assess driving performance is only useful if dealing with homogeneous categories and if the vision parameters are equal within a category. The categories in the present study were not homogeneous and even within one category vision varied over a wide range. In case of glaucoma, for example, visual acuity, contrast sensitivity and visual field extent differed significantly between individuals. If the goal is to assess the effect of vision on driving performance we believe that groups should be selected on the basis of vision parameters rather than on the basis of diagnosis. In the central field defect group (group 1) or central and peripheral field defect group (group 3) less people demonstrated a sufficient level of fitness to drive. Only 25% to 29% passed the practical fitness to drive test, as compared to 42% in the peripheral field defect group (group 2) and 64% in the mild visual field defect group (group 4). In contrast to the suggestion in the literature, it was here observed that subjects with central visual field defects were at a disadvantage with regard to driving compared to subjects with either peripheral or mild visual field defects. The main conclusion of this study is that the predictive power of the current vision requirements for driving was improved by taking compensatory viewing efficiency into account. Yet, the percentage of explained variance remained low, limiting the use of these tests to identify individual at-risk drivers. Contrast sensitivity and visual attention could equally well predict practical fitness to drive.

Four of the 28 subjects in the HH study group passed the practical fitness to drive test, indicating that some subjects in this group demonstrated sufficient compensatory viewing behavior and driving behavior during the on-the-road test ride. This number is too low to be used in any prediction attempt, since a negative prediction for all cases would result in 86% correct classifications. The overall negative conclusion is in clear contradiction with some reports.⁶³⁻⁶⁵ This can partly be explained, because our HH population is less positively selected than in the other studies. Our subjects suffer HH and were referred having a question related to their fitness to drive. The outcome was in most cases expected or feared to be negative. In the Warmink et al. study⁶⁴ (personal communication) most of the patients volunteered for an official driving evaluation. These patients were encouraged by their own experience of a likely positive outcome. It is possible that this clear self-selection bias had the effect that only the very best performing HH patients were included, which would account for the high number of patients passing the driving test in their sample. The study by Schulte

et al.⁶⁵ also suggested absence of driving-related disabilities in HH patients. Their nine patients were reported to be ‘neuropsychologically intact’ and thus not representative for the wider population of HH patients. Moreover, they used a driver-simulator task, which was inherently a simplification of a real-world driving situation (e.g., automatic transmission, no intersections). We didn’t have this positive bias or this simplification of the driving test and hence our results may be more indicative of the performance level in a HH patient population without hemi-neglect.

Both our studies executed a training program on viewing strategies in various conditions (laboratory tasks, mobility tasks, on-the-road driving) and the practical fitness to drive task was one of the parameters to evaluate the efficacy of the training program. In study A, 51 subjects participated in one of the three training programs and the percentage of subjects who passed the practical fitness to drive task increased remarkably from 20% to 42%. The type of received training program did not significantly influence practical fitness to drive, though the on-the-road training seemed to have the strongest effect. In study B, 17 subjects participated in the training program that consisted of three consecutive phases. Two of them passed the practical fitness to drive task, which they failed before the training. In both studies the training program and the number of training sessions was limited and not continued, even if it could be expected that the results of the training might still have improved. Nevertheless, we were able to assess measurable improvements in practical fitness to drive and some related visual tasks. Regular rehabilitation and driving training programs are always adapted to the individual needs and progress and we expect that this will further improve training results.

From these two studies we can conclude that explained variance of vision tests like visual acuity, visual field, contrast sensitivity are improved by adding a test on visual attention or compensatory viewing behavior. Nevertheless the sensitivity and specificity remain below 80% and 64% in any combination of these parameters. Use of these parameters as instruments to decide about fitness to drive might exclude many people, who are fit to drive, from driving.

A second conclusion is that a dedicated training program improves the performance on the practical fitness to drive test and might be considered as an important rehabilitation tool to improve participation of visually impaired people.

As long as vision tests are not demonstrated to have satisfactory predictive power to explain unsafe driving performance, we consider that an on-the-road test of practical fitness to drive should be used as the ultimate test for driving licensing in cases with scores of visual acuity and visual field slightly below the current limitations for these measures.

IN CONCLUSION We studied two non-random groups of subjects with visual deficits and no apparent other problems. Group A contained 100 subjects with visual acuity and/or visual field problems of retinal origin; group B contained 28 subjects with homonymous hemianopia without neglect.

Since driving proficiency depends on many visual and non-visual factors, it is not surprising that screening tests based on only two visual factors (visual acuity and visual field) are only moderately predictive of on-the-road performance. This was confirmed by our finding that 12 of 33 subjects who met current guidelines failed a road test based on the official Dutch licensing procedure, while 23 of 67 who did not meet the current guidelines passed the road test.

Others have shown that predictability can be improved by adding contrast sensitivity and the UFOV test, a test of the spread of attention in the stationary visual field. We found similar improvements by adding the AFOV test, a test of scanning efficiency in the non-stationary field of view. We also studied the effect of various forms of scanning training, since effective scanning can compensate, in part, for visual field defects.

After a training program the number of subjects in group A that passed the driving test increased from 10 to 21 of the group of 51 subjects, who had failed the initial road test. In group B 2 of 17 subjects, who had failed the initial road test, passed after training; the others showed variable improvements, but did not pass.

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