

## General summary

This dissertation concentrates on visual performance in patients with homonymous hemianopia (HH). Homonymous hemianopia indicates blindness for half the field of vision, in both eyes to approximately the same extent and for the same hemifield (either left or right). This visual field defect is caused by post-chiasmal brain damage. We studied visuo-spatial performance in neuropsychological tests and during driving in HH.

### 1. Part I: Introduction and methods

In *Part I: Introduction and aim of the project* we introduce the general questions and aims of the dissertation. We indicate that both practical and theoretical objectives can be formulated. On the one hand, valuable clinical application of the findings can be in the form of giving patients and caretakers realistic advice, and formulating and improving rehabilitation methods. On the other hand, theoretical interest is in testing predictions of (opportunities for) visual compensation in the driving task by visuo-spatial neuropsychological test performance. Several aspects of driving can be studied, for example accident rates. We focussed on fitness to drive. Fitness to drive is a medico-legal term indicating a prerequisite for holding a drivers' license. In Europe, the requirement with regard to horizontal field size is 120° or more. By this standard, patients with HH, in whom the visual field size is approximately 90°, are excluded from driving. As we live in a motorised society, the social and economic restrictions following being declared unfit to drive, are not to be underestimated. In the Netherlands, however, the regulations allow an assessment procedure on the road in the case of visual field extent (somewhat) below the norm. During this procedure the opportunity is offered to the clients to actually demonstrate their ability to drive fluently and safely in spite of visual impairment. The aspects of driving assessed as such, are referred to as practical fitness to drive.

The aforementioned and other crucial concepts, at the basis of this dissertation, are introduced in *Part I: Terms and concepts*. The description of visual and cognitive functions, their determining factors, the classification of the various tests which we use, and the qualifying terms, can be approached from various points of view. We adopt the new conceptual framework offered by the World Health Organisation (WHO), namely the International Classification of Functioning, Disability and Health (ICF). In ICF, human functioning is viewed as the outcome of an interaction of a person's physical or mental condition and the social and physical environment. We introduce this conceptual framework and explain how it associates to our research. We suggest that the outcomes of the visuo-spatial neuropsychological tests used are at the activity level rather than the impairment level and are to be qualified as performance rather than capacity. We discuss the consequences of these and other suggestions. We suggest for example that, in our patient population, neuropsychological tests with substantial visual components, no longer exclusively assess the functions they were originally devised for. We therefore question whether standard norms and interpretation can be maintained. To conclude we situate the concept of practical fitness to drive in this framework. The fitness or unfitness to drive is, in our study, a decision based on the results on a practical test-ride which attributes special emphasis on visual function and related visual limitations and compensations. The test-ride is hence situated on the activity level, as it is an assessment of actual driving ability presented by the client. Unfitness to drive is therefore conceptually an activity limitation. In contrast, medical fitness to drive is a decision based on

medical information (for example visual acuity or visual field extent), not on actual driving performance. Both practical and medical fitness to drive (can) lead to a participation restriction, i.e. not being allowed to drive. We point out that the restriction based on medical unfitness to drive bypasses the activity level in the framework. We suggest that fitness-to-drive decisions should (and can be in the Netherlands) be based on the outcome of a practical test-ride (activity level), because the resulting restrictions (if any) are then evidence based, namely on driving limitations. This is ethically and socially more acceptable.

Factors which can cause restrictions and limitations related to driving are discussed in *Part I: Driving-related Research*. Here it is explained why and how it can be expected that neuropsychological test performance can be related to driving(-related) performance. As visual information processing takes up a large part in the driving task, a detailed assessment of this processing is essential to understand and predict practical fitness to drive. In visual information processing, both lower- (i.e. sensory) and higher-order (i.e. cognitive) aspects are to be considered. 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. From the reviewed literature it appears that HH by itself, does not necessarily lead to (hemi-spatial) limitation, or to practical unfitness to drive. Therefore, in addition to detailed and specific ophthalmological assessment, also higher-order visual functions, measured by neuropsychological tests, should receive considerable attention as to meaningfully and successfully relate visual functioning to practical fitness to drive. We explain why and, more specifically, which (class of) tests should be included in our test battery. We suggest that selectivity in test choice and selectivity in patient population are of considerable importance and consequently further restrict our focus to visual hemi-spatial impairment in patients with expected visuo-spatial limitation. The observed interrelationships can be used for prediction and evaluation, but could additionally guide the therapist as to which components, skills or functions need specific attention in rehabilitation and assist in understanding why a client is (currently) unfit to drive, and perhaps what is the prognosis for future evaluation and improvement.

A test battery which could serve our purpose is presented in *Part I: A Visuo-spatial test battery*. In our aim to specifically and fully assess visuo-spatial functioning, we chose for a number of different assessments. We classified our range of tests, on an a priori basis, into four factors, namely basic visual scanning and search (BVSS), visuo-constructive and organisational tasks (VCO), visuo-integrative tasks (VI) and a task with a dynamic component (Dy). These tasks were evaluated in terms of speed and accuracy. Additionally, since we are more specifically interested in visual hemi-spatial impairment and limitation, we determined (when possible) a lateralisation score computed as an asymmetry index (AI). The AI expresses a lateralised perceptual bias, measured by the degree of differential lateralised performance, independently from general performance. This AI, combined with general performance, can help to distinguish between a hemi-spatial (and thus lateralised) impairment and a more general spatial, attentional or scanning deficit. We adopted a similar approach in scoring driving performance during the test-ride. A structured protocol was used with predetermined observational items. Those items were on a priori basis assigned to factors representing different aspects of the driving task. Given our specific interest, we specifically focussed upon visual performance during driving, reflected in the visual factor.

## 2. Part II: The project

In part I, we presented the general aim and questions of the project and the tools to accommodate them. The second part of the manuscript reflects the general structure of the project, starting with a pre-assessment, followed by an intervention which is subsequently re-assessed (post-assessment).

In *Part II: Driving and Visuo-spatial Test performance in Homonymous Hemianopia*, 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 found that 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. Four of the 28 patients passed the driving test. We concluded that this confirms that HH cannot be an absolute contra-indication for practical fitness to drive and justifies our current investment of effort in studying and hopefully future investment of improving fitness to drive in HH. With respect to the second issue, we found that visual performance during driving was significantly related to visuo-spatial neuropsychological 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 neuropsychological factors explained a considerable part of the variance (77%) in visual performance during driving.

The observed modest visual performance, and the subjective complaints and restrictions reported and experienced by the patients suggest the need for (research on) specific rehabilitation. In *Part II: Visual rehabilitation in Homonymous Hemianopia and related disorders* we focussed on the rehabilitation of visual field defects in general and of HH in particular. We also briefly referred to visual rehabilitation in hemi-neglect and other related disorders. After briefly discussing spontaneous recovery, only apparent to some extent and in the vast minority of patients, we introduced three types of rehabilitation techniques, namely restitution, adaptation and compensation. Restoration means (partially) restoring or enlarging the lost visual field. We concluded that this approach is very time consuming and only applicable in the minority of patients. The small size and location of the restored visual function questions its practical relevance. The second technique we discussed was adaptation using auxiliary optical devices. We specifically focussed on the use of prisms because this approach is currently popular in the US and preliminary evaluations are promising. The third, and by us adopted approach is the compensatory technique. The compensatory techniques originate from the plausible assumption that most complaints, limitations and restrictions are the result of a lack of a quick and full overview of the available visual space. This lack is a consequence of viewing behaviour which is not adapted to the visual field defect. In hemianopic patients it is characterised by small-amplitude ‘staircase’ saccades towards the blind hemifield and frequent repetitions of the scan paths during visual search and inspection. With our “Integrated Saccadic Compensation Training Program” we aimed at combining positive aspects from several approaches as to facilitate the learning of an optimal compensatory viewing strategy, which is integrated in a personal scanning style, and applicable in all daily life situations. Our training consists of three consecutive phases. 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. To enhance transfer, in the second phase, the eye movement principles are applied in several tasks requiring efficient scanning behaviour. In the third and final phase, the newly learned visual style is practised during car driving, again to promote transfer.

*In part II: Prediction and Evaluation of Driving and Visuo-Spatial Performance in Homonymous Hemianopia after Compensational Training* our intervention is evaluated. Seventeen HH patients, taking part in our training program, were again subjected to our visuo-spatial neuropsychological test battery and the driving test. We compared and interrelated visuo-spatial performance in driving and in neuropsychological tests, before and after the training. The results were in concordance with previously made claims. Firstly, visual performance during driving, an important aspect of the driving task, was 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. 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. The specificity of the improvement argues against a non-specific placebo effect. As indicated by our patients, more rehabilitation time and perhaps also more attention to aspects other than pure visuo-spatial function, should be incorporated in the rehabilitation program, as to reduce even more visual limitations and restrictions. Alternatively, in contrast to a collective rehabilitation aim, the rehabilitation goal could be tuned to the degree of limitation of the patient. We concluded that visuo-spatial disability, common and apparent in HH patients and consequential for practical fitness to drive, can be positively influenced by our visual rehabilitation program, and that continuation of (improvement of) rehabilitation efforts for HH is justified and highly desired. However, to validate the exact therapeutic effects, a randomised controlled trial with HH patients who are not trained is needed, but we questioned the ethical aspect of this option.

### **3. Part III: Additional findings in patients with HH and related impairments**

We employ two tests from the visuo-spatial battery to draw some more fundamental conclusions, namely on the relationship of lower- and higher-order visual impairment and the effects the former can have on the latter.

*In Part III: Grey Scales uncover similar attentional effects in homonymous hemianopia and visual hemi-neglect* we discuss the Grey Scales task. This task has been developed to quantify the early, automatic, (perhaps obligatory) ipsilesional orienting of visual attention, frequently assumed as the first component of the attentional deficits in visual hemi-neglect. This lateral attentional bias has been demonstrated in controls, in whom it is expressed as a leftward perceptual asymmetry and in neglect patients, expressed as an extreme rightward bias. Explanations for this attentional imbalance were up until now mainly formulated in terms of right hemisphere activation. We reproduced previous literature findings, considering controls and neglect patients. Additionally, we presented this Grey Scale task to 32 patients with left- and right-sided HH who had no clinical signs of impaired lateralised attention. Results revealed that HH patients showed an ipsilesional bias, albeit to a lesser degree than in neglect. Left-sided HH patients presented a quantitatively similar, but qualitatively opposite bias than the right-sided HH patients. We concluded that sensory effects can be an alternative source of attentional imbalance, which can interact with the previously proposed (right) hemispheric effects. This suggests that the perceptual asymmetry is not necessarily an indicator of

impaired right hemisphere attention. It rather suggests a pattern of functional cerebral asymmetry, which can also be caused by asymmetric sensory input and hence illustrates our point that a lower-order visual impairment can give rise to an apparently higher-order effect.

A similar conclusion was drawn in *Part III: Hemianopic Visual Field Defects elicit Hemianopic Scanning*. Previous explanations for the defective hemianopic scanning behaviour and for the variability in success of compensating for HH had been in terms of extent of the brain injury. We investigated whether brain injury is necessary to elicit these limitations or whether merely a visual field defect would be sufficient. We therefore simulated HH in 16 healthy subjects without brain damage by using on-line eye movement registrations and compared their scanning performance, on a dot counting task, to their own “normal” condition and to real HH patients’ performance. We evidenced clear parallels between simulated and real HH, suggesting that hemianopic scanning behaviour largely is visually elicited, namely by the visual field defect, and not by the brain damage. We concluded that most typical HH oculomotor dysfunctions, as for example ipsilateral hypometric saccades, do not result from the brain damage but are visually elicited and that complaints as for example slowness of vision and prolongation of scanpaths, can no longer be merely associated to brain damage. We further observed age-related processes in compensating for the HH, namely worse compensation to the created visual impairment with higher age and, at first sight paradoxically, that the visually elicited limitations can be most pronounced during (seemingly) the simpler situations. We further concluded that at least for some HH patients, more emphasis can be devoted to visual than to cognitive components in rehabilitation and that diagnosing higher-order visuo-spatial impairment can only occur in the light of concomitant lower-order visual impairment.

In preparing the HH project and devising the “Integrated Saccadic Compensation Training Program”, we evaluated by means of a case study, an Italian neglect rehabilitation program. The modifications to the original program and its evaluation is described in *Part III: Evaluation of the effectiveness of a hemi-neglect rehabilitation program and generalization to driving: a case study*. We evaluated by means of traditional and clinical neglect tasks, complemented by a dynamic tracking task (a basic driving simulator) and by a test-ride in an advanced driving simulator. After the program, we observed strong improvements on the clinical (non-trained) neglect tasks. By that performance, the patient would no longer be diagnosed with the neglect-syndrome. However, in the tracking task and the more ecologically valid driving simulator, we still observed unacceptable lateral positions on the road and unsteadiness in steering in spite of acceptable visual exploration. We concluded that this training can help to compensate for the scanning deficit, most pronounced in clinical tasks. But since some aspects of real life tasks do not change even after this intensive training, we have no evidence of functional improvement of neglect. We concluded that not every visually related aspect of activities of daily life can easily be compensated for.

Finally, we notify a problem in measuring and evaluating visual field defects (perimetry) in *Part III: Quadrantopia can shift to Hemianopia with shift of task-demands*. We found that the form and extent of the visual field defect in a patient who had suffered brain damage, was strongly dependent on the perimetric procedure used. When perimetry is determinative for holding or withdrawing drivers’ licences, this suggests that the procedure needs to be

explicitly and unambiguously specified as the outcome and therefore the conclusions can substantially differ.

#### **4. Appendix: An analytic exercise**

In *Assessing visual search in the AFOV test (appendix)* we discuss how the AFOV (Attended Field Of View) test can be used to assess and express the efficiency of visual search. We define an efficient search strategy as a strategy which allows the subject to respond to targets in a fast and evenly distributed manner. Hence, the test should provide a measure of general search time as well as a measure of distribution. The mean threshold presentation time is calculated as an estimate of general search time. We further present a measure expressing the ‘flatness’ and a measure expressing the ‘asymmetry’ of the distribution across the search field. We suggest that both measures in combination with the mean threshold presentation time give an adequate description of the efficiency of visual search in the AFOV test. By considering these three parameters, typical visual search patterns associated with specific visual field impairments can be differentiated.