Part II: The Project
Driving and Visuo-spatial Test performance in Homonymous Hemianopia

1. Abstract
We studied practical fitness to drive in 28 patients with homonymous hemianopia (HH). We focussed upon visual performance during driving and related this to neuropsychological visuo-spatial test performance. Visuo-spatial tests were classified a priori in four visuo-spatial factors, and were evaluated on three components, namely lateralisation, speed and accuracy. Driving safety and fluency was assessed by means of a practical test-ride and scored using a structured protocol. We conclude that HH can not be considered a definite contra-indication for holding a drivers licence since not all patients failed the test-ride. The most frequent remark made by the driving expert was a lack of stability in steering. We found that visual performance during driving was significantly related to visuo-spatial test performance, which was operationally defined as a function of typical visual HH disability. A specific combination of the lateralisation, speed and accuracy components derived from the visuo-spatial factors explained 77% of the variance in visual performance during driving.

For deciding which type of mobility-rehabilitation goal is feasible in HH, our results suggest to administer the Grey Scales task, the Trailmaking test, the Bells test and a Hidden Figures Test.

2. Introduction
Although auditory, kinaesthetic, and vestibular senses are of importance, the most substantial information being processed while driving is of a visual nature. Visual function can, at the impairment level, be conceptualised as incorporating two aspects namely lower-order (sensory) visual function and higher-order (cognitive) visual function, both possibly resulting in disabilities, including impaired driving performance.

Although sensory visual functions are appropriate for clinical assessment of (loss of) visual function, they clearly do not reflect the visual complexity of the driving task. Higher-order deficits can be an alternative limiting factor, in addition to obvious physical and sensory limitations (e.g. Sivak, Olson, Kewman, Won, & Henson, 1981). In a recent review article by Owsley and McGwin (1999), the relationship between various eye conditions and driving habits, performance and safety is discussed. They conclude that visual acuity, although the most commonly used visual screening test for driving licensure, is only very mildly associated with driving safety. Visual field assessment, another commonly used screening procedure, does not provide for consistent and conclusive findings either. These lower-order visual functions do show some relationship with driving in some patients, but clearly do not provide a full account. This has led researchers (e.g. Owsley & McGwin, 1999) to conclude that visual perception during driving, or any other complex task for that matter, is dependent not exclusively on visual sensory function and physiologic optics, but also on higher-order visual functions. Neuropsychological tests, assessing these of higher-order visual functions, could thus also and perhaps more successfully serve the purpose of screening, evaluating and understanding practical fitness to drive and guiding possible rehabilitation and adaptation.

Traditionally, fitness to drive is defined in medico-legal terms, and is related to impairments, as defined by the WHO classification. We however use a different conceptualisation, namely

* This manuscript was submitted to Neuropsychological Rehabilitation (Tant, Brouwer, Kooijman & Cornelissen).
“practical fitness to drive”, which is to be located at the disability level and is hence assessed accordingly. Fluency and safety of driving was therefore evaluated on-the-road, as we consider this to be the primary and most direct method for determining practical fitness to drive. This practical driving test is (except for the scoring system) similar to the "test-ride" as conducted by the Dutch Licensing Authority (Department of Adaptations), as this is considered to be the golden standard for determining fitness to drive in the Netherlands. In the test-ride, it is examined whether the subject can drive adequately, given the visual impairment.

Neuropsychological test performance has previously been used in relation to studying practical fitness to drive. In this respect, concepts of visual search, visual speed, visual and divided attention, and visuo-spatial impairments are frequently put forward as alternative determinants (e.g. Shinar & Schieber, 1991; Brouwer, in press). However, not all cognitive impairments are expected to adversely affect practical fitness to drive. Specific cognitive impairments, like visuo-spatial dysfunctioning, are more likely to be related to safe and fluent driving. Visuo-spatial perception is one component of cognitive functioning which globally refers to our ability to process and interpret visual information about where (parts of) objects are in space. It underlies our ability to move around in an environment and orient ourselves appropriately. It is not unreasonable to assert that driving has a high visuo-spatial component, and that ongoing and related action is highly dependent on this visuo-spatial information.

A specific interest in visuo-spatial functioning can hence be considered to be a logical consequence of the nature of the driving task. Additionally, since we specifically limit our focus on patients suffering homonymous visual field defects due to post-chiasmal brain damage (and homonymous hemianopia in particular) and since this condition is known frequently to accompany, intensify and/or provoke visual-spatial disability, it validates our effort of studying visuo-spatial test performance in this patient group in relation to driver performance.

From discussions on lower-order visual function (e.g. Owsley & McGwin, 1999), it emerged that extent of the visual field or presence of visual field defects can be an important factor determining practical fitness to drive. Further evidence for this statement is for example provided by Hartje and colleagues (Hartje, Willmes, & Pach, 1991) and by Hannen and colleagues (Hannen, Hartje, & Skreczek, 1998). In these studies, it was reported that homonymous visual field defects due to brain damage resulted, in nearly all cases, in failure on an on-the-road driving test, suggesting clear negative effects of homonymous visual field defects on practical fitness to drive. However, not all literature points inexorably at the devastating effects of homonymous visual field defects on the safety and fluency of driving or driving-related performance. There is evidence which indicates that homonymous visual field defects and homonymous hemianopia by itself can not be an absolute and inevitable contra-indication for holding a drivers licence.

An early demonstration that homonymous hemianopia not necessarily results in unfitness to drive was provided by Vos & Riemersma (1976) and was confirmed by Warmink and colleagues (Warmink, de Jong, & Kempeneers, 1998). Further, a study by Szlyk et al. (Szlyk, Brigell, & Seiple, 1993) shows clearly that different levels of driving performance can be observed within the hemianopic patient group. A similar conclusion was drawn by Racette and Casson (1999). An even more optimistic conclusion was reached by Schulte and co-
workers (Schulte, Strasburger, Muller-Oehring, Kasten, & Sabel, 1999). In their study, no negative effects of visual field defects were found with respect to measures of driving performance in a driver simulator task, suggesting that homonymous visual field defects do not necessarily and by definition lead to decline in (simulator) driving performance.

The current research hence focuses on two main questions. The first concerns practical fitness to drive in patients with homonymous hemianopia (HH). The second questions concerns the relationship between visual performance during driving and other visually related characteristic, with a special emphasis on neuropsychological visuo-spatial test performance. We will study driver performance by means of a practical test-ride. The study population will be patient suffering HH. Our interest is in studying the effects of a visual field defect and associated disorders. We will therefore invest effort in differentiating HH from hemi-spatial neglect, which is considered to be primarily a hemi-spatial attentional problem, rather than primarily a hemi-spatial visual problem.

Patients with hemi-spatial neglect frequently suffer right sided brain damage, in combination with left HH. Hemi-spatial neglect might be considered as an extreme case of hemi-spatial dysfunction resulting in severe hemi-spatial disability. Therefore, severe neglect is often considered as highly indicative for unfitness to drive. Occasional case reports have been described which show that visual field defects in association with neglect behaviour are potentially dangerous for driver and pedestrian (Robertson & Halligan, 1999; Barrett, Schwartz, Crucian, Kim, & Heilman, 2000; Tant, Brouwer, Kooijman, & Cornelissen, in press). As a consequence, on-the-road driving assessment is usually considered as very hazardous and alternative testing (if at all) is usually suggested. Hence, homonymous hemianopia and hemi-spatial neglect need to be clearly differentiated, both on the basis of rehabilitation methods and -outcomes, but also on the basis of severity of disability and hence its differential implications for practical fitness to drive.

By excluding patient with hemi-spatial neglect, we aim at studying the population of patients suffering visual and visually related impairments, rather than primarily attentional impairments. As a consequence, we do not expect any differences in disabilities between left and right HH patients, since they suffer equal (but inverse) visual impairment.

The second question concerns relating visual performance during driving to other visual factors. As already mentioned, lower-order visual dysfunctions (like acuity or the presence of a visual field defect) can not be the sole cause of practical unfitness to drive. In our research, these factors will be held constant, namely our patients will have optimal acuity and HH. We will investigate if other personal characteristics like age, time since lesion, driving experience etc. are perhaps also important factors in relation to visual performance during driving. Macular sparing is in this respect an interesting characteristic. It is well recognised (e.g. Kerkhoff, 1999) that field sparing and reading speed are nearly linearly related. We are interested in its relationship to driving performance. As we conceptualise driving as a primarily visuo-spatial task, in which orientation and global overview are more important than e.g. reading directions, we do not expect macular sparing to be a crucial factor in driving performance. The presence of homonymous visual field defects can lead to subjective visual complaints. We will examine whether these subjective visual complaints (as measured by a questionnaire) can also be related to practical fitness to drive.

Our primary interest is however in relating higher-order visual function to practical driving performance. As already argued, we will focus on visuo-spatial functioning, both in
neuropsychological tests and during driving. From previous research, no specific or limited number of tests emerged which showed a consistently high correlation with practical fitness to drive. Therefore, a small selection of testing methods, purely on empirical grounds, is not obvious. Hence, a broad range of visuo-spatial tests were selected, which had been moderately correlated to practical driving performance in previous studies. These tests are classified a priorily in different visuo-spatial factors, and are evaluated on different components, namely lateralisation, speed and accuracy.

Our envisaged model predicting visual performance during driving by these factors and components is strongly bound by a priori considerations. Firstly, we assume that a (structural) lateralised visual field defect can result in (functional) differential lateralised performance. Homonymous hemianopia is a lateralised visual dysfunction that, if not properly compensated for, will lead to relatively poor visual performance with regard to the side of the blind hemifield. As we assume that good compensation for the HH is a prerequisite for practical fitness to drive and other visuo-spatial tasks, we presume that the extent of differential lateralised performance is a basic component in a model predicting practical fitness to drive. This lateralisation is considered to be a measure of typical hemianopic disability, possibly and most likely affecting all other components. We find it intuitive that highly differential lateralised performance leads in general to more difficulties in constructing an accurate mental spatial representation which is essential in these visuo-spatial tasks. This will lead to more time consumption and less accurate performance. Forcing lateralisation firstly in the prediction model expresses our assumed basic and primary status of this component.

Secondly, HH is caused by brain damage. It is commonly observed that brain damage resulting in mental slowness. In addition, it can safely be argued that the mere visual effects of the lateralised visual field defect will primarily result in more time consumption during visual tasks (Zihl, 1999). We will therefore force speed as the second component in the model.

Thirdly and finally, we will force accuracy in the model. We expect that visual performance during driving can be related to this specific visuo-spatial information. To support our conceptualisation of the status of our components, we expect to observe the traditional speed and accuracy trade-off. More importantly, we hope to observe that worse performance in terms of speed and accuracy is related to higher (i.e. worse) lateralisation scores. Additionally, we are interested in which visuo-spatial factors are of most importance in relation to driving and by which specific tests they are represented.

To conclude, we will try to shed more light on the relationship of visuo-spatial impairment and visual performance during driving. We hypothesise that not all HH patients are practically unfit to drive and that visual performance during driving is related to visuo-spatial test performance, operationally defined as a function of components of typical visual HH disability.

3. Method
3.1. Patients
3.1.1. General
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 optimally 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. Three patients were excluded on the basis of severe hemi-spatial neglect (see further). One patient with left HH suffered severe object-agnosia. As several tests proved not to be applicable and/or resulted in extremely deviant performances, inclusion of this patient would have highly distorted group analyses. As a consequence and as severe object-agnosia is not considered to be typical for HH, this patient was also excluded from the analyses. Hence, twenty-eight patients participated in this study. Table 1 provides some relevant characteristics of these patients.

### Table 1. Summary of patient characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Hemianopia</th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>Patients (number)</td>
<td>15</td>
<td>13</td>
<td>28</td>
</tr>
<tr>
<td>Age (years)</td>
<td>mean</td>
<td>range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>53</td>
<td>29-76</td>
<td>53</td>
</tr>
<tr>
<td>Gender (number)</td>
<td>male</td>
<td>female</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Time since injury (months)</td>
<td>mean</td>
<td>range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>34.4</td>
<td>6.4-157</td>
<td>39.3</td>
</tr>
<tr>
<td>Aetiology (number)</td>
<td>CVA</td>
<td>TBI</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Macular sparing (°)</td>
<td>mean</td>
<td>range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.8</td>
<td>0-10</td>
<td>2.85</td>
</tr>
<tr>
<td>Driving experience before injury (years)</td>
<td>mean</td>
<td>range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>5-47</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0-47</td>
<td>25</td>
</tr>
<tr>
<td>Continued driving since injury (number)</td>
<td>yes</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

A number of chi square tests were performed to analyse the patient characteristics. There proved to be no significant difference in the number of left and right HH patients in this sample ($\chi^2$ (1, \(N=28\)) = .143, ns). There are significantly more males than females, ($\chi^2$ (1, \(N=28\)) = 9.143, \(P < .005\)), equally distributed across both left and right HH groups ($\chi^2$ (1, \(N=28\)) = 1.257, ns). Also the aetiologies are equally distributed across both groups ($\chi^2$ (2, \(N=28\)) = 2.45, ns). T-tests reveal no differences in age (t (26) = -.059, \(P < .954\)), macular sparing (t (26) = -.122, ns), time since injury (t (26) = -.644, ns) or driving experience before injury (t (26) = 4.27, ns) between both HH-groups. Chi square test show that more patients discontinued driving since injury ($\chi^2$ (1, \(N=28\)) = 7.001, \(P < .01\)) but the distribution of patients who (dis)continued driving since injury is equal across both HH groups ($\chi^2$ (1, \(N=28\)) = .048, ns).

#### 3.1.2. Neuropsychological Screening

Prior to the visuo-spatial assessment and driver assessments, all subjects were subjected to a general neuropsychological screening battery. Standardised tests were administered to exclude dementia, aphasia and apraxia. For each individual patient, there was no indication of global cognitive decline as assessed by the Cognitive Screening Test (CST) (De Graaf & Deelman, 1991) and the Mini Mental Status Examination (MMSE). For assessing aphasia,
two subtests from the SAN test (Deelman, Liebrand, Koning-Haanstra, & van der Burg, 1987) were administered evaluating receptive verbal abilities. There was no indication of receptive aphasia in this sample. Ideational and ideomotor apraxia was assessed using a modified version of a method by De Renzi (De Renzi, Faglioni, & Sorgato, 1982). No impairments were found. Further, all patients performed within the normal limits on a form discrimination screening test (VPOR), confirming adequate general lower-order aspects of visual function, apart from the HH.

In order to exclude patients with severe hemi-spatial visual neglect, we used a battery of four clinical cancellation tasks, a line bisection task and a drawing tests. We used the cut-off criteria reported and found in literature reports or manuals of the tests in question (see table 2). For each cancellation task, we imposed an additional “lateralisation-requirement”. This was done in order to make a distinction between a general inattention deficit resulting in a general scanning deficit, and hemi-inattention resulting in a lateralised scanning deficit. This requirement holds that for a "neglect-score" (as opposed to a "general attention deficit-score") the difference between left-sided and right-sided omissions should also be equal to or exceed the cut-off score (i.e. there should be a clear lateralisation). When applicable, the laterality is labelled as either "left" or "right" depending on the side of the anomalies. We decided that, using this battery and cut-off criteria, a patient is considered to suffer severe hemi-spatial visual neglect, if at least four (of maximally six) neglect-scores are obtained and if these scores are identical in laterality. As previously mentioned, three patients were excluded on the basis of these neglect-criteria.

<table>
<thead>
<tr>
<th>Clinical Hemi-neglect tests</th>
<th>Cut-off (omissions)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Albert’s line cancellation Test</td>
<td>2</td>
<td>Halligan &amp; Marshal (1989); Vanier, Gauthier, Lambert, Pepin, Robbillard, Dubouloz, Gagnon, &amp; Joanette (1990)</td>
</tr>
<tr>
<td>3. Search for O’s</td>
<td>3</td>
<td>clinical practice</td>
</tr>
<tr>
<td>6. Representational Drawing test</td>
<td>2</td>
<td>Wilson, Cockburn and Halligan (1987)</td>
</tr>
</tbody>
</table>

3.2. Test procedures
3.2.1. Driving Assessment
A practical test-ride is used to assess driving competence on the level of disability. The on-the-road test took place in and near the city of Groningen, and was conducted by a certified and official driving examiner of the Dutch Licensing Authority, using the standard test-routes and protocols. The cars used for the on-the-road test had dual operation and were maximally adapted to the needs imposed by motor impairments of the individual patient.
To assess performance while driving in a detailed manner, a structured protocol, with predetermined observational items was added to the procedure. This structured protocol (Test-
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ride for Investigating Practical fitness to drive, i.e. TRIP) is a checklist of different aspects of the driving task and had to be filled in by the expert after the test-ride. It contains 55 items judging specific qualities and behaviours during driving. These items are scored on a 4-point scale, where a score of “1” indicates insufficient and inadequate performance, a score of “2” indicates dubious performance, “3” indicates sufficient and “4” indicates good performance. Based on a priori considerations, we constructed separate subscales or factors with these 55 items. The visual factor (VIS) was constructed by joining all items in which, in our opinion, predominantly visuo-perceptual behaviour was reflected. This included 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 held 25 different items. The operational factor (OPER) joined 8 items and reflected fluency of instrumental and psycho-motor aspects of driving like handling the brakes and shifting gears. The tactical factor (TACT) reflected all aspects in which (tactical) choices, anticipation, and adaptation were represented. This factor was comprised of 15 items. Some items were represented in more than one factor. The sum of all TRIP items is indicated by the TOT factor. These four factors (VIS, OPER, TACT and TOT) are hence all directly derived from (combinations of) specific TRIP items.

At the end of the TRIP, both a global impression and end-verdict were provided, based on a global and subjective impression of the expert. The global impression was provided by evaluating three global aspects, namely practical fitness to drive, technical handling and execution, and traffic insight, each scored on the 4-point scale. Similarly to the other factors, a GLOB factor was constructed, combining these three items. All these factors were expressed proportional to their respective maximum factor score for ease of inter-comparison and will subsequently be referred to as factor scores. A factor score of .25 indicates performance at the “insufficient and inadequate” level. Factor scores of .50, .75 and 1 indicate performance at respectively “dubious”, “sufficient” and “good” level. The minimum level for passing would be the “sufficient” (i.e. .75) level. The end-verdict provided by the expert indicates whether or not the subject would be declared fit to drive (pass or fail).

Whenever the driving expert scored an item as “insufficient and inadequate”, he was given the opportunity to also qualitatively express his opinion on the cause and reason for the specific inadequacy. This provides some qualitative indications of the practical driving performance.

3.2.2. Visuo-spatial Assessment

3.2.2.1. Cerebral Visual Disorders (CVD) Questionnaire

The quality of the subjective reports of the visual (field) impairment can be considerably improved by using a structured protocol with specific items assessing specific disabilities (Zihl, 2000). Providing likely examples from everyday life enhances recognisability, accuracy and reliability of the subjective reports by the patients. We use a (translated) Cerebral Visual Disorder questionnaire, originally developed and described by Kerkhoff et al. (Kerkhoff, Schaub, & Zihl, 1990) and modified by Dittrich (1996, version E1.1, personal communication). This questionnaire quantitatively and qualitatively assesses visual disabilities 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. Kerkhoff et al. (1990) significantly correlated the subjective complaints as measured by their questionnaire with objective measurements of visual dysfunction. The concordance of visual impairment expressed by the subjective complaints and verified by objective measurements,
proved to be correct in 80% to 98% of the 269 brain damaged people tested. The complaints most characteristic for HH were bumping into obstacles and slow vision (Zihl, 2000). We scored eight visual disabilities as absent or present (0-1) (Kerkhoff et al.-part) and 12 specific situations on a 5-point scale, ranging from “no problem” (0) to “mostly a problem” (4) (Dittrich-part). 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.

3.2.2.2. Visuo-spatial Tests: factor (component) scores

Previously we argued for selectivity and specificity in test choice, namely for testing visuo-spatial functioning. In our aim to assess as many relevant aspects, finding a balance between quality and quantity, we chose for a battery of visuo-spatial test, which we classified, on an a priori basis, into four factors, 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 lateralisation, speed, and accuracy. The speed and accuracy components are traditional aspects for evaluating general test performance. Lateralisation, expressed as an asymmetry index (AI), qualifies and quantifies a lateral perceptual bias. It expresses the nature and degree of differential lateral performance, independently of general performance. The details on the construction of the factors are discussed elsewhere but are summarised in table 3. We can confine ourselves here in summarising the rationale. The BVSS factor is constructed of 16 different visuo-spatial tasks. The speed, accuracy and lateralisation 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 lateralisation 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 lateralisation score. The Dy factor is the evaluation of different aspects of the tracking task. The speed component is a combination of RTs and sidewind factor. The lateralisation index is a combination of differential RTs and an evaluation of the lateral position. There is no accuracy component in this factor.

When necessary and possible, transformations were inforced on the raw data, following suggestions by Stevens (Stevens, 1996), to approximate normal distributions of the scores. The data were then normalised for intercomparison. The respective component scores of each factor were then averaged, providing a factor component score.

Visuo-spatial test performance is hereby operationally defined a comprising four different visuo-spatial factors, with are evaluated in terms of lateralisation, speed, and accuracy. These respective factor component scores can hence be entered into a model, according to our a priori considerations, to predict visual performance during driving.
Table 3. Summary of construction of the Visuo-Spatial factors. The components used for each test are marked.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Visuo-spatial Test</th>
<th>Dependent Variables</th>
<th>Basic performance</th>
<th>Lateralisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Speed</td>
<td>Accuracy</td>
<td>AI</td>
</tr>
<tr>
<td>Basic Visual Scanning and Search (BVSS)</td>
<td>Trail Making Test</td>
<td>✓</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Counting Dots</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Position Discrimination</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TAP Eye movements</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>TAP Visual Scanning</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>The Attended Field of View Test</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Detection Task</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reading words</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>Reading strings</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Zihl Dotcounting test</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td></td>
<td>Line bisection</td>
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<td></td>
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<td></td>
<td>Albert’s line cancellation Test</td>
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<td>✓</td>
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<td>Mesulam Structured Shape cancellation</td>
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<td>Search for O's</td>
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<td>✓</td>
<td>✓</td>
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<td>The Bells Test</td>
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<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>Grey scales</td>
<td></td>
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<td>✓</td>
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<tr>
<td>Visuo-Constructive and Organisational (VCO)</td>
<td>WAIS-R Block Design Test</td>
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<td>Matrix copy test</td>
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<td>Representational Drawing test</td>
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<tr>
<td></td>
<td>Complex Figure Test</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Visuo-Integrative (VI)</td>
<td>Position Determination</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blocks</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hidden Figures Test</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overlapping Figures Task</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Dynamic (Dy)</td>
<td>Tracking task</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Results

4.1. Practical Driving Test

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. The comments of the 28 protocols were inventoried. Then we tagged per protocol whether the comment was either present or not. This showed that lack of stability in steering is the most reoccurring comment (11 protocols). This deficiency is especially evident in complex situations. Complex situations could be busy traffic, difficult road design, distraction by conversation or an upcoming manoeuvre. The unsteadiness tended to be more apparent in the left HH group but the higher occurrence was especially evident in simple situations. Unacceptable lateral deviations, either to the left or to the right, were reported in eight protocols. 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 over the road”. It was remarked that in some cases, this was most apparent on broad roads, with minimal markings and low traffic. More obstacles and narrow roads led to better performance. In five protocols the driving instructor commented that the patient could not adequately overview a complex traffic scene (e.g. large intersection) and as a consequence chose a wrong lane. Viewing performance was labelled as unstable, variable or inconsequent in seven protocols. Five of them pertained to right HH patients. Although the viewing behaviour was described as adequate, it was only apparent in some situations, hence the viewing style not being a routine. Some of the patients performed best in uncomplicated situations and while not being distracted. However, in others the opposite was observed. Their scanning behaviour improved when complicated situations were at hand or expected. The speed was commented upon as too high in eight protocols, equally distributed across both HH groups. Too low speeds were also frequently observed (10 protocols), as well in city as in rural areas. In seven protocols, driving behaviour was labelled as too uncertain, sometimes despite adequate viewing behaviour. These patients tended to decrease their speed. This frequently intensified the impression (by others) of this uncertainty and as a result led these patients in being an obstacle for other traffic participants. Driving too closely to the right side of the road and taking rightwards turns too widely was commented upon in four and five protocols respectively, all pertaining to right HH patients.

MANOVA analysis was performed entering all factor scores derived from the practical driving test, as dependants and the side of hemianopia as between-subjects factor. This revealed no significant effect of hemianopia ($F(5, 22) = .737$, ns). Chi square analysis on the data of the end-verdict revealed that significantly more patients failed than passed ($\chi^2 (1, N=28) = 14.286, P <.001$), but the distribution was equal in both HH groups ($\chi^2 (1, N=28) = .862$, ns). The factor scores are summarised in table 4.

Table 4. Summary of mean TRIP factor scores for both HH groups and pooled data.

<table>
<thead>
<tr>
<th>TRIP Factors</th>
<th>LHH</th>
<th>RHH</th>
<th>Pooled data</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIS</td>
<td>.53 (.21)</td>
<td>.57 (.14)</td>
<td>.55 (.18)</td>
</tr>
<tr>
<td>OPER</td>
<td>.63 (.16)</td>
<td>.66 (.11)</td>
<td>.65 (.14)</td>
</tr>
<tr>
<td>TACT</td>
<td>.62 (.15)</td>
<td>.68 (.10)</td>
<td>.65 (.13)</td>
</tr>
<tr>
<td>TOT</td>
<td>.58 (.18)</td>
<td>.61 (.12)</td>
<td>.60 (.15)</td>
</tr>
<tr>
<td>GLOB</td>
<td>.53 (.17)</td>
<td>.54 (.15)</td>
<td>.53 (.16)</td>
</tr>
</tbody>
</table>

Finding no interactions with the side of the hemianopia, we pooled the data from both HH groups and performed one-sample T-tests to evaluate whether the factor scores were different from "sufficient"-level (i.e. .75) and from "dubious"-level (i.e. .50). All factor scores were significantly different from "sufficient"-level. All factors, except the VIS and GLOB factor yielded significant differences from "dubious" level (see table 5).

Table 5. Summary of T-test evaluation of TRIP factor scores.

<table>
<thead>
<tr>
<th>Test value</th>
<th>TRIP factor score</th>
<th>Test value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dubious (.50)</td>
<td>(mean)</td>
<td>Sufficient (.75)</td>
</tr>
<tr>
<td>$\bar{t} (27) = 1.501$, ns</td>
<td>VIS (.55)</td>
<td>$\bar{t} (27) = -5.946$, $P &lt;.001$</td>
</tr>
<tr>
<td>$\bar{t} (27) = 5.576$, $P &lt;.001$</td>
<td>OPER (.65)</td>
<td>$\bar{t} (27) = -3.971$, $P &lt;.001$</td>
</tr>
<tr>
<td>$\bar{t} (27) = 5.748$, $P &lt;.001$</td>
<td>TACT (.65)</td>
<td>$\bar{t} (27) = -4.198$, $P &lt;.001$</td>
</tr>
<tr>
<td>$\bar{t} (27) = 3.325$, $P &lt;.005$</td>
<td>TOT (.60)</td>
<td>$\bar{t} (27) = -5.369$, $P &lt;.001$</td>
</tr>
<tr>
<td>$\bar{t} (27) = 1.142$, ns</td>
<td>GLOB (.53)</td>
<td>$\bar{t} (27) = -7.253$, $P &lt;.001$</td>
</tr>
</tbody>
</table>
For the remainder of the analyses, we will only consider the VIS factor as our specific interest is in visual performance during driving. For prediction, we do not consider the other factors. The Pearson correlations of the different factors were all highly significant and ranged from .71 to .98 (all \( P < .001 \)). We do not use the end-verdict as the to-be predicted score, since we observed far more failures than passes and logistic regression results in 86% correct classifications without any factors in the model.

### 4.2. CVD Questionnaire

Since the CVD questionnaire comprises two parts, we firstly checked if both parts considerably agreed in both HH groups. We therefore performed an MANOVA entering the "Kerkhoff et al. part", the "Dittrich part" and the subjective disability score with side of the hemianopia as between-subjects factor. This analysis yielded no significant result (\( F(2, 25) = .832, \) ns). Since also the correlations between the parts proved to be significantly high (see table 6), we will henceforth only use the subjective disability score, which is a combination of both constituent parts.

#### Table 6. Correlations of the CVD questionnaire parts.

<table>
<thead>
<tr>
<th></th>
<th>Kerkhoff et al</th>
<th>Dittrich</th>
<th>Subjective Disability score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerkhoff et al.</td>
<td>.557**</td>
<td>.926**</td>
<td></td>
</tr>
<tr>
<td>Dittrich</td>
<td>.517*/.613*</td>
<td>.829**</td>
<td></td>
</tr>
<tr>
<td>Subjective Disability score</td>
<td>.910*/.943**</td>
<td>.825*/.841**</td>
<td></td>
</tr>
</tbody>
</table>

above the diagonal: correlations for the pooled patient population (\( N = 28 \))
below the diagonal: correlations for LHH (\( N = 15 \)) and RHH (\( N = 13 \)) respectively
* correlation is significant at .05 level (2-tailed)
** correlation is significant at .01 level (2-tailed)

### 4.3. Visuo-spatial Tests

#### 4.3.1. Factors and factor components

##### 4.3.1.1. BVSS factor components

#### 4.3.1.1.1. speed

The speed component of the BVSS factor (BVSSsp) consists of 12 speed assessments. All Pearson correlations, except of the TAP eye movement test (\( r(28) = .333, \) ns), with the BVSSsp factor were significant and ranged from .48 (\( P < .01 \)) to .82 (\( P < .001 \)). The three tests with the highest correlations were the Bells test (\( r = .82 \)), Trailmaking part B (\( r = .80 \)) and letter-reading speed (\( r = .75 \)). The three highest correlations for the left HH group were with the Trailmaking part A and B (\( r = .86 \) and \( r = .79 \)) and the Mesulam cancellation (\( r = .75 \)). For the right HH group, the three highest correlations were with the Bells test (\( r = .91 \)), letter-reading speed (\( r = .88 \)) and Search of O’s (\( r = .87 \)).

#### 4.3.1.1.2. accuracy

The accuracy component of the BVSS factor (BVSSac) consists of 11 accuracy assessments and is expressed in terms of omissions, errors and deviations. A higher score hence indicates worse performance. For the remainder and for comparing accuracy components scores across factors, we will use the inverted factor components score so that higher scores indicate better performance. Only the accuracy of the Line bisection test (\( r = .07 \)) and the TAP visual scanning (\( r = .16 \)) did not correlate significantly with the BVSSac factor. All other Pearson correlations ranged from .38 (\( P < .05 \)) to .78 (\( P < .001 \)). The three highest correlations were observed with the Bells test (\( r = .78 \)), Position Discrimination (\( r = .70 \)) and the Zihl Dotcounting test (\( r = .69 \)). The Bells test (\( r = .78 \)), the Search of O’s (\( r = .76 \)) and the Position
Discrimination ($r = .68$) showed the highest correlations in the left HH group. The Mesulam cancellation ($r = .76$), the Bells test ($r = .62$) and the Zihl Dotcounting test ($r = .58$) showed the highest correlations for the right HH group.

### 4.3.1.1.3. lateralisation

The lateralisation component of the BVSS factor (BVSSai) consists of 13 lateralisation indices. The AIs resulting from the Line bisection ($r = .30$), Search of O’s ($r = .14$), Alberts Line Test ($r = .02$), the Bells test ($r = .06$) and the TAP visual scanning ($r = .34$), did not correlate significantly with the BVSSai. All other Pearson correlations were significant and ranged from $0.40$ ($P < .05$) to $0.82$ ($P < .001$). The Grey Scales ($r = .81$), the lateralisation based on the standard deviations of the Detection Task ($r = .75$), the AFOV and the TAP eye movements (both $r = .65$) showed the highest correlations. For the left HH group, the three highest correlations were observed with the word reading test ($r = .65$), the AFOV ($r = .62$) and the Detection Task (standard deviations) ($r = .61$). For the right HH group, these were the Search of O’s ($r = .66$), the Bells test ($r = .45$, ns) and the letter reading test ($r = .41$, ns).

### 4.3.1.1.4. intercorrelations

We intercorrelated the BVSS factor components. We used the unsigned values of the lateralisation scores to correlate with. The factor components were not significantly interrelated. The results are summarised in table 7.

<table>
<thead>
<tr>
<th></th>
<th>Speed</th>
<th>Accuracy</th>
<th>Lateralisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>-.17</td>
<td>.35</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>-.30 / -.12</td>
<td>-.24</td>
<td></td>
</tr>
<tr>
<td>Lateralisation</td>
<td>.32 / .39</td>
<td>-.29 / -.21</td>
<td></td>
</tr>
</tbody>
</table>

above the diagonal: correlations for the pooled patient population ($N=28$)
below the diagonal: correlations for LHH ($N=15$) and RHH ($N=13$) respectively
no significant correlations were found at .05 level (2-tailed)

### 4.3.1.2. VCO factor

#### 4.3.1.2.1. speed

The speed component of the VCO factor (VCOsp) only consists of the speed assessment of the normalised Complex Figure test score.

#### 4.3.1.2.2. accuracy

The accuracy component of the VCO factor (VCOac) consists of 4 accuracy measurements and is expressed as number of items or elements completed. Hence, a higher score indicates better performance. All test scores correlated significantly with the VCOac factor. Pearson correlations ranged from $0.38$ ($P < .05$) to $0.79$ ($P < .001$). The three highest correlations were observed with the Block Design ($r = .53$), the Complex Figure Test ($r = .42$) and the Matrix test ($r = .40$). For the left HH group, the highest correlations were respectively with the Complex Figure Test ($r = .90$), the Matrix test ($r = .72$) and the Block Design ($r = .70$). For the right HH group, only the correlation with the Block Design was significant ($r = .40$). The Complex Figure Test and the Representational Drawing test (both $r = .44$) were not significantly correlated with VCOac in the right HH group.
4.3.1.2.3. lateralisation
The lateralisation component of the VCO factor (VCOai) consists of two AIs. The observed Pearson correlations were .87 for the Representational Drawing test ($P < .001$) and .38 ($P < .05$) for the Complex Figure Test. For the left HH group, we observed correlations of respectively .76 ($P < .001$) and .42 (ns) for these tests. For the right HH group, the same pattern was observed, namely $r = .95$ and .05 respectively.

4.3.1.2.4. intercorrelations
We intercorrelated the VCO factor components. They were significantly correlated. The results are summarised in table 8. We used the unsigned values of the lateralisation scores to correlate with. The significant correlations in the RHH group disappeared for the Speed component.

<table>
<thead>
<tr>
<th></th>
<th>Speed</th>
<th>Accuracy</th>
<th>Lateralisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>-.33</td>
<td>.45*</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>-.62*</td>
<td>.01</td>
<td>-.65*</td>
</tr>
<tr>
<td>Lateralisation</td>
<td>.64*</td>
<td>.31</td>
<td>-.62* / -.68*</td>
</tr>
</tbody>
</table>

above the diagonal: correlations for the pooled patient population ($N=28$)
below the diagonal: correlations for LHH ($N=15$) and RHH ($N=13$) respectively
*correlation is significant at .05 level (2-tailed)

4.3.1.3. VI factor
4.3.1.3.1. speed
The speed component of the VI factor (VIsp) consists of the assessment of the Overlapping Figures test.

4.3.1.3.2. accuracy
The accuracy component of the VI factor (VIac) consists of four assessments. Performance is expressed as number of items successfully completed. Hence, a higher VIac score indicates better performance. The Position Discrimination test did not correlate significantly with VIac ($r = .34$, ns). The other Pearson correlations were .72 for the Hidden Figures test, .67 for the Blocks and .52 for the Overlapping Figures test. For the left HH group the observed correlations were .81 for the Blocks, .73 for the Hidden Figures test and .52 for the Overlapping Figures test. In the right HH group, only the Hidden Figures test correlated significantly ($r = .79$, $P < .001$). The Overlapping Figures test ($r = .52$) and the Blocks ($r = .33$) did not reach significance.

4.3.1.3.3. lateralisation
The lateralisation component of the VCO factor (VCOai) consists of two different measurements of the Overlapping Figures test, namely AIs based on strategy and on omissions. They both correlated significantly with the VCOai ($r = .77$ and $r = .73$ respectively). For the left HH group, the Pearson correlations were respectively $r = .48$ (ns) and $r = .66$. For the right HH group, the correlations were $r = .82$ and $r = .80$ respectively.

4.3.1.3.4. intercorrelations
We intercorrelated the VI factor components. Speed and accuracy correlated significantly, both in the pooled sample as for each HH group. The significant pooled correlation of
accuracy and lateralisation disappeared in the respective HH groups. The results are summarised in table 9. We used the unsigned values of the lateralisation scores to correlate with.

<table>
<thead>
<tr>
<th>Table 9. Intercorrelations of the VI components</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Speed</td>
</tr>
<tr>
<td>Accuracy</td>
</tr>
<tr>
<td>Lateralisation</td>
</tr>
</tbody>
</table>

above the diagonal: correlations for the pooled patient population (N=28)
below the diagonal: correlations for LHH (N=15) and RHH (N=13) respectively
* correlation is significant at .05 level (2-tailed)
** correlation is significant at .01 level (2-tailed)

4.3.1.4. Dy factor

4.3.1.4.1. speed

The speed component of the Dy factor (Dysp) consists of three measurements which all correlated significantly. The RT in the single task correlated significantly with the Dysp (r = .85, P < .001). The Pearson correlation of RT in the double task condition was .73 (P < .001) and the sidewind factor correlated .52 with Dysp (P < .005). The same pattern was observed in the left HH group (respectively .88, .66 and .52). For the right HH group, the pattern was double task RT (r = .89), single task RT (r = .87) and sidewind (r = .57).

4.3.1.4.2. accuracy

There is no accuracy component in this factor

4.3.1.4.3. lateralisation

The lateralisation component of the Dy factor (Dyai) is derived of RTs and lateral positions both in single and double task conditions and hence consists of four measurements. Neither of AIs based on the RTs, correlated significantly with the Dyai. The AIs based on the lateral positions in single and double task conditions correlated significantly (respectively r = .75, and r = .91; P < .001). For the left and right HH group, the pattern was identical, namely r = .81 and r = .82 for the left HH and r = .87 and r = .97 for the right HH group.

4.3.1.4.4. intercorrelations

We intercorrelated the Dy factor components. They were not significantly correlated. The results are summarised in table 10. We used the unsigned values of the lateralisation scores to correlate with.

<table>
<thead>
<tr>
<th>Table 10. Intercorrelations of the Dy components</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Speed</td>
</tr>
<tr>
<td>Lateralisation</td>
</tr>
</tbody>
</table>

above the diagonal: correlations for the pooled patient population (N=28)
below the diagonal: correlations for LHH (N=15) and RHH (N=13) respectively
no significant correlations were found at .05 level (2-tailed)
4.3.2. Factor components: Intracorrelations

We intracorrelated the respective factor components. All speed factor components intracorrelated significantly (and positively) in the pooled patient population, and ranged from .41 (\(P < .05\)) to .74 (\(P < .01\)). The pattern of intracorrelations generally corresponded well in both HH groups.

All accuracy factors correlated positively. The correlations between the BVSS and VI factor did not reach significance (\(r = .37\), ns). The other Pearson correlations were .69 (BVSS x VCO, \(P < .01\)) and .57 (VI x VCO, \(P < .01\)). This pattern of intracorrelations corresponded well in both HH groups.

Using raw lateralisation scores and pooling data from both patient populations with mainly quantitatively similar but qualitatively opposite results (see also Tant, Brouwer, Kooijman, & Cornelissen, submitted) can obscure underlying associations. We therefore used the absolute values of the respective AIs for intercomparisons. None of the Pearson correlations reached statistical significance.

We finally averaged the respective speed, accuracy and lateralisation components of the four different factors into global component scores. Their intracorrelations are displayed in table 11. For the lateralisation indices, unsigned values were used. We observe a negative correlation between speed and accuracy. Lateralisation is not significantly correlated neither with speed or accuracy. The nature of the trend is indicative however: positively for speed and negatively for accuracy.

<table>
<thead>
<tr>
<th>Table 11. Intracorrelations of the Global factor component scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Speed</td>
</tr>
<tr>
<td>Accuracy</td>
</tr>
<tr>
<td>Lateralisation</td>
</tr>
</tbody>
</table>

above the diagonal: correlations for the pooled patient population (\(N=28\))
below the diagonal: correlations for LHH (\(N=15\)) and RHH (\(N=13\)) respectively
*correlation is significant at .05 level (2-tailed)
**correlation is significant at .01 level (2-tailed)

4.4. Associations with visual performance during driving

4.4.1. Patient characteristics and visual performance during driving

Patient characteristics were correlated with the visual factor score (VIS). Pearson correlations were computed for the continuous data. For dichotomous data (gender and driving continuation) point-biserial correlations were used (Howel, 1992). The Eta statistic was computed for expressing the association with the aetiology. The results are summarised in table 12.
We observed high negative correlations of visual performance during driving with age, and surprisingly also with driving experience. Since age and driving experience are highly correlated ($r = .90$, $P < .001$), we recomputed the correlations with the VIS factor, controlling for age. These partial correlations are displayed in table 13. For the pooled group, all characteristics measured, except gender, correlated significantly with the VIS factor. Driving experience and macular sparing correlated positively, time since injury negatively. This pattern of results is confirmed in both HH groups. None of the respective Pearson correlations proved to be different in both HH groups.

Entering the four continuous data sources of patient characteristics in a stepwise regression analysis with the VIS factor as dependent, yielded a model with age, sparing and driving experience as significant predictors explaining 66.7% of the variance ($F(3,24) = 16$, $P < .001$). Time since lesion was not included in the model. More detailed statistics resulting from this analysis can be seen in table 14.

---

**Table 12. Association of patient characteristics with VISual factor score**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Pooled HH group (N=28)</th>
<th>LHH (N=15)</th>
<th>RHH (N=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-.70**</td>
<td>-.75**</td>
<td>-.60**</td>
</tr>
<tr>
<td>Time since injury (months)</td>
<td>-.13^a</td>
<td>-.23^a</td>
<td>-.01^a</td>
</tr>
<tr>
<td>Macular sparing</td>
<td>.41^a</td>
<td>.47^a</td>
<td>.29^a</td>
</tr>
<tr>
<td>Driving experience before injury (years)</td>
<td>-.50**a</td>
<td>-.61**a</td>
<td>-.35**a</td>
</tr>
<tr>
<td>Gender</td>
<td>.02^b</td>
<td>.15^b</td>
<td>.19^b</td>
</tr>
<tr>
<td>Driving continuation</td>
<td>.50**^b</td>
<td>.53^b</td>
<td>.50^b</td>
</tr>
<tr>
<td>Aetiology</td>
<td>.26^c</td>
<td>.35^c</td>
<td>.01^c</td>
</tr>
</tbody>
</table>

*correlation is significant at .05 level (2-tailed), ** correlation is significant at .01 level (2-tailed)

^a Pearson correlation, ^b point-biserial correlation, ^c Eta statistic

**Table 13. Association of patient characteristics with VISual factor score when controlled for age**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Pooled HH group (N=28)</th>
<th>LHH (N=15)</th>
<th>RHH (N=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time since injury (months)</td>
<td>-.41^a</td>
<td>-.54^a</td>
<td>-.26^a</td>
</tr>
<tr>
<td>Macular sparing</td>
<td>.47^a</td>
<td>.40^a</td>
<td>.54^a</td>
</tr>
<tr>
<td>Driving experience before injury (years)</td>
<td>.41^a</td>
<td>.63^a</td>
<td>.37^a</td>
</tr>
<tr>
<td>Gender</td>
<td>.14^b</td>
<td>.42^b</td>
<td>.08^b</td>
</tr>
<tr>
<td>Driving continuation</td>
<td>.45^b</td>
<td>.43^b</td>
<td>.50^b</td>
</tr>
</tbody>
</table>

*correlation is significant at .05 level (2-tailed), ** correlation is significant at .01 level (2-tailed)

^a Pearson correlation, ^b point-biserial correlation

**Table 14. Statistics from stepwise Regression Analysis entering continuous data sources from the patient characteristics with VIS factor as dependent.**

<table>
<thead>
<tr>
<th>Variables Entered</th>
<th>R² (Adj. R²)</th>
<th>R² Change</th>
<th>Change Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>.49 (.47)</td>
<td>.49</td>
<td>$F(1,26) = 24$, $P &lt; .001$</td>
</tr>
<tr>
<td>Sparing</td>
<td>.60 (.57)</td>
<td>.11</td>
<td>$F(1,25) = 7$, $P &lt; .012$</td>
</tr>
<tr>
<td>Driving Experience</td>
<td>.67 (.62)</td>
<td>.06</td>
<td>$F(1,24) = 4$, $P &lt; .045$</td>
</tr>
</tbody>
</table>
4.4.2. Visuo-spatial assessment and visual performance during driving

4.4.2.1. CVD and VISual factor

The Pearson correlation between the subjective disability score and the VIS factor score proved not to be significant ($r(28) = -.12$, ns), neither for the pooled population, nor for the left ($r(15) = .01$, ns) and right HH groups ($r(13) = -.36$, ns).

4.4.2.2. Factor components and VISual factor

As argued, our envisaged model predicting visual performance during driving by visuo-spatial factor component scores, is strongly bound by our a priori considerations. We hypothesised that lateralisation should be the first component of our model, due to its status of primary disability and its expected knock-on effect on subsequent processes. We also justified the argumentation for forcing speed secondly and accuracy thirdly.

A preliminary regression analysis predicting the VIS factor and using the three global component scores as predictors and forced into the model in the suggested sequence, resulted in an $R^2$ of .58 ($F(3, 24) = 11, P < .001$; $R^2$ adj. = .52). This analysis indicates that visuo-spatial performance during driving can be predicted by global visuo-spatial neuropsychological test performance. Each component added significantly to the increase of variance explained. Interestingly, when age was forced into the model (before these three components), the total $R^2$ increased to .61 ($F(4, 24) = 9, P < .001$; $R^2$ adj. = .54), but lateralisation and speed did no longer add significantly to the $R^2$ increase. When age was entered lastly, it did not add significantly to the $R^2$ increase ($F(1, 23) = 2$, ns).

Our primary aim was however to relate specific (rather than global) neuropsychological test performance to visual performance during driving. As suggested by our a priori framework, we performed a regression analysis predicting the VIS factor score, using the 11 factor components scores. As argued, we entered the respective component scores in a blockwise manner. We forced lateralisation as the first block, speed the second, followed by accuracy. Within the respective (component)blocks, the method was stepwise for factor determination. Hence, we firstly forced into the model all four lateralisation factor components in a stepwise manner, secondly, all four speed factor components were forced, also in a stepwise manner, and finally, the accuracy factor components. This procedure produced four models. The final model explained 76.8% of the variance ($F(4, 23) = 19, P < .001$; $R^2$ adj. = .73). From the lateralisation components, only the BVSS factor was retained. This was also the case for the speed component, given the previous retention of lateralisation components. Finally, the accuracy components from the BVSS and VI factor (in this sequence) were retained, given previous retained components (see table 15).

<table>
<thead>
<tr>
<th>Variables Entered</th>
<th>Components</th>
<th>Factors</th>
<th>$R^2$ (Adj. $R^2$)</th>
<th>$R^2$ Change</th>
<th>Change Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateralisation</td>
<td>BVSS</td>
<td>.22 (.19)</td>
<td>.22</td>
<td>$F(1,26) = 7, P &lt; .012$</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>BVSSS</td>
<td>.51 (.47)</td>
<td>.29</td>
<td>$F(1,25) = 15, P &lt; .001$</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>BVSS</td>
<td>.71 (.68)</td>
<td>.20</td>
<td>$F(1,24) = 17, P &lt; .001$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VI</td>
<td>.77 (.73)</td>
<td>.05</td>
<td>$F(1,23) = 5, P &lt; .029$</td>
<td></td>
</tr>
</tbody>
</table>
5. Discussion
5.1. Practical Driving Test
In the practical driving test, it is examined whether the subject can drive safely, fluently, and adequately, given the visual impairment. This test-ride differs from a regular driving examination in the sense that specific situations and occurrences are sought and observed in which the impairment in question is thought to be a hampering factor. Since we are studying patients with expected visuo-spatial disabilities, we focussed upon the visuo-spatial performance during driving.

Although the left HH group tended to perform slightly worse, we found no significant difference in driving performance between left and right HH groups. Although left and right HH results from right and left sided brain damage respectively, our result does not imply that overall left and right sided brain damaged patients perform equally well on the practical driving test. As mentioned in the patient section, we took effort to exclude the patients with severe hemi-neglect, both on theoretical and practical reasons. These patients frequently suffer right sided brain damage, in combination with left HH, and are thus an integral part of unselected right sided brain damaged groups. As hemi-spatial neglect is considered to be an extreme case of hemi-spatial dysfunction resulting in severe hemi-spatial disability, inclusion of these hemi-neglect patients hence degrades overall performance in (unselected) right sided brain damaged groups. Hence, not finding differences between left and right HH groups indicates that we were successful in selecting HH patients with quantitatively comparable impairment and disability. In this sense, our left and right HH groups are not representative for unselected right and left sided brain damaged groups.

In the HH group in general, typical problems are expected, namely in the visual and visuo-spatial domain. Indeed with respect to practical driving performance, we observed the VIS factor to be worse than the other factors. This is based on the observation that the VIS factor score is not statistically different from “dubious” level, while the other factors (OPER, TACT and TOT) are significantly better (table 5).

However, although some factors are significantly better than “dubious” level, we can conclude that the overall quality of the practical driving performance is generally low (table 4-5). This is firstly suggested by the global appreciation of the driving expert (GLOB score), which is not statistically different from the “dubious” level (table 5). This indicates that the driving expert, based on his global and subjective impression, scored the driving performance just as “dubious”. Secondly, none of the TRIP factor scores reached the “sufficient” level (table 5). This indicates that, whatever aspect measured during the driving test, it was never rated as “sufficient”, which is the minimum level for passing. Finally, only four patients in our group actually passed the practical driving test, as indicated by the end-verdict (table 4). 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. This overall negative conclusion is in clear contradiction with some reports (Vos and Riemersma, 1976; Warmink et al., 1998; Schulte et al., 1999). This contradiction can at least partly be explained by our selection methods and criteria. We believe that our HH population is less positively selected, and hence more representative for the “HH population”. Our population can be described as patients, without severe hemi-neglect, suffering HH and having a question related to their fitness to drive. This query often was formulated in terms of the possibility of re-evaluation of their fitness to drive, or evaluation of the safety of their driving participation. The outcome was in most cases
expected or feared to be negative, since this was, in most cases, the reason for referral. In the Warmink et al. (1998) study (personal communication) most of the patients volunteered for an official (and hence decisive) driving evaluation. These patients were possibly encouraged by others or by their own experience of a likely positive outcome. This would suggest that, in their population, a clear self-selection bias (to the positive end) could be present, in that only the very best performing HH patients are included. This would account for the high number of patients passing the driving test in their (selected) sample. The study by Schulte et al. (1999) also suggested absence of driving-related disabilities in HH patients. However, they used a driver-simulator task, which was inherently a simplification of a real world driving situation (i.a. automatic transmission, no intersections etc.). Further, it is important to note that their nine patients were reported to be “neuropsychologically intact” and thus their sample is (perhaps) not representative for the wider population of HH patients. We neither had this positive bias (rather the opposite if any), nor this simplification of the driving test (again rather the opposite if any) and hence our results are more indicative of the performance level in a less self-selected HH (without hemi-neglect) patient population.

It was our aim, by constructing the different factors from the TRIP items, to differentiate different aspects of the driving task, namely visually related performance (VIS), and behaviours related to more operational (OPER) and tactical (TACT) skills. These were complemented by a total sumscore of the TRIP items (TOT) and a more global and subjective impression (GLOB). It could be hypothesised that (at least some of) these factors could be independent of each other. However, in our sample, clearly they were all highly related, with correlations ranging from .71 to .98. As a consequence, one could question the validity of the different skills or aspects. However, this interrelationship can have several reasons. Firstly, it could be that problems in one domain are also expressed in other domains. Brain damage, for example, is causing the visual impairment and can thus result in visual disability. But additionally, it can also result in forms of motor impairment, possibly affecting the OPER factor. The brain damage can further lead to diminished insight, empathy and anticipation and increased impulsivity, resulting in a depressed TACT score. Hence, brain damage can influence the VIS, OPER and TACT score and hereby (at least partly) account for the interrelatedness of these factors. A similar argument can be made for the possible “knock-on” effects of the visual field defect. It is highly likely that compensational efforts for the visual impairment absorb attentional resources, leaving less to allocate to other tasks as for example anticipation, or simultaneously handling brakes and gears. The visual compensational behaviour also consumes time. So, when visually exploring the environment in order to obtain an overview, there is less time to devote to other aspects as for example visual communication with other traffic participants. The combination of brain damage and visual impairment could also have its effects on visuo-spatial memory and space representation. For example, it could take more effort and time to find and handle the gear-stick, where one used to find it blindly using visual space representation and memory. These are all possible reasons why theoretically unrelated factors could now be related, i.e. because one disorder (e.g. brain damage) or one impairment (e.g. a HH) can be expressed in different types of disability.

A second reason for the high intercorrelations between the factor scores is a possible rater bias by the driving expert. The TRIP protocol is completed after the practical driving test. During the test, the expert observes the performance of the patient and hence forms an overall quality opinion. This opinion (expressed by the end-verdict and the GLOB factor) is
established by the end of the test-ride. It is not inconceivable that scoring the TRIP items afterwards is biased by this overall impression, producing interrelatedness. Assuming that the visual disability is the most characteristic and basic disability in our HH patient group, we conclude that the evaluation of the practical driving test by means of the TRIP protocol, as currently used in this HH patient group, is highly visually based. The interrelatedness of the factors can be caused by one common (i.e. visual) disability or impairment underlying different aspects of the driving task. But alternatively, the interrelatedness can also be induced by a (post-hoc) scoring bias. Hence, the validity of the different operationally defined driving aspects or skills does not necessarily have to be questioned on the basis of the observed intercorrelations.

The most frequent remarks made by the driving expert indicate not that vital information from the affected hemi-space was apparently missed or neglected. Most patients showed at least some form of (occasional) compensation for their HH and this activity possibly resulted in an unsteadiness in steering, which was the most reported remark. It was however more remarked in complex situations. This might indicate that the unsteadiness increased with increasing compensational effort. Further, in situations where creating an overview was rendered difficult, either by complex road-design, by the large to-be-viewed area, by absence of road markings, or combinations of those, patients tended to show spatial disability, expressed as i.a. deviant lateral positions and misinterpretation of road design and choosing a wrong lane. Another type of compensation adopted was dramatically reducing speed. Although apparently safe, this is not always effective, since it frequently resulted in the patients being an (unacceptable) obstacle for other traffic participants. Finally, it appeared that typical lateral anomalies are only observed for the right HH group, as indexed by driving too closely to the right side of the road. This observation is most likely biased and induced by the fact that we drive on the right side of the road. Quantitatively similar lateral anomalies for the left HH group would result in driving too closely to the left side of the lane, approaching or crossing the midline, dangerously near traffic from the other direction. This upcoming traffic is a source of constant feedback of and correction for the (deviant) lateral position, firstly possibly resulting in an unsteadiness in steering, which tended to be more apparent in the left HH group, but secondly also in a less constant leftward deviation.

5.2. CVD questionnaire

We used the (translated) Kerkhoff et al. (1990) CVD questionnaire, which was adapted by Dittrich (1996, version E1.1, personal communication)). Both parts correlated significantly, but not extremely highly (.56) (table 6). Although both parts query visual complaints, they apparently measure not exactly the same visual disabilities. Therefore a combination of both parts (i.e. the subjective disability score) provides a better description of the variety of visual complaints. However, despite (at least for the Kerkhoff part) of evidence of its high predictive value (i.e. subjective complaints verified by objective tests; Kerkhoff et al., 1990), we found no significant correlation with the VIS factor. Several causes for this absence of correlation can be formulated. Firstly, the CVD questionnaire does not include any questions related to driving. Secondly, the questions are formulated in terms of simple disabilities, translated from (or due to) primary visual impairments. This accounts of course for the high correspondence of the questions and the objective measurements. The driving task and also more specifically, the VIS factor however does not stand for a simple disability, because it has more and other possibilities for compensation. It is imperative to keep in mind that performance on the
practical driving test can be influenced by a variety of different factors from possibly different levels and their interactions. For example, driving experience could partly compensate disabilities caused by reduced visibility due to light-scatter. Hence, a patient complaining about light-scatter does not necessarily show a driving disability. We thus would suggest that the CVD questionnaire taps mainly at the impairment level, where driving performance and more specifically the VIS factor, is a measure on the disability level. Clear and highly significant relations between impairments and disabilities are not obvious (as evidenced by our data), since compensation can mask the causal relations.

5.3. Visuo-spatial factors and their components
Lower-order (sensory) impairment (e.g. a visual field deficit) as a standard, is not unequivocally related to practical fitness to drive. Practical driving performance -apart from personal characteristics- can also be influenced by impairment at a higher-order level. Higher-order cognitive function can be assessed by neuropsychological tests. Neuropsychological test results are reported to correlate only moderately highly with measures of driving performance (Brouwer, in press). This can have several causes as is discussed by (Withaar, Brouwer, & van Zomeren, 2000). Their arguments can be complemented by the observation that, in previous studies, most tests are not specifically assessing the most likely and prominent dysfunctions of the patients under study. We argue that selectivity in test choice and selectivity in patient population are logically linked. The necessity for selectivity results from the conceptualisation of the driving task (what components of the driving task are important and can be adequately measured by neuropsychological tests) and from the specific dysfunctions of the patient population. When patients suffer a specific and well defined impairment, assumed that these impairments can be neuropsychologically tapped, and these impairments are related to important aspects of practical fitness to drive, this specific neuropsychological test performance can be strongly related to the safety and fluency of driving. We therefore considered a specific group of patients (namely HH patients) assessed with specific tests (namely visuo-spatial tests). On a priori theoretical considerations, we classified our neuropsychological visuo-spatial tests from our extensive battery into four factors, each representing a visuo-spatial domain. These factors were defined as basic visual scanning and search (BVSS), visuo-constructive and organisational (VCO), visuo-integrative (VI) and dynamic (Dy). These factors were evaluated in terms of lateralisation, speed, and accuracy (components).

From the significant intercorrelations of the four speed components it can be concluded that rapidity, with which visuo-spatial tasks are completed, is a prominent and robust variable in all factors. The same conclusion, although to a somewhat lesser degree, can be drawn for the accuracy component. The importance of the speed component had also been suggested by for example Brouwer (in press). He argued, both on theoretical and empirical grounds, that visual speed emerges as a crucial factor of neuropsychological test performance, and that it is associated with safety and fluency of driving as assessed by test-rides. Contrary to the other components, the lateralisation components are not significantly interrelated. This is in agreement with previous literature on perceptual asymmetries which confirms that, across tasks, only low to modest intercorrelations are observed (Nicholls, Bradshaw, & Mattingley, 1999). It was suggested that different tasks do not index one single common lateralisation factor, but tap a set of attentional processes, some of which are overlapping, and others which are task-specific. This literature refers to tests specifically designed to tap lateralised
differences (commonly with chimeric stimuli). We however derived the asymmetry indices mostly from tasks not specifically designed for this purpose. When the intercorrelations derived from the “specialised” tests are only low to moderately high, our intercorrelations can be expected to be even less.

We conclude that in general the expected relationships between speed, accuracy and lateralisation were observed. The interrelatedness is expressed as a speed-accuracy trade off as indexed by the negative correlation between the two components. Further, we observe the trend that worse performance in terms of speed and accuracy is related to a higher (i.e. worse) lateralisation score. Conclusions in terms of causality can not be drawn from this data, but we hypothesise (as also evidenced in our regression analysis) that asymmetry in visual performance (lateralisation) is the most basic of the components, influencing the others. Hence, we expected that a high asymmetry would result in poorer performance both in terms of speed and accuracy. Although not always statistically significant, the same trend appears in all factors (tables 7-11). It can further be noticed that the significances only arise in the VCO, VI and Dy factor. These factors have higher-order visuo-spatial aspects, either constructive, integrative, or dynamic, whereas tasks from the BVSS factor are more concerned with the elementary process of scanning and search. It appears that the expected relationships between the different components is only apparent in tasks (factors) where different visuo-spatial aspects are combined.

From the absence of interrelatedness of the components in the BVSS factor it can be concluded that the tests from this factor can adequately convey information about the three aspects of visuo-spatial performance, assessed relatively independently of each other. The speed component of the BVSS factor correlated most highly with performance on unstructured cancellation tasks (e.g. the Bells test) and on the Trailmaking test. The accuracy component was most strongly related to unstructured cancellation tasks (e.g. the Bells test) and the Zihl Dotcounting test. The lateralisation component from the BVSS factor was most highly related to the AI derived from the Grey Scales and the AFOV test. In order to dramatically reduce the number of tests, still be able to reproduce significant information about the three components and taking availability of norms in mind, our results suggest to present patients the Trailmaking test (part B) for a speed measurement, the Bells test for an accuracy measurement, and the Grey Scales task for the AI.

These three components from the BVSS factor were all retained in our final regression analysis (to be discussed further). In this analysis also the accuracy component of the VI factor was retained. The intercorrelations of the different tests with the Vlac component suggest that the Hidden Figures test would be the best selection for representation of this factor.

5.4. Predicting visual performance during driving
A combination of age, macular sparing and driving experience significantly predicted visual performance during driving. The combination of the three retained patient characteristics explained 67% of the variance in the VIS factor (table 14). When only the objectively verifiable/medical characteristics (age and macular sparing) are considered, 60% of the variance in VIS could be accounted for (table 14). When performing regression analysis on the basis of neuropsychological information, using the three global component scores (lateralisation, speed and accuracy), 58% of the variance was explained. Hence, prediction on the basis of global visuo-spatial neuropsychological information is less effective than on the
information of all retained patient characteristics, but is more effective than on the basis of age alone (49%). This has practical implications since this suggests that better predictions of visual performance during driving can be obtained using global neuropsychological measures than using a simple age registration, which would be morally, ethically and politically an incorrect criterion. Further analysis suggested that age did no longer provided additional information after considering the global neuropsychological data. Interestingly, when age was forced firstly into this model, the lateralisation and speed components no longer added significantly to the prediction model. We take this to indicate that, with respect to visual performance during driving, lateralisation and speed are highly age dependent and that accuracy is less influenced by age. This high age-dependency is not a new finding. A study by Szlyk et al (1993), observing different levels of driving performance in HH patients, suggests that, besides the effects of visual field loss, age is an evenly important factor in a brain damaged population. These authors conclude that age-related losses, when compounded by brain damage-associated impairments, may further increase the on-the-road risk of the older hemianopic patients while driving. This suggests that with increasing age, equal dysfunction might lead to higher levels of disability. This is in line with a previous point we made namely that disability is not exclusively determined by dysfunctions, but that also 'personal characteristics' exert a possible important influence. Another example of such a ‘personal characteristic’ is for example driving experience, which can obviously be a source of compensation. This is also suggested by our data, since driving experience contributed significantly to the prediction model. In the same respect, the importance of macular sparing emerged. Although, it is generally agreed that macular sparing is crucial for e.g. comfortable reading, it is, in our opinion, less obvious how it can be so important for visuo-spatial task performance in general, and visual performance while driving in particular. This visual performance is firstly dependent on using a spatial representation by having and creating an overview of the (visual) situation. For this stage, we would not expect macular sparing to be a crucial factor. But secondly, using this spatial representation also implies specifying (e.g. identification of objects) and updating it. For this, constant scanning is required. At this stage, macular sparing can be an important factor, since it could reasonably be assumed to be positively associated with e.g. ease of identification of individual objects and hence negatively with the amount of compensational effort to be invested. We previously argued that compensational effort could be associated with unsteadiness in steering, hence accounting for the association of macular sparing and practical driving performance in general and visual performance during driving in particular.

However, as we previously argued for selectivity and specificity, we were most interested in the regression analysis using the different component scores (lateralisation, speed and accuracy) from the four visuo-spatial factors (BVSS, VCO, VI and Dy). In this respect, we are using specific neuropsychological information, namely from different domains of visuo-spatial task performance (i.e. different factors) assessed on different aspects (i.e. different components). As already theoretically argued, we forced the components by block in a specific order into the model in accordance with our a priori view on importance and basic status of the components. We argued that lateralisation is the most basic component, followed by speed and accuracy. This resulted in a model retaining four factor components explaining 77% of the variance in the VIS factor, which is more effective than on the basis of the patient characteristics or age alone (67% and 49% respectively). The model included the lateralisation component of the BVSS factor, the speed component of the BVSS factor and
finally the BVSS and VI accuracy components (table 15). In terms of specific tests, which proved to be good representatives for the factors, our results suggest the Grey Scales task (for lateralisation), the Trailmaking test (part B) (for speed), the Bells test (for accuracy) and the Hidden Figures test (for accuracy). Post-hoc regression analysis, substituting these specific test performances for their factor components, resulted in 60% of the variance explained ($F(4, 23) = 9, P < .001; R^2_{adj} = .53$). By administering these four neuropsychological visuo-spatial tests, better prediction of the VIS factor is obtained compared to when only using age, which has, as already mentioned, practical implications.

As previously mentioned, logistic regression analysis predicting pass/fail scores is statistically futile, as only four patients passed. In the same respect, detailed analysis producing cut-off scores for the neuropsychological tests is likewise. However, for rehabilitation purposes, it is desirable to differentiate which patients approximate practical fitness to drive from those who are dramatically unfit to drive, assuming that specific rehabilitation success in the former group is more self-evident. It could be argued that for the former group, rehabilitation specific for driving could be attempted, whilst for the latter group more modest mobility goals should be formulated. We therefore defined the former group as being represented by the patients with a visual performance during driving in the upper quartile to present some tentative indications. This revealed that the AIs from the Grey Scales task ranged from $-0.69$ to $+0.54$ in the upper quartile and from $-1$ to $+1$ in the other group. Hence, a Grey Scale lateralisation score more extreme than $[-0.69, +0.54]$ could be considered a negative indication. With respect to the Trailmaking test (part B) the longest completion time from the upper quartile was 196 s and the worst performance on the Bells test was five omissions. The lowest score on the Hidden Figures test in the lower quartile was 0.03 (number of correctly marked items per second). The combination of scores representing worse performances could be considered a negative indication for adaptive visual performance during driving and for success of rehabilitation related to practical fitness to drive.

6. Conclusion
We posed two general questions namely one concerning the practical fitness to drive in HH patients and the other whether the visual performance during driving could be related to visuo-spatial neuropsychological test performance. With respect to the first issue, we would like to give a differentiated answer. Driving performance during our practical driving test was generally modest in our HH patient group. The most frequent remark by the driving expert was a lack of stability in steering. Only four of the 28 patients passed the driving test. Hence, the majority of the HH patients failed the test-ride, but not all of them. This justifies our current investment of effort in studying fitness to drive in HH and hopefully future investment of improving fitness to drive in HH. This further confirms that HH cannot be an absolute contra-indication for practical fitness to drive. With respect to the second issue, we confirm that visual performance during driving can be significantly related to visuo-spatial test performance. A specific combination of the lateralisation, speed and accuracy components derived from different visuo-spatial factors explained 77% of the variance. Substitution of the retained factor components by their respective most representative tests, suggests to administer the Grey Scales task, the Trailmaking test, the Bells test and the Hidden Figures Test. These are tests which could be administered for deciding whether or not rehabilitation efforts should be invested with respect to driving or, alternatively, that more modest rehabilitation goals should be set with respect to mobility.
7. Reference List


Visual rehabilitation in Homonymous Hemianopia and related disorders*

1. Introduction
This chapter focuses on the rehabilitation of visual field defects in general and of homonymous hemianopia in particular. Some reference will be made to visual rehabilitation in neglect as a related disorder. Since the differential diagnosis has clear and important implications for rehabilitation, it will receive special emphasis. Other related disorders, for example, the visual agnosias and prosopagnosia, will only be touched upon because of the present limitations of specific structured rehabilitation efforts for these particular problems.

2. Visual Field Defects and related disorders: forms, frequency of occurrence and diagnosis
2.1. Homonymous hemianopia and related disorders
Homonymous hemianopia or hemianopsia (HH) is a visual field defect (VFD) in which, for both eyes to the same extent (homonymous), half of the visual field (hemi) is blind (anopia). Like all unilateral VFDs, it is the result of unilateral post-chiasmal brain damage. Nearly 80% of patients with unilateral post-chiasmal brain damage acquire a homonymous VFD (Zihl, 1994). Due to the structural organisation of the visual bundles and the crossing of temporal half-field information in the optic chiasm, left-sided brain damage results in right-sided VFDs and vice versa. Common causes are cerebrovascular accident (CVA), traumatic brain injury (TBI) and tumours. Forty per cent of HH involve lesions of the occipital lobe, 30% involve the parietal lobe, 25% involve the temporal lobe and 5% involve the optic tract and lateral geniculate nucleus (Pambakian & Kennard, 1997). Nearly 66% of the unilateral homonymous VFDs are homonymous hemianopias. The most common other types are quadranopia (about 14%) and paracentral scotomas (about 14%) (Zihl, 1994). Quadranopia refers to the loss of vision in one quadrant of the visual field, either the upper or the lower. Paracentral scotomas are regions of blindness mainly in the central field region but sparing the fovea. It has been estimated that 20-30% of all patients with CVAs in rehabilitation centres have homonymous VFDs (Kerkhoff, 1999). These percentages indicate the significance of the homonymous VFDs and the importance of structured rehabilitation efforts for this group of patients.

Visual field defects can result in complaints and (visual) dysfunctions. Patients complain, for example, about having a limited overview, bumping into obstacles or persons, getting lost while going for a walk, finding reading very exhausting, missing or misreading words, getting dizzy in busy streets et cetera. These complaints are partly due to a common underlying defective mechanism, namely visual scanning. Visual scanning deficits can be studied through the registration of eye movements. Examples of normal and defective scanning patterns can be seen in figure 1 A-C. Figure 1A represents normal scanning behaviour while counting a number of dots on a computer screen under free viewing conditions. Figures 1B and 1C are illustrations of scanning patterns of hemianopic patients. Figure 1B is a clear illustration of a defective scanning pattern, while figure 1C shows the eye movements registered in a neglect patient, clearly ‘neglecting’ the left side of the screen”.

Patients frequently do not understand the nature of their visual deficit (see further notes on hemianopic anosognosia) and cannot explain it to others. This may result in insecurity, depression and social isolation (Zihl & Kennard, 1996). These complaints can be the direct result of the VFD per se, but they can also be caused by other disorders resulting from the post-chiasmal brain damage. The type and severity of related disorders will depend on the size and location of the brain damage involved. Impairments in spatial contrast sensitivity, light and dark adaptation and colour vision have been observed in more than 20% of patients with posterior brain damage (Zihl, 1994). Higher-order visual disorders can also co-occur, for example visual agnosia, prosopagnosia, disorders in visual space perception, Balint's syndrome, visual illusions and hallucinations, and visual neglect. It is very plausible to assume that the presence of a VFD and the resulting scanning deficiency augments the negative effects of those related disorders. This has indeed been argued in the case of neglect, for example by Webster and colleagues (1984) and by Agrell, Dehlin and Dahlgren (1997).

Perhaps the most common associated disorder is visual neglect. Since neglect is the main topic of another chapter, it will not be discussed extensively here. Rather we will confine ourselves to some general remarks about neglect and discuss the differential diagnosis more thoroughly.

Visual neglect can be defined as the tendency not to notice, that is to neglect, contralesional (visual) stimuli. This failure is not due primarily to hemifield blindness, although, as mentioned, the two conditions often co-occur. It has been estimated that approximately 70% of neglect patients also suffer from a homonymous VFD (Kerkhoff & Schindler, 1997). However, these authors suggest interpreting this estimate with caution, since, because both HH and visual neglect may result in failure to react to visual events in the contralesional hemifield, the differential diagnosis of HH is difficult. It has further been argued that visual neglect is more severe when it occurs simultaneously with homonymous VFDs (Webster et al., 1984; Agrell et al., 1997).

2.2. Homonymous Hemianopia and visual Neglect: differential diagnosis
Since visual neglect occurs more often after right-sided brain lesion, it can co-occur and/or be confused with left-sided HH. A global guideline for the differential diagnosis in clinical settings is that HH patients will try to compensate by turning the head and/or eyes to bring a
stimulus into their preserved visual field. In contrast, patients with neglect do not seem to be aware that there is, or could be, anything of interest on their contralesional side. This is true even of neglect patients with intact visual fields. Another frequently proposed criterion is the alleged awareness of the visual problem in HH, and its absence in neglect. The lack of awareness of the VFD, due to brain lesion or hemianopic anosognosia (HAN), may range from uncritical underestimation to explicit and intractable denial of the deficit.

Two studies, investigating the occurrence of HAN in relation to the presence of neglect (Bisiach, Vallar, Perani, Papagno, & Berti, 1986; Celesia, Brigell, & Vaphiades, 1997), suggested that the relationship is not unequivocal. Forty-eight of the 64 patients described in the two studies presented with HAN. Of those, 37 were diagnosed with neglect; the remaining 11 were found to have no neglect. Thus 24% of the patients with HAN had no neglect. Sixteen patients showed awareness of their VFD (no HAN). Of these, nine were diagnosed as having neglect. Thus 56% of the patients with awareness also had neglect.

In conclusion, these results caution against the use of the presence of awareness for distinguishing visual neglect from HH, as they indicate that most patients with VFDs have HAN and that neglect patients can also show some form of awareness. Furthermore, very few of the patients with awareness (no HAN), had complete and full understanding of their deficit. The majority suffered from “hemianopic misinterpretation”. They were aware of some deficit but misinterpreted its cause. Usually the deficit is interpreted as a failure of one eye rather than the blindness of one hemifield. We can ask whether, in terms of rehabilitation or differential diagnosis, this difference is important. But apart from this, these findings demonstrate that awareness is not the simplest notion and that it is troublesome as a differential criterion.

Differential diagnosis on the basis of a single criterion proves not to be feasible. Kerkhoff and Schindler (1997) provide ten criteria which can be used to differentiate. They argue that none of the distinguishing features by themselves can differentiate, but taken as a whole, they can successfully classify almost all patients. We (briefly) summarise the ten criteria.

- HH patients can usually describe some of their visual deficits accurately (e.g. specific reading problems, bumping into obstacles). These deficiencies are usually later confirmed by objective measurements. This contrasts with the subjective reports by neglect patients, which are usually not specific, inaccurate and not relevant.
- Another distinguishing feature is the modality specificity. HH is by definition restricted to the visual modality. In neglect, the hemispatial deficit is not necessarily restricted to the visual modality, as forms of tactile, acoustic and motor neglect have been reported.
- Aetiology and location of the lesion can also give informative cues for differential diagnosis. HH most often occurs after lesions located at sites supplied by the posterior arteries. Left and right-sided lesions occur with almost equal frequencies. The most common cause of neglect is reported to be extensive medial cerebral artery territory infarctions in the right hemisphere. Most common lesion sites are supplied by the central and/or parietal branches.
- Extinction is often regarded as a residual symptom of neglect. It is a multimodal phenomenon in which a stimulus which elicits a response when presented singly, no longer does so under conditions of double simultaneous stimulation (DSS). The neglected stimulus is usually the stimulus on the left. DSS is usually performed in both hemifields
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When testing in the intact hemifield, HH patients do not show any form of extinction. Neglect patients either do show extinction or, in contrast to the normal pattern, react more slowly to the more central target (when presented in the right hemifield).

- When drawing inherently symmetrical objects from memory (e.g. a house or the face of a clock), HH patients usually deliver complete and symmetrical drawings, with equal level of detail on both sides of the drawing. Some neglect patients on the other hand, completely omit one side of the drawing (usually the left), or show a clear discrepancy in accuracy and level of detail between left and right sides of the figure.

- The presence of visual-spatial dysfunctions renders a neglect diagnosis more likely. The perception of visual horizonticality and verticality, subjective middle, determination of position and orientation are functions associated with the dorsal route. Impairments in these functions make parietal lesions (and thus neglect) more likely and pure occipital lesions (and thus HH) less likely.

- The size and type of error, made in line bisection tasks, provides another way of disentangling neglect and HH. In more than 90% of trials, HH patients mark the midline with a contralesional deviation. This means that the deviation is in the direction of their blind hemifield. Neglect patients, on the other hand, make the opposite bisection error: they deviate ipsilesionally, that is in the direction of their intact hemifield. Further, in our own work, we very rarely noticed any omissions in the HH group (i.e. not bisecting a line in the case of multiple lines on one page), in contrast to the neglect group.

- If perception (with fixed fixation) in the deficient hemifield can be modulated (e.g. by cueing), the diagnosis of absolute HH is by definition not applicable. Some forms of cueing can elicit relief (usually transient) of neglect symptomatology. The simplest form of visual cueing would be, for example, to abruptly present a very salient stimulus in the left hemifield by flashing a white light on a dark background. This stimulus is likely to elicit an orienting response because cueing attracts attention. Once a stimulus has captured attention, it can be reacted to. This is not the case in HH, because there is, by definition, no possibility of perception in the defective hemifield. However, in HH, there can also be some form of residual perception, for example spared movement perception without light detection. This phenomenon is usually referred to as blind-sight and can be understood as the residual capacity to react to movement, but not to the mere presence of a stationary stimulus. A patient cannot tell whether a stimulus is present or not if it is stationary. But when it starts to move, the direction of the movement can be indicated. In these experiments patients make remarks like: ‘I don't know if anything is there, but if there is, my feeling tells me it moves upwards’. However, these spared functions are not the result of cueing (attracting attention) but presumably of spared residual capacity, which is always available, and hence no temporary phenomenon (contrary to cueing). In conclusion, we would suggest not using moving stimuli as cues but rather simple presentation of (on/off) stimuli to try to elicit reaction.

- Informative observations can be made during visual field testing. When perimetric testing shows a hemifield deficit, it can be the expression of either neglect symptomatology, HH, or both. However, it was noticed that the HH group performed the perimetric assessments without any problems, with stable fixations and relatively good understanding and concentration. In contrast, some neglect patients had difficulty maintaining central fixation. Neglect patients clearly found it difficult to suppress reflexive eye movements to
the light stimuli presented. It was further noticed that repeated measurement and slight modification of perimetric procedures could affect results significantly in pure neglect but not in HH. When measured with kinetic perimetry, the VFD in neglect patients appeared larger and different when targets moved inwards to fixation (standard procedure), than when they moved outwards from fixation. Additionally, a possible influence of the presence and type of the fixation point suggests visual neglect.

- Finally, measuring visual evoked potentials (VEPs) using hemifield stimulation, can possibly differentiate. When measuring electrical activity in left and right primary visual cortex, there is a clear discrepancy in response to the stimulation of either hemifield in HH. Usually a (near) normal response is measured when stimulating the intact hemifield, whereas either no signal, or only a negligible signal can be picked up for the blind hemifield. In patients with pure neglect, responses to both hemifields are identical and (near) normal.

2.3. Visual fields: assessment and properties
To properly diagnose lost visual field function (e.g. HH) and alternatively residual (e.g. macular sparing) or restored visual field function, very precise assessment is required. The controversy regarding macular sparing is a clear illustration of the importance of precise measurement techniques. Macular sparing, or the sparing of a small part of the central visual field, has been reported in many cases of HH. Some authors report that about 70% of HH patients show a visual field sparing of (less than) five degrees of visual angle (e.g. Kerkhoff, Munssinger, & Meier, 1994). Yet others have argued that this sparing is a measurement artefact caused by inaccurate fixation during perimetry (e.g. Bischoff, Lang, & Huber, 1995). However, using eye movement measurements and fixation control by scanning laser ophthalmoscope (SLO), it was shown that macular sparing and even a small vertical strip of hemifield overlap does exist (Trauzettel-Klosinski, & Reinhard, 1998). This finding does not disaffirm that, in past research, the amount of macular sparing could have been overestimated. The most plausible explanations for macular sparing are dual blood supply to the occipital pole and bilateral cortical representation of the fovea. Controversy exists as to which of the two mechanisms is responsible. The second explanation has however been challenged, for example, by Gray, Geletta, Siegal and Schatz (1997).

Advanced measurement techniques are not always feasible in clinical settings. The most crude, but also the fastest method is the confrontational test. It involves the comparison of the VF of the examiner with that of the patient. A major disadvantage of this test is its lack of standardisation and the difficulty of reporting the findings objectively. For a more thorough discussion we refer the reader to Elliot, North, and Flanagan (1997). To enhance standardisation and quality of the output, several perimetric techniques and devices can be used, which can be either automated or manually operated. Depending on the clinical or research question, static, dynamic (i.e. moving) or coloured targets can be used. With these different types of targets, different functional channels or regions of the visual pathway can be probed.

The Goldmann technique is a widely used manual perimetric test with moving (usually white) targets. To quantify the status of visual fields exactly and to ensure the quality of follow-up measurements, automated perimetry in combination with continuous fixation control has been suggested (Schiefer, Skalej, Dietrich and Braun, 1999). Examples of such devices in clinical use are the Tübinger Automated Perimeter (TAP) and the Humphrey Field Analyzer (HFA).
Using these techniques, visual field regions can be described as intact or deficient. In addition, reference can also be made to ‘grey areas’, as opposed to white (intact) and black (deficient) sectors. A grey area, or relative defect, is an area in the visual field with only partial function, for example, residual performance in light detection. It is presumably the result of spared neuronal fibres in the damaged visual pathway. These areas are usually situated between an intact and a deficient area and are therefore also called ‘transition zones’. A transition zone must be distinguished from an island of residual vision in a blind area. In such an island of residual vision there is intact visual function. In contrast, a transition zone hosts only inconsistent light detection. Subjectively, stimuli in transition zones are reported as reduced in clarity, brightness or brilliance (Kasten et al., 1999). By assessing and mapping all these aspects of the functioning of the visual fields, a detailed and precise description or diagnose concerning the VFD can be provided.

3. Rehabilitation

We will extensively discuss rehabilitation efforts for HH patients. As already mentioned, we are not aware of extensive, structured, evaluated specific treatment attempts for related higher-order visual disorders, other than for neglect. We will first briefly mention the few approaches to related disorders. Since neglect is the topic of another chapter, we will again be very brief. We would like to point out that the treatment attempts for HH could also be applied to the patients with other co-occurring visual disorders. These rehabilitation efforts can have beneficial effects when, for example, a defective scanning strategy, caused by the HH, exacerbates the other disorder. In such cases, partial improvement can be expected. But since the treatment approach is specific for the HH, the other co-occurring dysfunction by itself might not improve.

3.1. Visual disorders related to Homonymous Hemianopia

Since homonymous VFDs are caused by post-chiasmal brain damage, several other disorders can co-occur. The type and severity of the related disorders will depend on the size and location of the brain damage involved. Higher-order visual disorders include visual agnosia, prosopagnosia, visual neglect, Balint's syndrome, visual illusions and hallucinations. Attempts to treat visual agnosias are very rare. The main therapeutic approach seems to be to improve visual recognition by using non-visual cognitive strategies, such as context information. Zihl and Kennard (1996) report that no systematic study of the treatment of Balint's syndrome has been attempted. Their own success in treating three patients with Balint's syndrome and three patients with agnosia was rather limited. The method of treatment of visual illusions and hallucinations depends on the underlying cause. Possible causes are epileptic phenomena, visual deafferentation, delirium, drug intoxication and withdrawal states. When the disorder is drug related, withdrawal of the drug usually leads to rapid resolution. When it is the result of abnormal neuronal discharges, anticonvulsants are prescribed. Interestingly, the disorder also responds well to some types of anticonvulsants when caused by reduction of visual input.

Almost all therapeutic approaches to neglect are based on some type of cueing. Only a very few have been shown to result in lasting improvements. We shall restrict ourselves here to
listing briefly some therapeutic approaches and some references. One group of therapeutic approaches can be classified as visual-cognitive training programs. This type of approach was pioneered by Diller and Weinberg (1977). Its principles have recently been successfully (re)applied by Pizzamiglio and colleagues (e.g. Pizzamiglio et al., 1992). Other approaches make fewer demands on cognitive functioning. Robertson uses left limb activation to treat visual neglect (e.g. Robertson, North, & Geggie, 1992). Caloric stimulation (left ear by cold water or right ear by warm water) is another example of a non-cognitive treatment method (e.g. Rubens, 1985), as are eye-patching (e.g. Butter and Kirsch, 1992), use of optical aids (e.g. Rossi, Kheyfets, & Reding, 1990) and neck muscle vibration (e.g. Karnath, Christ, & Hartjes, 1993).

3.2. Homonymous Hemianopia
3.2.1. Spontaneous recovery
Active intervention has to be differentiated from (passive) spontaneous recovery and spontaneous adaptation. One might argue that, if spontaneous improvement (either recovery or adaptation) is expected, therapeutic intervention is not needed. But even if spontaneous improvement can (still) be expected, therapy should not be denied to the patient. He or she may develop erroneous compensatory strategies or may become depressed while waiting for intervention (Zihl & Kennard, 1996).

Kerkhoff (1999) estimated that in 15% of patients with CVA, spontaneous field recovery of variable extent occurred within the first two to three months after brain lesion. Some very rare cases have been reported with longer recovery periods. Due to higher cortical magnification factors for peripheral visual fields, field recovery has been reported to be larger in the periphery (about seven degrees) than in foveal regions (about three degrees) (Kerkhoff, 1999). Higher cortical magnification factors indicate that the visual cortical representation of the fovea is much larger than that of the peripheral retina. As a consequence (to put it simply), a particular small area of cortex is devoted to a very small area of foveal retina, while an area of cortex of the same size will respond to a much larger area of peripheral retina. Most field restorations appear to affect peripheral visual fields and are rather small. This raises the possibility that these limited structural gains will not necessarily lead to significant functional improvements other than in performance on perimetric tests. Concerning the quality of vision, Zihl (2000) states that recovery of light sensitivity is typically followed by recovery of colour and form vision. If at all, not all functions are to be restored completely. This is the case in hemiamblyopia, where the recovered region only subserves light detection, and even this may also be subnormal.

On the basis of eye movement recordings, Zihl (1995) estimated that nearly 60% of HH patients do not show effective compensatory oculomotor behaviour. It is our opinion that there are at least two reasons for this. One reason relates to the lack of awareness of the VFD and the other to the attentional capture phenomenon. As Zihl (2000) correctly points out, it is very plausible to assume that, if patients are fully aware of missing half of a visual field, they can spontaneously use adaptive eye movements to compensate for the visual field loss. But as already mentioned, very few HH patients are aware of their VFD. It seems that patients have no direct experience and no direct sensation of the absence of vision, so that the visual field loss has to be inferred or deduced from visual experience and, in particular, from failures. It follows that awareness is never immediate and is more dependent on cognitive abilities such as memory, and probably also on motivation and personality. This means that compensation will rarely be automatic and is usually the product of a conscious learning process.
There is a second reason why compensation is not automatic. Attentional capture, and more specifically the proximity effect, causes eye movements away from the VFD, which is deleterious for effective compensation. Visual targets can attract attention (attentional capture) and consequently elicit eye movements towards them. As a result of the proximity effect, which refers to the tendency of the eyes to move to the nearest target, targets close to fixation capture attention and elicit eye movements. Since in HH these targets are by definition in the preserved hemifield, the eyes have a tendency always to move in that direction. Effective compensation, however, requires eye movements in the opposite direction.

3.2.2. Rehabilitation methods
Rehabilitation aims at reducing the degree of the patient’s handicap or participation. This can be accomplished by restitution, compensation or adaptation. Restorative approaches operate on the level of impairment and aim, in HH, at (partially) restoring or enlarging the lost visual field. Their success is usually measured by conventional perimetry, indicating structural improvement of the visual field in quantitative and/or qualitative terms. Compensation operates on the level of disability (or activity). It entails replacement of the lost visual function (e.g. a hemifield) by another function (e.g. eye movements). Compensation thus implies behaviour by the patient and is therefore usually assessed by tasks which closely resemble activities of daily living (ADL). Adaptation can imply adjustment of the patient or adjustment of the environment. Adjustment of the environment is usually not considered to be the expertise of neuropsychologists but of ergonomists and videologists. The major emphasis in environmental modification consists of concentrating objects in the seeing hemispace. For example, rooms could be organised, so that when the patient sits in his or her ‘comfy chair’, nearly all objects are situated in the seeing hemifield. In the following discussions only the adjustment of the patient will be considered.

3.2.2.1. Restoration
Anatomically, the visual system is very strictly organised with very dedicated and specific hard-wired neuronal connections. It therefore seems unlikely for any type of restitution to be possible. However, there are clear hints at visual system plasticity leading to (partial) restoration of some visual function.

Inducing structural visual field enlargements has been shown to be possible. Some studies at the beginning of the 1980's and some remarkable cases have been the basis for the optimism concerning the possibility of inducing some restoration of lost visual function. The earliest studies suggesting induced recovery (e.g. Zihl and von Cramon, 1985) showed significant decreases in the extent of the scotoma after repetitive stimulation with light stimuli at the borders of the scotoma. However, most of these early studies suffered from major methodological problems in the evaluation of the success of the treatments: too little time post lesion, large measurement variability, possible eccentric fixation, changes in detection strategies by the subjects and reliance on subjective clinical impressions. Most of these problems were later overcome and it was concluded that minor field enlargements (ranging from five to twelve degrees) were evident in some of the studies. This hinted at the possibility of restoring visual fields (Kerkhoff, 1999).

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1 Videology regards the research and rehabilitation of visual function due to impairments of the sensory, oculomotor and central nervous system.
Further optimism about the possibility of substantial restoration of lost visual function has been aroused by some remarkable cases which have shown that it is in principle possible to influence, at least temporarily, underlying brain structure so as to regain some visual functions. Nadeau, Crosson, Swartz, & Heilman (1997) describe a patient with a left-sided superior quadranopia, who showed significant structural enlargement of the visual field when gaze was directed to the far right. Regional blood flow measurements showed a non-specific increase of nearly 40% in the activity in the damaged hemisphere in this posture. The authors conclude that these gaze related alterations in visual function and synaptic activity suggest engagement of some form of arousal-like mechanism, since the changes in cerebral blood flow were broadly distributed rather than restricted to specific areas known to be related to visual processing. Another remarkable case was reported by Trexler (1998). This patient demonstrated attentional control over the size of her VFD. More specifically, she demonstrated the ability voluntarily, or intentionally, to modify/reduce her right homonymous hemianopia to a right upper quadranopia. Her ability to do so, was constrained by mechanisms and manipulations typically related to attention (e.g. fatigue, and stimulus density). Perimetric results were complemented by PET imaging techniques suggesting significant increases in regional blood flow in several broadly distributed brain areas. Clearly such cases are very rare and, in consequence, the mechanisms involved (extreme ipsilesional gaze and volitional control) are of limited use for application in rehabilitation in general. However, they indicate that restoration of visual function by changing visual processing at the brain level is a possibility.

3.2.2.1.1. Restoration methods
Recent studies of the induced restoration of visual fields by restorative training have been summarised by Kasten et al. (1999, see table 2). Several types of studies show induced restoration of the VF.
Recently, computer based training programs have been developed to stimulate the transition zones systematically (e.g. Kasten, Strasburger, & Sabel, 1997; Van der Wildt & Bergsma, 1997). In a randomised, double-blind, placebo-controlled experiment with nineteen post-chiasmatic patients with VFDs, Kasten and co-workers trained an experimental group for approximately 175 hours with their computer based Visual Restitution Training (VRT)-program. During VRT, hundreds of light stimuli are presented in succession in the transition zones. The placebo group performed a fixation training, which required foveal visual search, for a comparable amount of time. The experimental group showed an average increase of 5° in field size. The placebo group showed an average decrease of 1°. Furthermore, the positive effects of light detection in the experimental group generalised to colour and form discrimination within the crucial areas. The investigators also report some transfer to performance on paper-and-pencil tests of visual exploration and attention. Further, positive influences on activities of daily living were reported by 72% of the patients from the experimental group, in contrast to only 17% from the placebo group. These results are positive and clearly promising, but we would like to caution against too much optimism. Indeed, a 5° increase of VF seems impressive, since as little as 2-3° of foveal vision is generally sufficient for reading. However, it is not clear from the report whether the restoration indeed affects foveal vision, and a 5° shift of the visual field border in peripheral fields will have much less functional significance. But then again, it remains unclear to us how a 5° shift of the visual field border can lead to such impressive subjective improvements.
Not all studies which show evidence of VF restoration had this as their aim. Kerkhoff (1999) reports that saccadic and visual exploration training (a compensatory rather than a restorative rehabilitation approach) also led to a small but significant increase in visual field size (five to seven degrees) in nearly one-third of their patients. This increase is most likely due to the procedures and techniques used in their compensatory therapy, which are also applied in the restorative training methods, namely repetitive stimulation in transition zones. It thus seems that VF restoration can also be attained as a ‘side effect’ of compensatory therapy.

3.2.2.1.2. Mechanisms of restoration of vision and implication for rehabilitation
As is pointed out by Sabel (1999), the plasticity of the human visual system is probably vastly underestimated. Sabel argues for a review of the concept of hard-wired visual pathways with strict, fixed and unchangeable topographical organisation and receptive field properties. The dominant issue in current discussions of the neural mechanisms, which underlie the restoration of vision, is the role of surviving tissue. Survived fibres within the visual pathways may explain residual and restored vision. There is, however, also the possibility of re-routing. That is, an alternative brain structure takes over the function of the disrupted pathway. For example, if the retina-geniculo-striate (‘new’) visual pathway is injured, the retina-tectal (‘old’) pathway might be used to process and mediate some visual information, for example, movement. It is argued that at least some of the rare blindsight phenomena can be ‘explained’ this way. Patients have been reported to be able to detect some targets (e.g. moving targets) presented in their blind hemifield. For a comprehensive review on blindsight, see Weiskrantz (1986). Since patients are usually unaware of this residual function and since it can sometimes be measured only when they are forced to guess, there is little hope that training of ‘the blindsight ability’ in itself can be a useful therapy.

As previously mentioned, the role of surviving tissue dominates the discussion at present. Evidence from animal studies suggests that restoration of vision following brain injury is the result of the combination of several factors and mechanisms (see Sabel, 1999; Kasten et al., 1999). The most crucial factor, however, seems to be the presence of a minimal number of residual neurons which have survived the injury. Sabel and Kasten further point out that brain structures like the tectum, lateral geniculate and visual cortex probably play the most prominent role in restoration. Plasticity, in their view, is (partly) due to rewiring in the form of changes in the size and location of receptive fields. We summarise some of their arguments here.

First, when damage occurs in the receptive fields themselves, that is, following post-chiasmal brain lesion, less improvement is expected. Indeed, it has been shown that visual field enlargement is larger in pre- versus post-chiasmic lesion groups. After pre-chiasmic lesions, there could be a take over of function by the intact neighbouring receptive fields in the primary visual cortex. A Second argument favouring the involvement of receptive field changes is that improvements in foveal regions occur slowly and are small. The receptive fields for the foveal regions are indeed numerous and small at the V1 level, while receptive fields for peripheral visual field regions are large (cortical magnification factor). Third, the involvement of receptive fields allows the possibility of axonal sprouting or the establishment of new synaptic connections. New lateral connections between neighbouring receptive fields can be formed by this mechanism. Alternatively, the disinhibition of silent synapses could also be a mechanism influencing receptive field properties. Following disinhibition, pre-
existing but inhibited connections could be activated by the lesion. A final mechanism which has been proposed to influence receptive field properties is an increase in synaptic efficiency, for example, by reducing the firing threshold of the few survived neurons so as to increase their performance.

As a more general remark, but also as a result of the mechanisms proposed to be responsible for restoration, the authors caution that there is never complete restoration and that some visual dysfunction always remains.

Since restoration seems limited and laborious, the obvious question to be answered before the implementation of training aimed at restoration in rehabilitation settings, is which patients are likely to benefit? Kerkhoff (1999) suggested that patients with incomplete lesions of the visual pathways are likely to benefit from restorative training. These patients show some residual perception of moving targets, the presence of relative scotomata and shallow gradients in the profile of light sensitivity in the scotomata or some striate cortex activity in PET or during fMRI. All these indicators presuppose some spared cortical structure. This sparing does not need to be massive. Sabel and co-workers argue that as little as 10% of a lesioned cortical structure can be sufficient to enable nearly 90% of the normal function of this structure.

3.2.2.2. Adaptation: Auxiliary Optical Devices

Another therapeutic approach is to adjust the patient to the environment. This can be achieved using optical aids. Different types of optical devices have been introduced for visual field rehabilitation purposes. Among these are devices such as mirrors, partially reflecting mirrors (beam splitters), reversed telescopes, glass prisms and fresnel (press on) prisms. Such devices can be incorporated into spectacles and have been applied in rehabilitation techniques, alone or in combination, as monocular (applied to one eye) or binocular systems (applied to both eyes) (see figure 2 A-B).

Cohen (1993) provides an overview of techniques used for peripheral field loss. In the following discussion, we will focus mainly on the prism-approach. Many of the features (both positive and negative) of the prisms are also applicable to the mirrors.

The rationale behind the use of prisms is to shift information from the non-seeing side closer to the seeing side. This can be actualised by wedge-shaped prisms with the base positioned towards the blind hemifield. Two effects can be accomplished with these devices: field relocation and field expansion.

3.2.2.2.1. Field relocation

Field relocation changes the position of the field loss relative to the environment causing an optical displacement of (a part of) the visual field. A part of the environment, which was not visible, now appears. At the same time a different part of the same angular span becomes invisible and thus disappears, as it is replaced by the previously unseen part of the visual field.
Binocular full prisms and sector prisms provide only for field relocation. Binocular full prisms (the entire carrier lens is covered by the prism) induce field loss in the far periphery on the seeing side. As they are full prisms, they generate this effect independently of eye and head position.

A binocular sector prism (figure 2 A.) covers only a part of the carrier lens. It is usually mounted in and near the edge of that portion of the lens corresponding to the non-seeing field. As a consequence, there is natural viewing in primary gaze: one sees an unshifted view when looking straight ahead (with the eyes). As gaze moves towards the non-seeing field, it encounters the prism-area and one sees an image which is shifted in the direction of the apex of the prism. This ‘image jump’ or ‘prism jump’, which occurs at the junction of the prism edge, induces an optical scotoma in the centre of the field and is called the jack-in-the-box phenomenon (Cohen & Waiss, 1996). Objects in that part of the world (angular span equal to the prism-power in degrees) will disappear, but may pop into view with head movements. This is where the name ‘jack-in-the-box’ comes from: a toy with a clown’s head (‘Jack’) on a spring, which is put into a box with the spring compressed. When the box is opened, the clown’s head pops all the way out.

3.2.2.2. Field expansion
The jack-in-the-box scotoma in a binocular system can be compensated for by head movements (and partly by eye movements). However it can be overcome by fitting the prisms monocularly. A monocular sector prism expands the field. Contrary to field relocation, field expansion indicates that the field seen simultaneously is larger with the device than without it (Peli, 1999). Field expansion can be accompanied by central diplopia and confusion. Diplopia means double vision and should be avoided when possible. It is the most frequently reported negative side-effect as it is very disturbing. Confusion refers to the perception of two different objects in the same perceived direction or at the same spatial location. It thus refers to the super-imposition of what is seen with the prism over what is seen without the prism. Importantly, this confusion is the desired effect, because one of these two objects was previously unseen.

3.2.2.2.3. Applications
The Visual Field Awareness System (VFAS) approach of Gottlieb, Fuhr, Hatch, & Wright (1998) incorporates a sector prism mounted in and near the edge of the patient’s blind hemifield. It is a monocular system, where the prism is preferably mounted before the eye ipsilateral to the visual field loss. The authors conclude that for most patients, VFAS not only improves visual awareness and increases measured recovery of vision, but also improves emotional outcomes and increases independence. The main drawbacks are the associated problems of central diplopia and confusion. This might explain the negative correlations of success with age. The initial rejection of the system by the older patients could perhaps be overcome with time, practice and vision rehabilitation therapy, although the mean number of treatment sessions for most patients was more than twenty, with each session lasting up to three hours. Another disadvantage, in the case of field restoration, is the progressive repositioning of the prism, which has to be mounted near the edge of the non-seeing field. The vast investment of time and money in the optical adjustments, the accompanying vision rehabilitation therapy and the problems experienced by older patients are clearly negative aspects in rehabilitation terms.
As is the case with all sector prisms (monocular or binocular), the effect of this type of system is limited to instances when the line of sight is directed through the prism sector itself. Thus when gaze is at the primary position or directed away from the hemianopic field where the prism is fitted, the sector prism has no effect on the field of view. The obligatory direction of gaze is a clear drawback because it requires intentional scanning. A slightly larger eye movement can have the same result in terms of field exploration, rendering this prism system perhaps even superfluous.

Peli (1999, 2000a, 2000b) developed an alternative system, with these considerations in mind. His type of hemianopic visual aid expands the field, rather than relocating it. Moreover, intentional scanning is no longer required to benefit from the effects of the prism, as it functions in all positions of gaze. And finally, Peli’s system avoids central diplopia. These effects are accomplished by using monocular sector prisms limited to the upper and/or lower peripheral fields and placed across the whole width of the carrier lens (see figure 2 B). Figure 3 shows an example of an upper sector prism on the left carrier lens (the prisms are indicated by the arrow). As the prisms only shift an upper and/or lower peripheral part of the blind hemifield to the seeing hemifield, they produce confusion only at those locations providing the field expansion. The combination of these properties results in a system which acts as a detection aid. Stimuli from the non-seeing hemifield can now be detected without active exploration. To put it simply: some (peripheral) parts of the non-seeing hemifield are shifted and added to the seeing hemifield. For illustration of the prism-effect, we refer to Peli (2000b figure 3) and to http://www.eri.harvard.edu/faculty/peli/index.html, where the prism-effect can be observed in a video simulation.

The patient is instructed to fixate only through the carrier lens, not through the prism. This way, the desired field expansion is the result of continuous peripheral diplopia (which is very much less disturbing than central diplopia) and continuous peripheral confusion. Only objects from the seeing hemifield over the height of the prism segments are seen in diplopia, that is, only objects in the upper and/or lower periphery. Peli (1999, 2000a, 2000b) reports expansion magnitudes of fifteen to twenty degrees. A further advantage of this type of prisms is that the ambiguity that may be associated with the confusion can be reduced. Namely, the objects seen through the prisms (shifted) and those seen through the carrier lens (not shifted) can be distinguished by a spectral cue. The shifted images actually appear slightly distorted in terms of resolution and colour. The ‘peripheral’ side-effects and the reduction in ambiguity can facilitate adaptation to the system.

As previously mentioned, in Peli's approach, the patient is instructed not to look through the prism to avoid central diplopia. Shifting information from the non-seeing side and adding it to the seeing side, restores the possibility of detecting this visual information. Once an object of interest has been detected in the periphery and its location determined (seeing or non-seeing side), it can be inspected and foveated through the carrier lens by making head movements. Since eye movements usually precede the head movements, this requires a new and adaptive type of gaze and viewing style. Peli (1999, 2000a, 2000b) reports that subjects are instructed only in the care and use of the prism and therefore assumes this new viewing style will result from an implicit learning process.
Of the twelve patients evaluated (Peli, 1999; 2000b), eleven showed the expected field expansion on binocular visual field testing. In contrast to other authors, Peli makes no special mention of adaptation (or other) problems specific to elderly patients. A crucial factor for the success of the system is, however, intact binocular function. The adaptation period was two to three weeks per prism and almost all patients reported significant improvement in the avoidance of obstacles after that time. Three patients with a considerable follow-up period of one year reported large improvements in daily life functioning. Two of them also resumed driving.

As this type of rehabilitation is relatively new, further improvements and refinements can still be expected, as also suggested by Peli (2000b). Further investigation is needed on some critical points. For example: the effects and necessity of eye and head movements when using such devices need to be considered. Clearly, using this hemianopic visual aid effectively requires a new viewing style. Research on how to teach patients (quickly) to adopt this is needed. Also the possibilities and limitations of the (cognitive) adaptation process should be further investigated. The influence of the visuo-spatial distortion that is introduced, and its effect on the mental representation of space is a question which is not only very interesting but also crucial for the broader and general use as a rehabilitation method. More specifically, the exact nature of the adaptation (for a suggestion see Peli, 2000b), and the presence of after-effects should be closely investigated.

3.2.2.3. Compensation
3.2.2.3.1. Compensatory programs
Another therapeutic approach is the compensation approach. It is fundamentally different from the previous approaches, in that visual input is not altered or changed, but intervention rather focuses on search and scan behaviour. The aim is to enhance the patients’ ability to explore their blind hemifield. These types of training methods are sometimes called ‘awareness enhancement training’ because it is assumed that the patient is trained to be aware of the deficit and to use compensatory eye and head movements for scanning the blind field. It can be a valid alternative and/or complement to the restorative training approaches, since field recovery, spontaneous or induced, is rather limited even after extensive training. It can also be a sound alternative and/or complement to the use of auxiliary optical devices because some types of (prism) systems demand intentional scanning (and thus compensation) if they are to be effective. Other optical systems create new visual problems, like diplopia and confusion, to which patients must adapt. Adaptation entails implicit learning and could (at least partly) be accomplished by compensatory behaviour.

The structure and aim of the compensatory therapies reflects the most frequently reported problem after visual field loss namely defective visual scanning and exploration (Zihl, 2000). The visual scanning pattern in hemianopic patients can be characterised by small-amplitude ‘staircase’ saccades towards the blind hemifield and frequent repetitions of the scan paths during search. Increased search times are observed, most pronounced in the blind hemifield, as is a lack of large-scale saccades promoting global spatial orientation (Kerkhoff, 1999). These saccadic or oculomotor problems are at the basis of the saccadic compensation training methods. They have been introduced, explored and used, for example by Zihl and von
Cramon (1985), Zihl (1994, 1995), Kerkhoff, Münssinger, Haaf, Eberle-Strauss, and Stögener (1992) and Kerkhoff et al. (1994). These studies confirm that compensatory strategies can be taught successfully in 10-25 training sessions of about 45 minutes spread over 4-6 weeks. The general structure of these compensatory treatment approaches can be summarised as follows.

Training starts with simple tasks which become progressively more complex. In a first phase, large amplitude saccades towards the blind hemifield are trained using computerised programs. This type of eye movement makes it possible to glance over visual space quickly without omitting a (portion of the missing) hemispace. Training is usually done in a perimeter (e.g. Zihl, 1995) or on a large computer screen (e.g. Kerkhoff et al, 1992, 1994). The patient is asked to detect and fixate stimuli in the blind hemifield as quickly as possible. Stimulus onset is usually accompanied by an acoustic signal. It is continuously stressed that the patient should move his/her eyes with one large sweep and not in a step by step manner. Zihl (1994) reports that it takes approximately 400-600 trials for the patient to increase this type of eye movement. In a second phase, a systematic search pattern, enabling the patient to search blind and intact hemifields without omitting relevant items, is demonstrated and learned. Patients are encouraged to adopt a systematic row-by-row or column-by-column strategy and start their search on the side of the blind hemifield. This has been operationally defined as, for example, ‘search on projected slides’ (Kerkhoff et al., 1992; Zihl, 1995). In a final step, the compensatory strategies are trained in everyday life situations. In the study by Kerkhoff and colleagues (1992), (visual) activities of daily living (ADL) relevant to the patient (e.g. finding a particular spice on a shelf) were listed and subsequently trained, whilst promoting the newly learned visual strategies.

Results show that, with this type of training, a clear improvement can be observed on several visual tasks. Zihl (1994) reports that, in a group of 126 patients, the mean extent of the field of search increased from 12° to 36° on the side of the blind hemifield, and search times decreased by more than 50%. In the study by Kerkhoff et al. (1994), similar improvement in oculomotor function was observed. Transfer to non-trained tasks was also measured: reduction of errors in search tasks, subjective improvements of visual functions as measured by questionnaires and return to work by 91% of the patients. These results were complemented by studies which recorded eye movements, and which reported a normalisation in the number of fixations and refixations and in rates of repetitions of scan paths following this type of compensatory training (Zihl, 1995). Since the mean increase in saccadic amplitude was significant but rather small (about 1°), the normalisation is presumably accomplished by the acquisition of a systematic, more spatially organised scanning pattern, which has its effect on the entire field of vision.

It is interesting to note that some restitution of the visual field was observed by Kerkhoff et al. (1992) in patients who had followed compensatory therapy. Mean visual field increase after therapy was 5° for 37 of 92 patients with visual field defects. The increase for the neglect group with VFDs (VFD+) reached 12° for 10 of the 30 patients. Thus in nearly one-third of the patients, a partial restitution of the visual field was observed. From the previous discussion of measuring visual fields, it should be clear that unless very precise control of fixation is guaranteed, the observed improvements can only be regarded as approximations. Further, the authors do not describe exactly where the improvements were located (central versus peripheral visual field) so that the improvement in functionality cannot be fully be appreciated.
Another interesting and important observation by Kerkhoff et al. (1992) is that frequent head movements had a clear negative effect on the success of the compensation training. Patients who made no head movements received on average 12 treatment sessions. This number increased to 21 and 26 sessions for the mid-frequent and frequent groups respectively. The reason suggested for this is that these head movements are too slow for rapid orienting. This clearly contradicts the assumption that head movements are a helpful compensatory mechanism for VFD patients. This should be taken into account when devising therapeutic methods.

3.2.2.3.2. **An integrated saccadic compensation training**

With these principles and positive findings in mind, we devised a similar approach. Our method combines previously mentioned principles of saccadic compensation training with principles and materials from the neglect rehabilitation training by Pizzamiglio and co-workers (e.g. Pizzamiglio et al., 1992). Our aim is to combine positive aspects from several approaches so as to facilitate the learning of an optimal compensatory strategy, which is integrated in a personal scanning style, and applicable in all daily life situations.

Our program contains three consecutive phases, each of which can last for a maximum of 6 hours. In the first phase, compensatory saccadic eye movements are trained. To enhance transfer, in the second phase the eye movement principles are applied in several tasks requiring efficient scanning behaviour. Some tasks from phase two had their origins in the neglect rehabilitation program of Pizzamiglio’s group (e.g. Pizzamiglio et al., 1992). In the third and final phase, the newly learned visual style is practised in daily life, again to enhance transfer. Unlike the original saccadic compensation training programs, we chose one task from daily life with a high practical and social value, and a large and highly demanding visual scanning component, namely driving a car. Patients have then to apply their scanning style while driving a car, in real traffic, under the close supervision of a driving instructor.

In the following paragraphs, we will try to give the reader a clear impression of how this compensatory training is carried out. We will therefore mainly focus on the principles, procedures and methods, minimising reports on results.

4. **The Integrated Saccadic Compensation Training Program**

4.1. **Establishing global understanding of visual problem and general aim of rehabilitation program**

All training sessions are on a one therapist–one subject basis. Before the first phase begins, primary visual functions are assessed and discussed extensively with the patient. Our patient group had normal or corrected to normal vision, except for the apparent VFDs. The existence and the cause of the VFD is shown, demonstrated and explained to the patient by means of the perimetric output and by confrontation. When available, scans from imaging techniques were also shown. Becoming aware of and understanding the nature and cause of the visual problem is believed to be the first step towards compensatory behaviour. Awareness of the deficit requires its discovery. The patient frequently does not directly sense but rather discovers the absence of the hemifield. The demonstration of the difference in perception in blind and not-blind hemifields was a very unpleasant surprise for some subjects, which shows that not all hemianopic patients are aware of their visual field defect (as previously discussed). Each of the three phases starts with a statement of the aim of the training involved, so as to further
increase understanding and motivation in the patient. A relatively large amount of time is devoted to explanation, understanding and instruction of the first training phase, as the success of following phases is dependent on its success. In this first phase, the ‘tools’ are provided which will have to be used in later phases.

4.2. First phase: Saccadic eye movement training
In the first phase, saccadic eye movements are trained. Our set-up enables us to project stimuli on a large screen, covering an area of approximately 100° horizontally by 60° vertically. The software presents a single target (digit or symbol) at a prespecified location for a prespecified maximum presentation time. Presentation time can be individually adjusted, but is kept to a minimum to speed up the response by the subject. The task of the subject is to name the target as quickly as possible. This vocal response was captured by a voice key which terminated the presentation of the current stimulus and initiated presentation of the next target. The interstimulus interval (ISI) could also be individually adjusted.

The eye movement training is structured into several blocks of increasing difficulty, as will be further explained. Patients run through the blocks in a fixed order, as each block incorporates previously trained principles. A block is offered only after the previous block has been completed successfully. Success is defined as running through the sequence without any stop or delay at the prespecified time parameters using the suggested principles (see further). Maximum training time is six hours.

4.2.1. Establishing understanding and aim of first phase
The first session of the training begins by clarifying why we train eye movements. We explain that when people without VFDs look straight ahead, they receive visual information from both hemi-spaces while our patients receive only half of this information. As a consequence they need to acquire the missing information actively. One (and in our view a very efficient) way of doing this is by employing the type of eye movements we are about to train. Thus, first it is stressed that the rehabilitation program aims at making frequent, large and fast saccadic eye movements into the blind hemifield (and back). These eye movements should be large and fast in order to create an overview of the full (hemi)space quickly. They should be frequent in order to anticipate new events and/or changes in the blind hemispace.

Secondly, we explain that priority should always be given to the movements of the eye, and not to movements of the head. The difference between eye and head movements is explained by demonstrating both possible ways of compensating. We explain that it is a misunderstanding to think that head movements are the only way of compensating for a visual field loss and that, sometimes, head movements can lead to the belief that one is compensating while in fact one is not. This is illustrated by making head movements while simultaneously making contralateral eye movements. To demonstrate this, the therapist fixates a point (e.g. the nose of the patient) while making large head movements. With this demonstration, it can be shown that the missing hemifield is linked to the position and movements of the eye, rather than the head. Other advantages of using eye movements are that they are faster and more accurate than head movements. Furthermore they cannot lead to neck-muscle complaints. For this reason, at the start of the training, the patient is strongly urged not to make any head movements at all. During the course of the training, as the amplitudes of the required eye movements become larger, it becomes impossible not to move the head. At that time, it is explained that in this instance the head and eye should collaborate in a sort of ‘rubber band way’. The emphasis remains on the movements of the eye, while the
head only assists at the last stage of the movement. Thus, the eye moves first and the head follows in a second step. Finally, we emphasise the importance of overshooting the target. An overshoot means (deliberately) making an eye movement which is too large. This is stressed by pointing out the hazards of an undershoot. We explain and demonstrate that when an eye movement into the blind hemifield undershoots a target, this target cannot be detected. In this case, the patient cannot be certain about the presence of a target: either there is no target and he/she can safely glance somewhere else or the target was missed because it was just a bit further away (in the blind hemifield). The safest action at that point is to check further laterally into the blind hemifield for a possible target. At the next, and all following fixations, this uncertainty will recur. This leads to an extensive and time consuming, piecemeal scanning pattern with many small amplitude saccades. This can be prevented by performing an overshoot as the starting saccade. ‘Jumping’ to the extreme end of the blind hemispace shifts all possible targets into the intact hemifield so that they can be detected. Absolute certainty about the presence of a target can be acquired only with one (large and fast) eye movement.

This part of the training is concluded by emphasising that the principles learned should be integrated into a new personal scanning style, which is adapted to the patient’s specific VFD.

4.2.2. Method
The method used to elicit the desired type of eye movements is different from previous reported approaches, where only an acoustic signal indicates the presence of a target. With our method, we provide predictability in time and space for all targets. We elicit the desired eye movements by a sequence of three events (triad) (see figure 4). The triad principle is maintained throughout the entire eye movement training. The first event or target in the triad is the ‘orientation point’. This point initiates the sequence and determines the orientation and position of the head. The subject knows that from this point on, the orientation of the head should be fixed. The orientation point is followed by a small and easy horizontal ipsilateral eye movement (into the seeing hemifield). This second event is always followed by a large horizontal contralateral eye movement (into the blind hemifield). It is stressed that the third action is the one to be trained and that the previous actions are for preparation purposes only. By explaining and maintaining this triad, the patient can predict the upcoming event making it possible to program and prepare all eye movements. Further, by using a fixed ISI, the targets are defined in time and space. The subject is strongly encouraged to use this predictability to plan and program the eye movements. The training starts with one triad as in the previous illustration. This simple sequence is repeated several times, forming a block of practice. In the following block, the same triad (and repetitions of it) is presented on another part of the large projection screen so that eventually the same triad is performed on the left, middle and right side of the screen with respectively a left (initial) head orientation, a straight ahead (initial) head orientation and a right (initial) head orientation. In this way, the subject learns through experience that the same eye movements can be performed with a totally different head position. In the next set of blocks, the amplitude of the contralateral eye movement is systematically enlarged. When the amplitude becomes too large, head movements are allowed using the previously described principle (rubber band view). The initial head position is to be
restored, as soon as the orientation point reoccurs. The different amplitudes are again repeated on different parts of the screen (‘same eye movements, different main head orientations’- principle). In this set of blocks, the basic features of the program are trained: contralateral eye movements which are frequent, large and fast.

In the next blocks, four triads occur within the same block forming a ‘chain’. The chains are repeated several times. The triads are identical except for their vertical position (see figure 5). They thus vary by row, starting at the top, moving downwards. As a consequence, all (four) orientation points are vertically aligned, as are events two and three. This again results in perfect predictability of the target positions. Thus, within one chain, a large part of the screen is systematically covered by four large contralateral eye movements. The same logic is applied as before; the location of the chain on the screen is varied and the amplitude of the contralateral eye movement within the chain is systematically enlarged.

The next set of chains is composed of identical but horizontally displaced sequences (see figure 6). Here, the initial head position changes within a block, but the eye movements remain identical. Again the amplitude of the contralateral eye movements is systematically enlarged. To end this set of blocks, the chains are finally composed of horizontally and vertically varied identical sequences. The order of the sequences within a chain remains fixed. The amplitude of the contralateral eye movement is again systematically increased. In this set of blocks the basics of the eye movements are incorporated into a systematic scanning pattern.

In all previous blocks, the sequences within the chains were identical in terms of the amplitude of the different eye movements. To train the overshoot principle the previous sets are repeated, but the amplitude of the contralateral eye movements now becomes unpredictable (but remains large) (see figure 7). Thus the patient is strongly encouraged to adopt a safe, quick but strenuous scanning pattern.

The eye movement training is concluded with a set of blocks consisting of sequences with diagonal directions (see figure 8). All aforementioned principles and variations are again applied.

### 4.3. Second phase: Application and integration of eye movements into the scanning pattern

#### 4.3.1. General

The second step in the rehabilitation process is to learn to use this type of eye movement effectively. In the first phase, all eye movements were elicited by using predictability in time and space as a cue. In the second phase, the patient is encouraged to plan and generate the eye movements endogenously. All tasks had to meet the following criteria. Firstly, the task had to
allow self-initiated eye movements so that most eye movements would be elicited endogenously (in contrast to exogenously), making the patient an active participant in the rehabilitation process. Secondly, the task had to be adaptive in that difficult levels were preceded by easy levels. This way, performance could be improved gradually. Finally, the task had to allow (almost) instantaneous feedback, either via evaluation by the therapist or by the personal experience of the patient. These principles are important for motivation and for corrective interventions, in the case of suboptimal performance.

For this purpose, we offered four different tasks with a large and difficult visual scanning component. In order to perform these tasks successfully, an overview of the visual space in question has to be created and used either for recognition, comparison or action, as will be explained further. The tasks selected, and the amount of time spent on them, depended on the specific problems and interests of the patient. In total, a maximum of six hours of training was given. The four possible training tasks were describing a picture, copying a matrix, reading and driving a car in a simple simulator. Care was taken to ensure that at least two different tasks were attempted, usually finishing with the driving simulation. The reading training was very rarely chosen (it was perhaps to easy for this patient group). For this reason, it will not be discussed here. The driving simulation was developed in our lab for this specific training purpose. The other training tasks were adaptations of the neglect rehabilitation program from the Pizzamiglio group, (e.g. Pizzamiglio et al., 1992), for use with our HH patient group.

4.3.2. Picture description
A large variety of different pictures was gathered from the internet: photographs, drawings, pictorial art of every day and imaginary objects and scenes, humans and animals. These pictures are presented using an LCD projector and a large projection screen allowing for picture sizes of up to 100° by 90°. The task is to describe the pictures verbally without omitting relevant items. To do this, the patients have to scan a considerable size of visual space effectively. They are expected to organise and plan the scanning strategy themselves using the large saccadic eye movements practiced in previous sessions. This proved not to be a trivial task: imagine seeing figure 9 at 85cm viewing distance at a size of 220 x 165cm. It takes considerable scanning to survey, integrate and finally recognise the picture. Whenever full recognition or description fails (e.g. omission of an element in the blind hemifield), the therapist intervenes and urges the patient to explore the picture more carefully. In the case of a failure of recognition, the therapist can assist in pointing out the important or relevant visual cues. When the patient is verbally less fluent, specific and directed questions can be asked about the picture, so as to elicit full exploration. The patient could make use of a laser pointer to point at elements he or she was describing. This way, the therapist could evaluate the amount of visual space covered (when in doubt).

4.3.3. Matrix copying
The original idea and principle was described by the Pizzamiglio group and has again been adapted for our HH patients. A stimulus consists of two identical matrices of dots separated by a midline. Each stimulus is presented on an A4 sheet of paper in landscape orientation (see
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In one of these matrices a line pattern is drawn connecting some dots. To elicit maximum scanning and exploration, the matrix with the pattern to be copied is always ipsilateral to the non-seeing hemifield. The level of difficulty varies with number of dots making up the matrix (4, 6, 9, 16, 20 and 25), the number and length of line segments to be copied, and the number of lines that cross.

The standard task for the patient is to copy this pattern of lines onto the other matrix. We adapted this task in several ways. First, when the patient makes one or more errors, the secondary task is to find and correct them as quickly as possible. Second, when the patient makes no errors at all, the therapist completes some extra matrices, either correctly or incorrectly. The patient has then to evaluate their completeness and correctness and, when necessary, complete and/or correct the pattern.

Patients are encouraged not to perform these tasks using a safe but piecemeal approach, that is, exploring one dot at a time. Rather, they are asked to adopt a kind of ‘gestalting strategy’, that is, organising the line patterns and working with larger components. This way we elicit the construction of an overview, using the eye movements learned in previous sessions. Further, we asked the patients, especially when they were finding and correcting errors, to begin by inspecting the full pattern ‘broadly, widely and quickly’, so as to get a kind of sense about its correctness and completeness. This was intended to promote global viewing and hence the construction of an overview of the matrices.

4.3.4. Driving simulation

The program developed in our lab presents a moving-road scene similar to commercial racing games (see figure 11). Using an LCD projector and projecting on a large screen, the total scene covers approximately 90° by 75°. The patient faces the screen and is first asked to keep the car in the middle of the road using a steering wheel. The difficulty of the task is varied by introducing a weak or strong ‘sidewind’, which ‘pushes’ the car randomly to the side of the road. In order to compensate for this, the patient must make corrective steering movements based on their evaluation of the current position on the road. To evaluate their position, they must compare the distance between the left and right sides of the road. For this, effective and quick scanning of the road is required. The patient is again strongly encouraged to use the previously practiced scanning principles.

As this task becomes familiar, a secondary task is introduced. Targets (traffic signs of approximately 3°) are presented just above the horizon, at eccentricities of 10°, 25° and 40° on the left and the right, in random order. Presentation time of these targets is set at three seconds with ISI's ranging from two to five seconds. The patient is asked to push any button in the steering wheel on detection of a target. He/she is warned of misses by an acoustic signal. This component in particular relies on the speed of scanning and the overshoot principle. Thus, to successfully complete both components of this training, extensive, fast and effective scanning of total space is required.
4.4. Third phase: Application and integration of scanning pattern into ADL: driving a car

From this point on in therapy, we assume that the proposed scanning principles can be employed autonomously by the patient. In the third phase of the training, we offer driving lessons, in real traffic, under the close supervision of a qualified driving instructor. A maximum of six hours of instruction was given. The cars used for the lessons had dual controls and were maximally adapted to the needs of the individual patient. The adaptations included automatic gear shifting, reverse pedal control, steering knobs et cetera. Since all patients had driven previously (before their HH-acquisition), the basic technical, theoretical and legal aspects of driving were skipped. The instructions to the instructor were to guide the patient safely through traffic, advising him/her on all possible aspects of driving. Again, difficulty levels (in terms of speed, traffic congestion and complexity) were systematically increased, when judged to be safe. The patient was told that the instructor was not a qualified (visual) therapist and that his assignment was to point out the important cues, signs and events for driving. The task for the patient was to pick up these cues, signs and events using the scanning principles trained previously. As such, the scanning goal is set by the traffic situation; the scanning method has to be developed and displayed by the patient, preferably using the principles trained previously.

4.5. Results

We applied this training program with 19 HH patients. After completing the program, all patients subjectively reported an improvement in their vision. They felt they perceived more, and reported experiencing less disability. This was usually confirmed by their partners. Although some subjects clearly had the impression that their visual field was larger, perimetric assessment indicated that no visual field restoration had occurred. This suggests that these patients were compensating for their visual impairment by adopting a better scanning strategy, which permitted them to perceive more in less time. These subjective reports were generally confirmed by objective measurements. Details of the assessments and results will be described elsewhere. In the present discussion, only general and tentative conclusions are presented.

We administered an assessment battery, before and after training, to evaluate scanning performance. Effective scanning is a prerequisite for, and an integral part of adequate visuo-spatial function and was evaluated using standard neuropsychological, experimental and ecological tasks. The mean interval between both assessments was six months. Group analysis revealed significant improvements on neuropsychological visuo-spatial tasks such as the WAIS Block Design and a Hidden Figures Test. Not all subjects improved, however. Depending on the specific tests, tentative and coarse inspection of the data reveals mostly improvement, some status-quo and decreases in performance in a very small number of patients. Future inspection of the data should shed some light on the characteristics of those few patients whose performance tended to decrease. Possible subclinical manifestations of hemi-spatial neglect and/or dementia could be important factors. A similar observation was made, analysing the results of the experimental visuo-spatial tasks such as the Attended Field of View test (AFOV, Coeckelbergh et al, submitted). This experimental assessment of scanning behaviour generally revealed improvement, but patients who did not improve on the neuropsychological tests tended also not to improve on this test. The final observations are based on an ecological, practical on-the-road driving test. Performance was measured by means of a structured protocol. From this protocol, we derived a ‘visual-factor score’. This
score gives an indication of visual performance during driving. We observed significant improvement after training. But again the previous remark holds: not all patients improved and those who did not, also tended not to have improved on the other tests. Additionally, although improvement was generally observed, the performance level was not necessarily at standard (“sufficient”) level. This finding suggests that, although compensation is possible, complete compensation is very difficult.

4.6. Conclusion
These results are positive, but they raise further questions, which we hope to be able to answer, at least partly, in the near future. For example, what characterises patients who do and do not improve objectively after following the program? Is there a relationship with age, aetiology, time since lesion, general cognitive function et cetera.? These issues can be of considerable importance for the development and future implementation of rehabilitation programs specifically for hemianopic patients.

5. General conclusion
Treatment for hemianopic field loss should more often be the focus of systematic rehabilitation efforts than it is at present. The absence of generally accepted and widely used rehabilitation techniques is perhaps the result of the view that the visual disorder can not be treated or that it poses no apparent problem for the patient. We hope to have shown the contrary with this chapter. The consequences for visual and cognitive functioning of the loss of a hemifield due to post-chiasmatic brain lesion should not be underestimated.

In this chapter, we briefly reviewed several therapeutic methods that can be applied at present. They all have their pros and cons, and they need more systematic exploration, refinement and evaluation. Future work and experiences will bring new insights in the possibilities of rehabilitation. In our opinion, compensatory strategies, complemented by the application of strategies to enhance transfer, seem to be a good choice for rehabilitation. These methods have proven to be effective, they do not demand too much of either patient or therapist, and they have a direct and positive impact on the disabilities. Also the ‘adaptive approach’, devising auxiliary optical aids, is in our view very promising. To make a start for future developments, we would like to stress that the different approaches need not to be mutually exclusive and that different (combinations of) approaches can be chosen on the basis of the needs, preferences, and abilities of the individual patient. In our view, an interesting approach could be a combination of optical devices and compensatory training.

6. References


Prediction and Evaluation of Driving and Visuo-Spatial Performance in Homonymous Hemianopia after Compensational Training

1. Abstract
In a previous study we observed that the majority of patients with homonymous hemianopia (HH) showed low to modest visuo-spatial performance on neuropsychological tests and during a driving test administered by an expert of the Dutch licensing authority, suggesting the need for specific therapeutic intervention.
Seventeen HH patients took part in a saccadic compensation training to reduce visuo-spatial limitation, with a special focus on compensation during driving. We compared and interrelated visuo-spatial performance in driving and in neuropsychological tests, before and after the training.
Generally, analysis corroborated results of the previous study, confirming that visual performance during driving is moderately correlated with visuo-spatial neuropsychological test performance. We found an improvement in visuo-spatial performance during driving after rehabilitation, but not in other aspects of driving, nor in neuropsychological test performance. This argues against a non-specific placebo-effect.
Our results suggest that HH is not necessarily a contra-indication for fitness to drive and that visuo-spatial limitation, common and apparent in HH and consequential for fitness to drive, can be reduced by the compensation training. Despite this improvement, driving performance did not meet the necessary standards in most patients, suggesting either that more rehabilitation is required or lower rehabilitation goals should be set.

2. Introduction
Nearly 80% of patients with unilateral post-chiasmal brain damage acquire a homonymous visual field defect (VFD), and nearly 66% of the unilateral homonymous VFDs are homonymous hemianopias (HHs) (Zihl, 1994). Patients with HH typically complain about bumping into obstacles, difficulties in reading, and having a limited overview, resulting in considerable restrictions in every day life. These limitations and restrictions suggest, in addition to the structural visual impairment (i.e. HH), also reduced visuo-spatial function (Zihl, 2000; Meienberg, Zangemeister, Rosenberg, Hoyt, & Stark, 1981; Kerkhoff, 1999).
Visuo-spatial functioning, is one component of higher-order (cognitive) functioning which can be evaluated using specific neuropsychological tests. In addition, this cognitive function relates to many activities of daily living, as for example driving.
In previous work (Tant, Brouwer, Kooijman, & Cornelissen, submitted), we assessed visuo-spatial performance in HH patients, both by an extensive neuropsychological test battery and by a practical driving test. We found that visuo-spatial neuropsychological test performance can be significantly related to visual performance during driving, as observed in an on-the-road test-ride. Additionally, it was observed that the majority of the HH patients failed the test-ride, and showed modest visuo-spatial neuropsychological and driving performance, suggesting the need for specific therapeutic intervention.
Driving-related therapeutic intervention in brain-injured patients has been discussed by Brouwer and Withaar (1997). They suggested to give all brain-injured patients, except those who are obviously unfit to drive (e.g. severe neglect patients), driving(-related) rehabilitation and suggested two different approaches. Firstly, to give all patients rehabilitation until a certain criterion of fitness to drive is attained. The associated research question would be to predict the amount of necessary training. Secondly, to give all patients the same amount of rehabilitation and assess their fitness to drive (before and) after training. The research question would be to predict fitness to drive after training and the progression resulting from the training. This last approach, which we adopted for this study, allows more stringent research planning and control.

Therapeutic approaches specific for HH have been scarce, despite the high occurrence of substantial visual disabilities (Neetens, 1994; Kerkhoff, Munssinger, Haaf, Eberle-Strauss, & Stogerer, 1992; Nelles et al., 2001). Although limited visual field recovery is definitely possible in some patients with HH, it is rarely sufficient to eliminate the limitations and restriction resulting from the VFD (Kerkhoff, 1999) and hence specific (adaptational or compensational) therapeutic approaches are needed. The use of optical devices has recently been (re)suggested but not fully evaluated (Peli, 2000; 2001). Another therapeutic approach is the acquisition of oculomotor compensational strategies and has been suggested to be an effective method for treatment of visual limitations and restrictions resulting from HH (Kerkhoff et al., 1992; Kerkhoff, Munssinger, & Meier, 1994; Nelles et al., 2001; Tant, Bouma, Kooijman, Cornelissen, & Brouwer, in press; Webster et al., 1984; Zihl & Kennard, 1996; Zihl, 2000). In addition to the significant improvement in basic oculomotor performance, as suggested by these authors, also transfer to visually related activities has been reported (e.g. Kerkhoff et al., 1994; Zihl, 2000). This confirms the potential of this type of intervention for reducing activity limitations and their consequences for everyday life (restrictions).

We hence invested considerable effort in (improving) this type of therapeutic intervention as to reduce visuo-spatial disability in our HH group, with a special focus on the application of the principles during driving, as we were guided by the low to modest (visuo-spatial) driving performance in our previous study (Tant et al., submitted). This modest performance can be explained by the limited driving experience after acquisition of the HH and/or can result as a consequence of non-adaptive viewing behaviour. We addressed both aspects in our integrated saccadic compensation training, which is described in detail in Tant et al. (in press). In brief, the compensational training consisted of three phases, each lasting for six hours maximally. In the first phase, saccadic eye-movements into the blind hemifield, which are frequent, fast, and (too) large, were trained. The aim of the second phase was to effectively use this type of eye-movements, during specifically designed visuo-spatial experimental tasks. In the third phase of the training, we offered driving lessons, in real traffic, under close supervision of a qualified driving instructor, in order to improve the integration of the learned principles into a personal and general scanning style.

The main issues of the present research concern the relationships of neuropsychological test performance, driving performance, and the effectiveness of our therapeutic intervention. First, can an integrated saccadic compensation training lead to better driving performance and more specifically to improved visuo-spatial performance during driving. Does this also lead to better visuo-spatial neuropsychological test performance. Second, can visuo-spatial
neuropsychological test performance predict visual aspects of driving performance after therapeutic intervention and do we observe similar relationships as before the therapeutic intervention. Third, can the effect of the intervention be predicted, from neuropsychological test performance or from other characteristics. To answer these questions, we will use and compare neuropsychological data and data from an on-the-road test-ride, both before and after the rehabilitation program.

We expect that visually related activity limitations will be reduced after the rehabilitation program and that visuo-spatial neuropsychological performance is related to visual performance during driving. More specifically, as this was the aim of the therapeutic intervention, we expect an improvement in visual performance during driving. Since we previously established a significant relationship between visuo-spatial neuropsychological measures and visual performance during driving, we do expect to find similar improvements in visuo-spatial neuropsychological test performance. With respect to the third question, we expect that patients with more limitations will benefit more from the intervention, as there is more opportunity for improvement. Personal characteristics, like age and time since lesion, are also expected to be related to the degree of improvement.

3. Methods
3.1. Patients
The seventeen patients reported are part of a larger HH patient population previously reported (Tant et al., submitted). They were referred by specialists who indicated the need for assessment on fitness to drive. All patients failed a practical test ride (see Tant et al., in press for details) and expressed the desire for participation in the visual rehabilitation program, which we offered (see Tant et al., submitted for details).

A summary of the patient characteristics can be seen in Table 1. There is no significant difference in the number of left- and right-sided HH patients. There are significantly more males than females ($\chi^2 (1, N=17) = 7.2, P < .01$), equally distributed across both left- and right-sided HH groups. The higher proportion of males is probably induced by our recruitment procedure, in combination with social factors. Namely, we recruited patients with driving needs. Being refused to drive is probably less restricting in the (elderly) female population because, a priori, they drove less (than their husbands) and also are less dependent on themselves for transportation. We suppose that experiencing less restrictions would result in less interest in participating in a driving-study. Most of the patients were victims of stroke, but the different aetiologies are equally distributed across both HH groups. There are no differences in age, macular sparing, time since injury, or driving experience before injury between both HH groups. Most patients discontinued driving since injury ($\chi^2 (1, N=17) = 7.2, P < .01$), but the distribution of patients who (dis)continued is equal across both HH groups.

Standardised tests were administered to exclude dementia (De Graaf & Deelman, 1991; Folstein, Folstein, & McHugh, 1975), receptive aphasia (Deelman, Liebrand, Koning-Haanstra, & van der Burg, 1987) and apraxia (De Renzi, Faglioni, & Sorgato, 1982). Adequate general lower-order aspects of visual function, apart from the HH, were confirmed by a form discrimination screening test (Warrington & James, 1991). We excluded patients with severe hemi-spatial visual neglect and severe object agnosia (see Tant et al., submitted).
Table 1. Summary of patient characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<th>Right</th>
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<td>35.1</td>
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<td>range</td>
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<tr>
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<td>Tumour</td>
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<td>1</td>
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<td>13</td>
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<td>no</td>
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<td>3.0</td>
<td>2.47</td>
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<td>0-5</td>
<td>0-5</td>
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<td>Driving experience before injury (years)</td>
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<td>31</td>
<td>30</td>
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<td></td>
<td>range</td>
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<td>18-44</td>
<td>5-47</td>
</tr>
<tr>
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<td></td>
<td>no</td>
<td>7</td>
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<td>14</td>
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</table>

3.2. Visual Assessment

Visuo-spatial assessment consists of both a practical driving test and an extensive neuropsychological test battery. For detailed procedure and scoring, we refer to Tant et al. (Tant et al., submitted; Tant, in preparation).

3.2.1. Practical Driving Test

A practical test-ride is used to assess driving performance on the level of activity. The on-the-road test took place in and near the city of Groningen, and was conducted by a certified and official driving examiner of the Dutch Licensing Authority, using the standard test-routes and protocols. The cars used for the on-the-road test had dual operation and were maximally adapted to the needs imposed by motor impairments of the individual patient (if any).

To assess performance while driving, a structured protocol, was added to the standard procedure. This structured protocol (Test-ride for Investigating Practical fitness to drive, i.e. TRIP) is a checklist of different aspects of the driving task and was completed by the expert after the test-ride. Previous versions were used by Withaar (Withaar, 2000) and De Raedt (De Raedt, 2000). The 55 items, judging specific driving qualities and behaviours, were scored on a 4-point scale, ranging from “1” (indicating insufficient and inadequate performance) to “4” (good performance). Based on a priori considerations, we constructed separate factors (or subscales) with these 55 items. Four driving factors (namely VIS, OPER, TACT and TOT) are directly derived from (combinations of) specific TRIP items. Some items were represented in more than one factor. In the visual factor (VIS, 25 items), predominantly visuo-
perceptual behaviour was reflected. This included 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. The
operational factor (OPER, 8 items), was to reflect fluency of instrumental and psycho-motor
aspects of driving like handling the brakes and shifting gears. The tactical factor (TACT, 15
items) reflected all aspects in which (tactical) choices, anticipation, and adaptation were
represented. The sum of all TRIP items is indicated by the TOT factor (55 items).
At the end of the TRIP, both a global impression (GLOB) and end-verdict were provided,
based on a global and subjective impression of the expert. The global impression was
provided by evaluating three global aspects, namely practical fitness to drive, technical
handling and execution, and traffic insight, each scored on the 4-point scale. The end-verdict
indicated whether the expert (officially) would declare the subject fit to drive (pass or fail).
The VIS, OPER, TACT, TOT, and GLOB factors are expressed proportional to their
respective maximum factor score for ease of inter-comparison and will subsequently be
referred to as factor scores (range: .25 – 1). Factor scores of .25, .50, .75 and 1 indicate
performance at respectively “insufficient and inadequate”, “dubious”, “sufficient” (i.e.
passing) and “good” level.

3.2.2. Neuropsychological Test Battery
The neuropsychological battery consisted of 25 clinically available or experimental visuo-
spatial tests (see Table 2). These were classified, on an a priori basis, into four factors
representing different aspects of visuo-spatial function, namely basic visual scanning and
search (BVSS, 16 tests), a visuo-constructive and organisational factor (VCO, 3 tests), a
visuo-integrative factor (VI, 4 tests) and a dynamic factor (Dy, 1 test). These four factors were
evaluated on multiple components, namely performance in terms of lateralisation, speed, and
accuracy. The speed and accuracy components are traditionally used for evaluating general
test performance. As HH is a lateralised visual dysfunction which, if not properly
compensated for, will lead to relatively poor visual performance with regard to the side of the
blind hemi-field, we assume that differential lateralised performance is a typical characteristic
of HH visual disability. The lateralisation component qualifies and quantifies the nature and
degree of differential lateral performance, independently of general performance. The nature
(qualitative aspect) is expressed by the sign the lateralisation index, where a positive index
indicates better right-sided than left-sided performance (as expected in left-sided HH) and the
opposite for a negative index (expected in right-sided HH). The degree of the lateralised
difference (quantitative aspect) varies between 0 an 1, where the former indicates no
difference and the latter indicates maximal difference. Hence the lateralisation index varies
between –1 and +1. When assessing (only) the quantitative aspect and comparing left- and
right-sided HH, the absolute values of the lateralisation scores will be used.

When necessary and possible, transformations were inforced on the raw test data, following
suggestions by Stevens (1996), to approximate normal distributions of the individual test
scores. The speed and accuracy data were then normalised for intercomparison. For each
factor, the measures of lateralisation, speed, and accuracy of the comprising tests were
averaged, providing for each factor, a factor (lateralisation, speed, and accuracy) component
score. Visuo-spatial test performance is hereby operationally defined by four different visuo-
spatial factors (namely BVSS, VCO, VI, and Dy), which are evaluated in terms of three
components (namely lateralisation, speed, and accuracy). There is no accuracy component in
the Dy factor (see Table 2). Averaging the four lateralisation, four speed, and three accuracy components of the respective factors, provides a global lateralisation, global speed, and global accuracy component score. For more details, we refer to Tant et al. (Tant et al., submitted; Tant, in preparation).

Table 2. Summary of construction of the Visuo-Spatial factors. The components used for each test are marked.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Visuo-spatial</th>
<th>Test</th>
<th>Components</th>
<th>Speed</th>
<th>Accuracy</th>
<th>Lateralisation</th>
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<tr>
<td>Basic Visual Scanning and Search (BVSS)</td>
<td>Trail Making Test</td>
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<tr>
<td></td>
<td>Counting Dots</td>
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<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Position Discrimination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>TAP Eye movements</td>
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<td>✔</td>
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<td></td>
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<tr>
<td></td>
<td>TAP Visual Scanning</td>
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<td>✔</td>
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<tr>
<td></td>
<td>The Attended Field of View Test</td>
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<tr>
<td></td>
<td>Detection Task</td>
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<td>✔</td>
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<td></td>
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<tr>
<td></td>
<td>Zihl Dotcounting test</td>
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<tr>
<td></td>
<td>Line bisection</td>
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<tr>
<td></td>
<td>Albert’s line cancellation Test</td>
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<td></td>
<td>Mesulam Structured Shape cancellation</td>
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<tr>
<td></td>
<td>Search for O’s</td>
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<td>✔</td>
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<tr>
<td></td>
<td>The Bells Test</td>
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<td>✔</td>
<td></td>
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<tr>
<td></td>
<td>Grey scales</td>
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<tr>
<td>Visuo-Constructive and Organisational (VCO)</td>
<td>WAIS-R Block Design Test</td>
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<td></td>
<td>Matrix copy test</td>
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</tr>
<tr>
<td></td>
<td>Complex Figure Test</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Visuo-Integrative (VI) | Position Determination | | | | | ✔
| | Blocks | | | | | ✔
| | Hidden Figures Test | | | | | ✔
| | Overlapping Figures Task | | ✔ | | | ✔
| Dynamic (Dy) | Tracking task | | ✔ | | | ✔

3.3. Procedure
After inclusion in the larger study, 28 patients were assessed by both a practical driving test and an extensive visuo-spatial neuropsychological test battery (pre-assessment). Twenty four patients failed the test ride, as indicated by the end-verdict of the driving expert. These patients were invited to participate in our saccadic compensation program (see Tant et al., in press for details). Eighteen patients accepted. One patient did not complete the rehabilitation program, due to a new brain insult. The total rehabilitation time for each patient was fixed to 18 hours, but the time span of the rehabilitation program was on average 25 weeks, ranging from eight to 73 weeks. After completion of the rehabilitation program, the driving test and neuropsychological battery were repeated (post-assessment).
4. Results
To address the issues of the effectivity of the rehabilitation program, both in terms of driving and neuropsychological test performance, the results of the practical driving tests and the neuropsychological test battery will be presented firstly and separately. The issues of prediction of visual performance during driving and improvement will be reported subsequently.

4.1. Practical Driving Test
All 17 patients had failed the practical driving test before the visual rehabilitation program, as indicated by the end-verdict of the driving expert. After the rehabilitation program, two patients (12%) (one left- and one right-sided HH) achieved a positive end-verdict, and hence passed the practical driving test. For the remainder of the analyses, in order to evaluate driving performance, we will use the TRIP factor scores (VIS, OPER, TACT, TOT and GLOB).

All TRIP factor scores intracorrelated significantly before the rehabilitation program, as well as after. Pearson’s R ranged from .68 to .97 and from .69 to .98 respectively (N= 17; all P < .005). Also the respective TRIP factor scores (pre- versus post-assessment) intercorrelated significantly (R-range: .72 - .85, N=17, all P < .001).

A MANOVA on the TRIP factor scores showed no difference in performance between left- and right sided HH, and revealed an effect of the rehabilitation program (F(5,11) = 4.6, P < .05). Univariate analysis showed a significant improvement only of the VIS factor (F(1,15) = 8.1, P < .05) (Fig. 1), which evaluates visual performance during driving. On average, none of the TRIP factor scores (pre- and post-assessment) reached the “sufficient-level” (all mean scores significantly differed from .75, as indicated by one-sample T-tests). However, for both patients who passed, all TRIP factor scores were at sufficient level (range: .75 - .78) after the rehabilitation program, while for those who did not pass, mean TRIP factor scores ranged from .47 to .59. For comparison, before the rehabilitation program, TRIP factor scores ranged from .58 to .77 for the two patients who passed. The mean TRIP factors, for those who did not pass, ranged from .44 to .60.

4.2. Neuropsychological Test Battery
Visuo-spatial neuropsychological test performance was a priori classified into four factors (Basic Visual Scanning and Search (BVSS), Visuo-Constructive and Organisational (VCO), Visuo-Integrative (VI), and Dynamic (Dy)), evaluated on different components (lateralisation, speed, and accuracy). After averaging the respective component scores of the different factors into a global lateralisation, global speed, and global accuracy score, it showed that all global scores significantly correlated pre- versus post assessment (r(N=17) = .88, P < .0005 for speed; r(N=17) = .96,
In contrast to the significant improvement in the visual driving factor (VIS, pre- versus post-assessment), we did not observe any multivariate (or univariate) effect of the rehabilitation in the global (visuo-spatial neuropsychological) component scores. MANOVA showed only a significant multivariate effect of side of the HH ($F(3, 13) = .48, P < .05$). Subsequent univariate analysis revealed this effect to be observed only in the global lateralisation score ($F(1, 15) = 11.2, P < .005$). This multivariate (and univariate) effect disappeared when using the absolute values of the global lateralisation scores, indicating that only the qualitative, not the quantitative aspect of the lateralisation component differed in both HH groups.

MANOVAs (and ANOVAs), performed separately for the respective (four) lateralisation, (four) speed, and (three) accuracy components of the different visuo-spatial factors, did not reveal any effect of the rehabilitation as indicated by a lack of statistical change, from pre- to post-assessment, in either speed, accuracy or lateralisation component. As was the case for the global component scores, for the lateralisation components, we did observe a multivariate effect of the side of the HH ($F(4, 12) = 16.48, P < .0005$). Univariate analysis showed that the left- and right-sided HH patients significantly differed on the BVSS ($F(1, 15) = 67.8, P < .0005$) and the VI ($F(1, 15) = 12.07, P < .005$) lateralisation. This multivariate (and univariate) effect disappeared when using the absolute values of the lateralisation scores, indicating that only the qualitative, not the quantitative aspect of the lateralisation component differed in both HH groups.

MANOVAs, performed separately for the four visuo-spatial factors (BVSS, VCO, VI, and Dy) using their respective component scores (lateralisation, speed, and accuracy), indicated no statistical change, from pre- to post-assessment, in either of the four analyses. Multivariate effects of the side of the HH were observed for the BVSS factor ($F(3, 13) = .17, P < .0005$), and the VI factor ($F(3, 13) = .47, P < .05$). This effect disappeared for the VI factor, when using the absolute values for the lateralisation score (as previously indicated). However, for the BVSS factor, in doing similarly, the effect of the side of the HH remained and univariate analysis revealed that left-sided HH patients showed worse BVSS accuracy scores (Mean = - .202, SD = .50) than right-sided HH patients (Mean = .227, SD = .31) ($F(1, 15) = 5.7, P < .05$).

### 4.3. Visual performance during driving (VIS)

Due to the nature of the visual impairment, visuo-spatial limitations can be expected in HH. We therefore focussed on the visual performance during driving (VIS factor derived from TRIP scores), which, as already indicated, significantly improved after the rehabilitation program. Bearing the restraints imposed by the low number of subjects in mind, we examined the interrelations of the VIS factor with personal characteristics and global (neuropsychological) component scores.
4.3.1. Personal characteristics
After correlating the VIS factor with the personal characteristics of the patients, we observed that age correlated significantly at pre-assessment ($r(N=17) = -.60, P < .05$), but this correlation disappeared at post-assessment ($r(N=17) = -.34, ns$), indicating, at pre-assessment, worse visual performance during driving with higher age. Neither macular sparing nor driving experience did show any significant relationship with the VIS factors, either at pre- or post-assessment. Driving experience was however highly correlated with age ($r(N=17) = .88, P < .0005$). When corrected for age, driving experience did correlate significantly with VIS at pre-assessment ($r(N=17) = .51, P < .05$), but not at post-assessment ($r(N=17) = .38, ns$), indicating, at pre-assessment, better visual performance during driving with more driving experience. In contrast to this pattern, time since injury did not correlate with VIS at pre-assessment ($r(N=17) = -.39, ns$), but did so at post-assessment ($r(N=17) = -.56, P < .05$), indicating, at post-assessment, worse visual performance with more time since injury.

4.3.2. Global (neuropsychological) component scores
We entered the global (lateralisation, speed and accuracy) component scores into a regression analysis, predicting visual performance during driving (VIS factor). The VIS factors could significantly be predicted by the global components derived from the same assessment occasion, namely at pre-assessment ($R^2 = .44, F(3, 13) = 3.4, P < .05$), and slightly better at post-assessment ($R^2 = .50, F(3, 13) = 4.3, P < .05$). Interestingly, it appeared that VIS at pre-assessment could also be predicted on the basis of the component scores at post-assessment ($R^2 = .54, F(3, 13) = 5.1, P < .05$). The reverse, however, did not yield a significant model ($R^2 = .33, F(3, 13) = 2.2, ns$).

4.3.3. Improvement
To assess the predictability of improvement in visual performance during driving, we forced the global neuropsychological component scores from either pre- or post-assessment into a regression analysis predicting the difference (from pre- to post-assessment) in VIS factors. Neither analyses resulted in a significant model, suggesting that visuo-spatial neuropsychological test performance cannot predict the visuo-spatial driving improvement. We also used an alternative strategy to investigate the predictability of the rehabilitation effects and came to the same conclusions. We predicted visual performance during driving at post-assessment, first by entering the VIS factor at pre-assessment ($R^2 = .52, F(1, 15) = 16.5, P < .001$), after which we entered the global component scores from either pre- or post-assessment and evaluated their addition to the variance explained. We observed no significant addition in either analyses, indicating that visuo-spatial neuropsychological test performance cannot explain any residual variance in visual performance during driving after rehabilitation which has not already been explained by visual performance during driving before rehabilitation.
We further investigated whether any of the personal characteristics showed any relation to the improvement in visual performance during driving. None of the characteristics correlated significantly with the difference score.

5. Discussion
5.1. Reduction of visuo-spatial limitations
In the on-the-road driving test, it is assessed whether the patient can drive adequately, given the visual impairment. This test-ride is not a regular driving examination, as specific concern
and importance is allocated to situations in which the HH can cause difficulties (limitations). To evaluate driving performance, we used a structured protocol (TRIP) from which we derived three factors, each representing an important aspect of driving. Since our visual rehabilitation program (integrated saccadic compensation training, (Tant et al., in press) aimed at reducing visuo-spatial limitations and restrictions, we focused on visuo-spatial performance, specifically during driving.

Although only two patients (12%) finally passed the driving test (as indicated by the end-verdict of the driving expert) after the rehabilitation program, we did observe an overall improvement of visual performance during driving (VIS). This conformed to our expectations and aim, since our rehabilitation program is visuo-spatially in nature. The operational (OPER) and tactical (TACT) aspects of driving, did not improve accordingly. As a result, the total TRIP score (TOT) and the global impression (GLOB), which incorporate all aspects and are hence global and general measures of driving performance, did not improve significantly (Fig. 1). All aspects were still subject to improvement, since none of them reached the “sufficient” level, suggesting the non-improvement not to be due to ceiling-effects. We need to remark in this respect that it cannot be excluded that the driving expert, in scoring the TRIP items, did not use the full range of scores (at the higher end), hence hereby lowering the maximum score and discrediting our conclusion concerning ceiling-effects.

In the current (pre versus post) design, influences other than the treatment effect, cannot simply be ruled out, but the specificity of improvement, namely only in visual performance, argues against a general and non-specific learning effect. In addition, Coeckelbergh et al. (Coeckelbergh, Kooijman, Brouwer, & Cornelissen, 1999) found no change in general driving performance in two post-treatment driving assessments, using similar protocols and driving tests. Our results hence suggest that we succeeded in improving visual performance during driving by the visual rehabilitation program.

Since visual information is generally considered to be the most important source of information in driving (Rockwell, 1972), our result is of considerable practical relevance for mobility-rehabilitation. Namely, it justifies the efforts in (improving) visual rehabilitation, since visual disability is apparent, consequential, and can be decreased in driving. On the other hand, since the improvement was not sufficient to meet the necessary standards, it suggests that more rehabilitation is required. This was also confirmed by the comments of the patients, who urged that they needed more rehabilitation time, especially in the third (driving) phase. Ideally, not only more time, but also other aspects, important for adequate driving, would need to be more addressed, since for passing the driving test, all aspects would need to meet at least the “sufficient” level.

As in previous work (Tant et al., submitted), in driving performance, we did not observe any difference between left- and right-sided HH patients. However, we did observe less accurate performance by left-sided HH patients on the BVSS factor. This result is not surprising, since left-sided HH patients suffered right-sided brain damage, frequently associated with visuo-spatial dysfunction (e.g. Zihl, 2000). That this differential performance was not a robust and general effect is not surprising either, since we excluded patients with hemi-spatial neglect. Such patients are visuo-spatially strongly impaired, and since in general they suffered right-sided brain damage, inclusion typically results in differential performance between left- and right-sided unselected brain damage groups. Since our left- and right-sided brain damaged patients (respectively with right- and right-sided HH) were “selected” in this respect, we did not expect to find robust quantitative differences in performance.
Neuropsychological test performance has previously been related to practical fitness to drive and has been reported to correlate only moderately high with measures of driving performance (e.g., Withaar, Brouwer, & van Zomeren, 2000; Brouwer, 2001; Engum, Cron, Hulse, Pendergrass, & Lambert, 1988; Engum, Lambert, Womac, & Pendergrass, 1988; Engum, Lambert, & Scott, 1990; Sivak, Olson, Kewman, Won, & Henson, 1981; Galski, Bruno, & Ehle, 1992; Nouri, Tinson, & Lincoln, 1987; Mazer, Korner-Bitensky, & Sofer, 1998; Nouri & Lincoln, 1993; Lincoln & Fanthome, 1994). In previous research, we confirmed a significant interrelatedness of visual performance during driving and visuo-spatial neuropsychological test performance in a larger HH sample (Tant et al., submitted). Since our visual rehabilitation program was aimed at reducing visuo-spatial limitations and restrictions, and since we observed improvement in visual performance during driving, we would also expect similar improvements in visuo-spatial neuropsychological test performance. Despite that we observed the expected intercorrelations of the visuo-spatial neuropsychological factors and their components from pre- to post-assessment, and the expected speed x accuracy trade-offs, each accrediting the general validity of our neuropsychological data, we did not observe any statistical improvement in neuropsychological test performance.

Low power due to the modest number of patients, high variability in individual neuropsychological test results, typical in brain damaged populations, and lack of sensitivity of the neuropsychological tests to the (type of) improvements, might account for the absence of statistical significances. Further, individual neuropsychological tests usually are short in time duration, while the driving tests typically lasted for one hour. It is generally accepted that “true function” can be more validly assessed over a longer period of time, as to minimise effects of coincidental fluctuations in performance. As a consequence, although obviously related, visuo-spatial driving performance and visuo-spatial neuropsychological performance do not share exactly the same functions and properties, and hence are not necessarily liable to the same influences.

Similarly, Webster and colleagues (Webster et al., 1984) concluded that their visual training did not improve (hemi-spatial) neuropsychological test performance, but did lessen the influence of the impairments on functional activities, leading to a similar suggestion, namely that both types of performances can be prone to different influences or differentially influenced by the same mechanisms. Conceptually clarifying this point, it can be argued that the visual rehabilitation program, due to its compensational nature, is likely to influence the driving performance and the neuropsychological test performance differently. Practical fitness to drive, as defined by our assessment and scoring procedure, is situated at the (activity-)performance level, as it is considered to be influenced by a combination of factors at the impairment level (HH and perhaps cognitive dysfunction) and by contextual (environmental and personal) factors. As a consequence, driving is relatively highly liable to influences of compensation (contextual factor). Neuropsychological tests aim at measuring (pure) cognitive functions, which are ideally indications of capacities (i.e., true abilities). In contrast to performances, capacities are (ideally) not liable to compensation and hence improvement. We therefore suggest that, although related, visual performance during driving and neuropsychological test performance are measures at conceptually different levels, and as a consequence are differently influences by our compensatory training.
5.2. Interrelations and predictability

The (patterns of) correlations, observed in this study, of the personal characteristics and the visual performance during driving (VIS scores) at pre-assessment, correspond well with observed correlations in a previous (larger) study (Tant et al., submitted). We observed worse VIS scores with increasing age and better VIS scores with increasing driving experience. Surprisingly, these relationships disappeared at post-assessment and a new relationship appeared, namely better VIS scores with shorter time since injury. Far from being obvious what causes this change of pattern from pre- to post-assessment, we suggest it to be related to the intervention in between, namely the rehabilitation program. The effects of the visual compensation somehow seem to weaken the influence of age and driving experience and strengthen the influence of time since injury.

As we previously conceptually suggested, we consider visual performance during driving (at pre-assessment) to be influenced by visual (i.e. HH) and probably by cognitive impairments (caused by the brain damage). In addition, in this pre-compensation state, performance is influenced by obvious personal characteristics, like age and driving experience. By participating in the visual rehabilitation program, an additional contextual factor is introduced, possibly blurring other influences (of age and driving experience in this case). On the other hand, the effects of visual compensation can also be conceived as a removal of (part of) the visual consequences of the visual impairment (i.e. HH), possibly revealing new influences. Both conceptualisations (addition of contextual factor and removal of influence of impairment) are directly inspired by ICF theorisation, which also suggests that the interpretations need not to be mutually exclusive. In the last interpretation and following ICF, visuo-spatial function would be more purely measured at post-assessment, as measurements are less distorted by negative effects of the visual impairment. We did find some indications for this suggestion in our results. Namely, we observed that the VIS factor could be predicted (as evidenced by the regression models) on the basis of the global (neuropsychological) component scores. This was our expectation, since it can be assumed that visuo-spatial function as measured during driving and as measured by neuropsychological tests, should be related. We observed that the prediction at post-assessment ($R^2 = .50$) seemed better than at pre-assessment ($R^2 = .44$). This confirms our suggestion, as we previously argued that at post-assessment neuropsychologically-assessed visuo-spatial function is more purely measured (less distorted by the visual impairment) than at pre-assessment, and it can be assumed that two more pure measures interrelate more strongly than when one is confounded. Additionally, and perhaps at first hand unobviously, as post-assessment neuropsychological performance gives a better indication of (“true”) visuo-spatial function than pre-assessment performance, visuo-spatial performance during driving at pre-assessment should at least equally well, or even more strongly, be related to neuropsychological performance at post-assessment than at pre-assessment (without the reverse being true). This pattern was observed in our data (VIS at pre-assessment by global factor scores at post-assessment: $R^2 = .54$ versus VIS at post-assessment by global factor scores at pre-assessment: $R^2 = .33$).

Clearly our results are suggestive for a change in visuo-spatial performance between both assessments. Although it can never be conclusively decided that this change is due to the visual rehabilitation program, the selective improvement in visuo-spatial performance during driving argues against a non-specific placebo-effect. But if the compensational effect is to be conceived as a relief of visual consequences of the visual impairment, it remains puzzling why it was not expressed in better visuo-spatial neuropsychological performance.
5.3. Prediction of improvement
Although visual performance during driving (VIS), before as well as after the rehabilitation program, could be predicted by visuo-spatial neuropsychological test performance, the improvement in VIS could not. Also, age, driving experience and time since lesion were related to, at least one of, the VIS measurements. None of them, however, were related to the improvement in VIS. Taken the limitations of the low number of patients in mind, these data suggest that all patients benefited equally from the intervention. This implies that this type of intervention can be applied for all patients but that the goals of rehabilitation should be dependent on the degree of limitation, so that modest goals are set for moderately limited patients and higher goals can be attempted for less limited patients.

5.4. Implications and conclusions
The transfer of treatment-related gains, as this is one of the major aims of cognitive rehabilitation (Levin, 1990) has been evaluated scarcely (Kerkhoff, 1999). Transfer to non-treatment related (visuo-spatially dependent) activities has previously been reported. Kerkhoff (1999) summarised the improvements of compensational scanning training as better identification and location of objects in the blind hemifield, reduction of errors in visual search, increase in search speed, and subjective improvements of visual functions as measured by a questionnaire. Additionally, also transfer of treatment related gains to daily life has been reported. Kerkhoff et al. (1994) showed significant improvements on a Table Test (finding objects on a table) and Webster et al. (1984) showed significant improvements on wheelchair obstacle-course performance. The improvements we observed, i.e. in visual performance during driving, can be classified as (part of) a socially important daily life activity. However, whether this improvement can be classified as transfer to a non-treatment related activity is debatable, since driving lessons were a part of the visual rehabilitation program, but the test-ride itself was never exercised. This does not devaluate the suggested positive effects of the rehabilitation program, since the ultimate aim of the program was to reduce visuo-spatial limitations and restrictions, where finally activities of daily living (rather than pure neuropsychological task performance) are the norm.

In conclusion, our results are in concordance with previously made claims. Firstly, visual performance during driving, an important aspect of the driving task, can be related to visuo-spatial neuropsychological test performance. Secondly, patients with HH can be fit to drive, since not all of our patients failed the driving test. Furthermore, since visuo-spatial disability, common and apparent in these patients and consequential for practical fitness to drive, can be positively influenced by our visual rehabilitation program, continuation of (improvement of) rehabilitation efforts for HH is justified and highly desired.
Although visual performance during driving significantly improved, driving performance did not meet the standard for passing the driving test for each patient, nor did we find any clear evidence of substantial improvement in neuropsychological test performance. As indicated by our patients, more rehabilitation time and perhaps also more attention to aspects other than pure visuo-spatial function, should be incorporated, as to reduce even more visual limitations and restrictions. Alternatively, in contrast to a collective rehabilitation aim, the goal could be tuned to the degree of limitation of the patient.
Finally, to validate the exact therapeutic effects of the visual rehabilitation program, a randomised controlled trial with HH patients who are not trained is needed, but whether this is an ethically defendable option, is however debatable.

6. Reference List


