Part I: Introduction and Methods
Part I: Introduction and Aim

Introduction and Aim of the project

1. General: Fitness to drive and Homonymous Hemianopia

This dissertation concentrates on fitness to drive in persons with a homonymous hemianopic visual field defect. Homonymous hemianopia (HH) denotes the loss of one hemi-field and is caused by post-chiasmal brain damage, usually following stroke. Fitness to drive is a medico-legal term indicating a prerequisite for holding a drivers license. It is defined in terms of minimal functional requirements described in legal regulations. In almost any country, the requirements for visual function are defined in terms of static visual acuity and horizontal visual field size. The standard in Europe with regard to horizontal field size is 120 degrees or more. By this requirement, patients with HH, in whom the visual field size is approximately 90 degrees, are excluded from driving. As we live in a motorised society, the social and economic restrictions following being declared unfit to drive, should not be underestimated.

2. Fitness to drive: requirements and characteristics

The origin of the requirements is historic and has never been put to empirical test. In fact, the evidence supporting their validity is rather weak. The question is whether these standards should not be subjected to rigorous investigation and perhaps revision. Because of the legal character of the requirements, such research is often precluded. In the Netherlands, however, the regulations allow an assessment procedure on the road in the case of (mild) cognitive impairment. Similar opportunities are created in the case of visual field extent (somewhat) below the norm. During this procedure the opportunity is offered to actually demonstrate that the subject is able 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. This original approach is based on theoretical and pragmatic evidence that driving allows for a great deal of compensation for limitations. This may involve compensatory strategies on the tactical and strategical level. Tactical adaptations could be anticipatory adjustments of speed and of the average following distance, providing time for compensatory eye-movements. Strategical adaptation could be choosing route and time for trips in which driving is not very time-pressured. In terms of the World Health Organisation’s (WHO) International Classification of Functioning, Disability and Health (ICF), formerly International Classification of Impairments, Disabilities and Handicaps (ICIDH), practical fitness to drive is defined on the activity (formerly disability) level, and is evaluated accordingly. It is thus recognised that fitness to drive is as closely related to learned driving skills and compensatory behaviours as to medical status. This is in contrast to the traditional medical concept of fitness to drive, which is only related to impairments.

3. Homonymous Hemianopia

Homonymous hemianopia (HH) is a frequent consequence of post-chiasmal stroke, estimated to strike some 48% of survivors. In comparison to this relatively high prevalence, only few HH patients have made use of the opportunity to have their practical fitness to drive assessed. As is shown in the files of the licensing authorities, of those HH patients who were actually assessed, a substantial percentage was declared fit to drive. However, this may have been atypical sample. At present, it is not at all clear what are the characteristics of those who do and those who do not pass the assessment of practical fitness to drive. Further, it is not clear

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1 In the course of realisation of this dissertation, WHO terminology changed from ICIDH to ICF.
which features determine, if and to what extent a HH patient could profit from driving oriented rehabilitation or visual aids, if a patient initially fails the driving assessment.

4. Goals
An important aim of this study is to provide more insight into these questions about individual characteristics, making use of standardised assessments and rehabilitation applied in a representative sample of HH patients. Based both on literature and on clinical experience, these characteristics are primarily sought in terms of neuropsychological test performance in the cognitive and visuo-perceptual and visuo-spatial domain. Having a better knowledge about the role of these individual characteristics is important both clinically and theoretically. Valuable clinical application can be in the form of giving patients and caretakers realistic advice, and improving rehabilitation methods. The theoretical interest lies in testing predictions of opportunities for compensation in the driving task as derived from cognitive psychological driver models. Besides its direct clinical and theoretical importance, the project may have policy implications for regulations with regard to fitness to drive, as implied above.
1. General
Throughout this dissertation a variety of terminology is used. Especially, as in this dissertation, when research is done interdisciplinary, a priori clarification and definition of the key-terms is highly recommendable. We will use the terms consistently as we are about to describe them. The description of visual and cognitive functions, their determining factors, the classification of tests which assess them, 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\(^1\)), formerly International Classification of Impairments, Disabilities and Handicaps (ICIDH). The ICF classification provides a unified and standard language and framework for understanding, studying, and describing health and health-related states in a bio-psycho-social model that emphasis the universal nature of disablement. ICF classifies functioning and is essentially an aetiology neutral classification. In this respect, it supplements the International Classification of Diseases, Tenth Edition (ICD-10) which provides an etiological framework. In ICF, human functioning is viewed as the outcome of an interaction between a person’s physical or mental condition and the social and physical environment. We will use this conceptual framework for its terminology and will also classify and situate our procedures in it, although ICF is not primarily intended for this at present. The framework, and how it in our view associates to our research, is summarised in Table 1.

2. ICF applied to the current research
2.1. General structure and terms
2.1.1. Functioning and Disability
ICF organises information in two parts, namely in Functioning and Disability, and Contextual Factors. Functioning and Disability has two components, namely one component concerning the body (in a broad sense) and one component concerning aspects of action, termed activities and participation. The body component comprises two domains, namely for functions of body systems and for the body structures. It is important to note that the “body” refers to the human organism as a whole and hence also includes the brain and its psychological or cognitive functions in addition to, for example, sensory functions. Cognitive (neuro)psychologists have the inclination to stress the conceptual differentiation of “body” and “mind” and parallel the distinction with “hardware” and “software”. Inapparently for them, in ICF both terms are at the body-level, the former referring to “structure”, the latter to “mental function”. ICF lists a total of 873 body items. We will use the term “cognitive” or “higher-order” function for what in the classification is referred to as mental function. The cognitive functions, most relevant to our research are orientation in place (b1141), attention (b140), and perception (b156). From the latter (perceptual functions), we will specifically address visual perception (b1561) and visuo-spatial perception (b1565). In addition to mental function, also sensory function is included in ICF, for which we will use the terms “sensory” or “lower-order” function. In this dissertation, visual sensory or lower-order functions (b210) will be focussed upon, more specifically functions of the visual field (b2101), which include scotomas and (hemi-)anopias.

\(^1\) The version we used is the ICIDH-2 Final Draft but has been approved by the WHO’s governing bodies and will be referred to as ICF. This document and further information can be found on the Internet at: http://www3.who.int/icf/icftemplate.cfm
Also qualitative functions involving light sensitivity, colour vision, contrast sensitivity and overall picture quality (b2102) can be relevant. Other functions of the body, addressed in this dissertation, are reflexive (b750) and voluntary (b760) control of movements. Applied to visual-compensational topics, we will discuss movements of the eye and head.

In addition to the functional aspects of the body, the ICF also addresses structural aspects. Body structures are anatomical parts of the body and include i.a. different structures of the brain (s110).

In ICF, changes in body function and body structure are considered to have physiological and anatomical causation respectively. In both domains, a negative change is termed an impairment, which can either be an anomaly, defect, lack, loss or reduction, addition or excess, or a significant deviation in body structure or in (lower- or higher-order) function. Hence, visual field defects, defective attentional and visuo-spatial function, and brain damage are referred to as impairments.

The second component in the Function and Disability-part, concerns action and is captured by the Activities and Participation-label. In a sense, all behaviour displayed by the subject in question resorts under this label. ICF defines activity as the execution of a task or action by an individual, for example an experimental test or reading and writing, or driving a car. Participation entails involvement in a life situation, for example social contact by being mobile, participation in community activities, obtaining a driving license. ICF provides a classification of 617 activities and 106 participations, unified as life areas. The listed categories of life areas, most applicable for our research, are purposeful visual sensory experience (namely watching, d115), basic learning (namely acquiring skills, d155), applying knowledge (namely focussing attention, d160), communicating with -receiving- visual stimuli (namely comprehending the meaning represented by signs, symbols, drawings, photographs etc., d315), and moving around using transportation (namely driving, d475). Conceptually, whether a category is considered an activity or a participation depends on the adopted theoretical framework.

Activity limitations (henceforth limitations) are difficulties an individual may have in executing tasks (formerly disabilities in ICIDH). Activities can be limited in nature, duration, and quality. Participation restrictions (henceforth restrictions) are problems an individual may experience in involvement in life situations (formerly handicaps in ICIDH). Participation may be restricted in nature, duration and quality. In ICF, functioning is an umbrella term for the positive aspects referring to body functions and structures, activities and participations. Similarly, disability refers to impairments, limitations and restrictions. In this dissertation, lower-order functioning, refers to sensory (body) functioning. Lower-order impairment refers to sensory impairment. Homonymous hemianopia (HH), a key-concept in this dissertation, is a lower-order sensory impairment. Higher-order functioning, in this dissertation, refers to cognitive or brain-related (in ICF termed “mental”) functioning. Higher-order impairment is formulated likewise. Agnosia and dyslexia are (neuropsychological) examples of higher-order impairment. Hemi-spatial neglect and visuo-spatial impairment are other examples and key-concepts in this dissertation.

Although ICF is basically not a classification of procedures, different types of tests can be situated in the framework. For example, it can be argued that a driving test is an assessment of
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an activity, whereas measuring intensity of social contact is at the participation level. In the present dissertation, most tests used are at the activity level. Activity is defined as the nature and extent of functioning at the level of the person and intrinsically implies human behaviour. However, we are in the opinion that a full description of human functioning should not only be composed of functioning at the level of the person, but also at the level of the body. The latter tests typically have a minimal (or non-)behavioural dependence and are at present not incorporated in ICF. These tests which reveal direct information about body function and structure are measures of impairments (in contrast to activities). CT-scans, for example, are applicable in ICF classification, as they can reveal structural changes in body aspects. Similarly, measurement of visual evoked potentials have (ideally) a minimal behavioural component, but can reveal brain-related impairment. Ideally, the same can be argued for perimetric tests, which reveal functional body aspects (i.e. visual field function). Consideration of this type of test outcome complements, in our opinion, significantly to the completeness of describing human functioning and disability. We would like to stress that, by definition, tests at the impairment level are not prone to the same influences as tests at the activity level. The latter are considered to be the product of a complex bio-psycho-social interaction, whereas the former are mere registrations of impairments, and are hence (ideally) not influenced by such interactions.

As a consequence and for the benefit of the completeness of describing functioning and disability, we performed some additions to the existing ICF framework (see grey areas in Table 1). We added a new column in the “Body” component hosting the non-behaviourally-dependent type of tests i.e. tests at the impairment level. We combined this cell with the “Activity and Participation” component. The combination is termed “outcome” which is a neutral term indicating test result but not implying active behaviour. The position of the new cell expresses the close relationship with (only) the body and the (relative) unproneness to contextual influences (distinct from activities and participation).

The above mentioned life areas (i.e. both activities and participations) are qualified by the two qualifiers of performance and capacity (note the linkage and orthogonal orientation in Fig. 1). The performance describes an individual executing a task or an action in his or her current context or situation, which includes all personal and environmental factors (to be discussed further). The capacity qualifier describes an individual’s ability to execute a task or an action and indicates the highest probable level of functioning that a person may reach in a given domain at a given moment. Hence, capacity reflects the environmentally adjusted ability of the individual, as a full ability is to be assessed in a uniform and standard context. Performance and capacity will appear to provide a crucial conceptual difference in this dissertation. Namely, we will (later) argue, based on cognitive-neuropsychological theorisation, that, in the HH population, neuropsychological tests are measures of performance, in spite of that they frequently are considered to be capacity assessments and even ideally assessments at the impairment level.

2.1.2. Contextual factors
As previously mentioned, ICF organises information into two parts (left and right parts in Table 1). We discussed the first part above, namely functioning and disability. The second part comprises the Contextual Factors, including two components, namely Environmental Factors and Personal Factors. The contextual factors interact with (i.e. influence) the constructs from functioning and disability, as for example “light” (environment) interacts with
"seeing" (body function), or the law on (obtaining and denying) drivers’ licences interacts with social contact.

The personal factors are not currently classified in ICF, but comprise internal influences and characteristics of the subject like age, gender, race, coping style, fitness, lifestyle, habits, character style, social status and background, education, individual psychological assets, overall behaviour pattern etc. They comprise the particular background of an individual’s life and living. Another example of a personal factor, and key-concept in this dissertation, is the personal scanning style or viewing method and strategy. An adapted scanning style determines if and how a patient with HH visually compensates for the visual impairment, and hence influences how the effects of the visual field defect translate to limitations and restrictions. Positive and negative aspects are not discussed in ICF, but we introduce the same terms as for the environmental factors (namely facilitators and barriers respectively). Examples of the former are driving experience for driving performance, and for the latter, misconception of the visual impairment resulting in non-effective or deleterious head-movements hindering effective compensation by eye-movements.

The environmental factors make up the physical, social and attitudinal environment in which people live and conduct their lives and can be facilitators (positive aspect) or a barriers (negative aspect). ICF provides classifications of which the following are most relevant for our research. Firstly, there are the assistive products and technologies, defined as any product, instrument, equipment or technical system, especially produced or generally available, preventing, compensating, monitoring, relieving or neutralising disability. Specific applications are the adaptations to indoor and outdoor mobility transportation means (e1201), but also specifically designed products, such as specialised vision devices (glasses, lenses, prisms, e1551) are important environmental factors. Another class of environmental factors are attitudes, namely observable consequences of customs, practices, ideologies, values, norms, factual beliefs and religious beliefs. These attitudes influence individual behaviour and social life at all levels. The attitudes classified are those of people external to the person whose situation is being described, and are hence not those of the person themselves. Relevant to our research are the individual attitudes of people in positions of authority (e430). Also part of the environment are the services, systems and policies. Services are the provision of benefits, structured programmes and operations, in order to meet the needs of individuals. Systems are administrative control and monitoring mechanisms. Policies are the established rules, regulations and standards, which govern or regulate the systems that control services, programmes and other infrastructural activities. Relevant to our research are the health services, system and policies (e580). These are services and programmes aimed at delivering interventions to individuals for their physical, psychological and social well-being, such as primary care services, acute care, rehabilitation and long-term care services. In addition, specifically in relation to driving, the legal services, systems and policies (e545) will be mentioned, since in most countries HH precludes legal driving.

2.2. Interactions and further examples
A person's functioning and disability is conceived as a dynamic interaction between health conditions (diseases, disorders, injuries, traumas, etc.) and contextual factors. Contextual factors include both personal and environmental factors. There is a dynamic interaction among all entities: interventions in one entity have the potential to modify one or more of the other entities. The interactions are specific, complex and can be bi-directional. We summarise the most obvious relationships applied to the current research (see Fig. 1).
Impairments in body functions are usually linked to impairments in body structures, as for example a homonymous visual field defect is caused by unilateral post-chiasmal brain damage. The impairment can have consequences for activities and hence may lead to limitations. For example a visual field defect may result in a scanning deficit (assessed by a visual scanning task) or problems with reading (assessed with a reading test). Impairment does not necessarily lead to limitation, as for example specially designed lenses, or a successful rehabilitation program (i.e. contextual factors) may help to compensate sufficiently for the impairment and limitation imposed by it. Limitation may lead to restriction, i.e. when the consequences are also discernible in life situations, as for example a reading limitation may result in not reading the newspaper any more and hence being deprived from some type of information leading to ignorance. However, also restrictions can be apparent without accompanying (or eliciting) limitations. They can directly result from impairments in combination with contextual factors (i.e. barriers). For example, patients with HH may be declared unfit to drive by law (and hence do not drive any more and are thereby deprived from some types of social events), despite sufficient capacity to drive fluently and safely.
Similarly, a limitation does not necessarily lead to a restriction, as contextual factors (i.e. facilitators) can reduce the influence of an impairment on real-life situations. For example, specific adaptations to entrances of public buildings can make it perfectly possible for a hemiplegic patient not to be deprived from cultural and social happenings.

Whether an activity or participation is qualified as capacity (environmentally adjusted) or performance (executing tasks under influence of current personal context), depends on its determination by contextual factors. Conceptually, if test result is dependent on environmental and/or personal factors, then by definition performance is observed, in contrast to capacity, which is context-free.

Further, as previously argued, if outcome is at the impairment level and hence minimally behaviourally-related (as e.g. CT scans, perimetric tests), it is also considered to be context-free, defining impairment assessments as measures of capacity. In ICF, it is stated that both capacity and performance qualifiers can be used with and without assistive devices and personal assistance. This seems paradoxical, as assistive devices, in ICF, are environmental factors, and as such are by definition incompatible with the notion of capacity. But when assistive devices (and personal assistance) do not act upon the function at hand or are considered to be part of the uniform and standard environment, then the paradox is resolved. For example, when dyslexia (reading function) is assessed, subjects can wear their corrective lenses or spectacles, such that reading is not complicated by blurry letters. Obviously, corrective lenses or spectacles do not fundamentally distort the reading function. Optimal optical correction is considered to be part of the uniform and standard environment. On the other hand, whispering the words to-be-read to the (dyslexic) subject, would fundamentally act upon the reading function at hand. Consequently the reading outcome would obviously not be considered to reflect reading capacity.

2.3. Neuropsychological tests
Fundamental to this dissertation are the higher-order visual functions which are assessed. The majority of the neuropsychological tests used, aim at assessing visual attention and visuospatial function and hence pretend to be measures at the impairment level. In table 1 they are referred to as “ideal” neuropsychological tests. However, we would like to argue that in our patient group their outcome should be conceptualised at the level of activity (“actual” neuropsychological tests). For this it is crucial to (re)appreciate a fundamental issue in interpreting neuropsychological test results, namely never to conclude to a higher-order impairment, if influences at another or lower level have not been excluded. Applied to our HH patient population, it could be argued that for any test, in which visual information is of substantial importance, its outcome is determined by the lower-order impairment (i.e. the visual field defect) and by contextual factors (e.g. non-adapted scanning style). Hence, the outcome which is observed is at the activity level and is further to be qualified as performance rather than capacity. These considerations are not without consequences. Firstly, it could be questioned whether the standard norms for visually based tests can validly be used in our patient group, as we argue that the tests could be considered assessments at different levels (ideal versus actual neuropsychological tests; impairment versus activity).

Secondly, interpretation of neuropsychological test at the performance level is not a standard enterprise. The effects of a visual impairment on performance will be negative, whereas the contextual effects can go either way. Contextual factors can facilitate, for example having participated in a visual rehabilitation program which allows patients to effectively compensate for the visual impairment. On the other hand, absence of (immediate) care could result in
depressive states or improper and ineffective compensational efforts, hence forming a barrier. Since the performance is effected by several factors which each can be positive or negative, conclusions about the function (which was the primary reason for applying the neuropsychological test) become extremely complicated and opaque.

Thirdly and on the basis of the above, it can be questioned whether indications of true capacity can still be obtained in our patients using visually based tests. Even if so, it can be argued that this is not “normal” capacity but rather “hemianopic” capacity. Namely, maximal performance (i.e. capacity) can only be obtained when fully and perfectly compensating for the visual impairment. Hence behaviour displayed by non-or suboptimally compensating HH patients are always indications of performance. Performance can be improved for example after visual cognitive rehabilitation and at this stage would approximate (more) the level of capacity (shift in status). As a consequence of this shift in status, comparison of visual neuropsychological test results by HH patients before and after a (successful) visual rehabilitation program might be considered conceptually problematic.

2.4. Fitness to Drive
Traditionally fitness to drive is defined in medico-legal terms. The visual (body) functions, which are used to decide on whether someone is fit to drive, are of a lower-order nature, namely visual acuity and horizontal visual field extent. Not acquiring the norm results automatically in being declared (legally) unfit to drive. Note that we use, in this respect, the term “declaration”, which suggests the involvement of authority rather than outcome of test results in the decision process. Using ICF terminology and conceptualisation, an interaction of lower-order impairment (medico) and environmental factors (legal) results in a participation restriction, namely being refused to drive a car or obtaining a driving license and hence being deprived from this popular and socially important type of mobility. Further note that this is an example of the presence of a participation restriction, without touching upon the activity construct. Typically a restrictions (e.g. not driving a car anymore) is jointly caused by a limitation (e.g. not being able to drive a car). Medico-legal unfitness to drive restricts driving without personal evidence-based limitation information. It is uniquely associated with (lower-order) impairment and is hence likewise conceptualised in ICF terminology.

In the Netherlands, a different conceptualisation of fitness to drive is used, namely practical fitness to drive, as opposed to medical fitness to drive. Practical fitness to drive is situated at the activity-performance level, and is hence assessed accordingly, namely by a practical driving test. We would like to stress that we consider fitness to drive to be related to activity and to be contextually influenced, qualifying it as performance.

Practical fitness to drive is assessed by an on-the-road driving test (activity). Driving performance is thereby evaluated, attributing special emphasis on visual function, and related or to-be expected (visual) limitations. When fitness to drive is evaluated, it is recognised that both lower- and higher-order impairments (e.g. visual field defects and visuo-spatial impairment respectively) and contextual factors (e.g. driving experience, visual compensation, personality characteristics, etc.) can be crucial determining elements. Patients with HH, considered medico-legally unfit to drive, may prove to be practically fit to drive by adequately performing the test-ride. They can do so by effectively compensating for the visual impairment for example after visual rehabilitation, spontaneous adaptation, or using assistive devices. We suggest that the outcome of such a test-ride should (and can be in the Netherlands) be the basis for fitness-to-drive decisions because the resulting restrictions (if any) are then evidence based, which is ethically and socially more acceptable.
In this chapter it is explained why it can be expected that neuropsychological test performance in the domain of higher-order visual functions is related to practical fitness to drive. It will be argued that visual information-processing takes up a large part in the driving task. This visual information processing can be influenced by both lower- and higher-order visual impairment (dysfunction) and should be assessed accordingly. It will be explained why and, more specifically, which class of tests of visual function should be included in a battery used to understand and predict practical fitness to drive. We will plead that selectivity in test choice and selectivity in patient population are of considerable importance in this line of research. Since our particular interest in visual hemi-spatial impairment, we will therefore focus on patients with homonymous hemianopia (HH) and related hemi-spatial disability. We will argue that only detailed and specific ophthalmological and neuropsychological tests can meaningfully and successfully be related to practical fitness to drive. This conduct is imposed by the conclusion that HH by itself, does not necessarily lead to hemi-spatial limitation, or to practical unfitness to drive. In addition to the need for specificity and selectivity, the tests need to be sensitive, as to be able to observe different levels of hemi-spatial disability. By our own research, to be reported further, we aim to enhance insights into the relationship between hemi-spatial (dys)function and practical fitness to drive.

1. The importance of Vision in Driving

1.1. General

Driving is a complex skill requiring many sub-skills on the strategical, tactical and operational level. These skills require adequate perceptual, cognitive and motor processes. These processes are linked by a mental schema in a co-ordinated manner, presumably stored in procedural memory (Van Winsum & Brouwer, 1997; Brouwer, in press). It is assumed that the application of the schemata is triggered by the visual context of the driving situation and hence is very much dependent on visual information-processing. Thus, although auditory, kinaesthetic, and vestibular senses are of importance, the most substantial information being processed while driving is of a visual nature. Rockwell (1972) is referred to, in nearly all driving-related texts, stating that vision constitutes over 90% of information-input to the driver.

1.2. Lower and Higher-order Visual Function

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 (nor of any other activity of daily living for that matter). In visual sensory tests, perceptual influences which are important and inherent to driving, such as searching and finding targets in a cluttered array, stimulus uncertainty, simultaneous processing of information etcetera, are minimised. Higher-order impairment can also be a limiting factor, as alternative or in addition to obvious physical and sensory impairment (e.g. Sivak, Olson, Kewman, Won, & Henson, 1981). Shinar and Schieber (1991) argue that higher-order perceptual functions are conceptually more relevant to the driving demands and manifest a much faster rate of age-related deterioration. In this respect, concepts of visual search, visual speed, visual and divided attention, and visuo-spatial impairments are frequently put forward as alternative determinants of practical fitness to drive (e.g. Shinar & Schieber, 1991; Brouwer, in press). In the following discussion, a clear distinction will thus be made between lower- and higher-order visual function.
1.3. Impairment and Limitation
The confusing status of the term “fitness to drive” has been elucidated in previous discussion. It has been argued that practical fitness to drive is situated at the activity-performance level and is assessed accordingly. This is in contrast to medical fitness to drive, which is a restriction resulting from impairment. Assessments of primary visual functions and higher-order cognitive functions are ideally evaluations on the impairment level and can thus (only) possibly be related to medical fitness to drive. This is not to say that these impairments are irrelevant, as obviously they can elicit limitation and thus influence practical fitness to drive. However, and in addition, also other 'individual' factors (such as e.g. driving experience, compensatory behaviour etc.) and non-specific cognitive factors (such as e.g. fluid intelligence) can have as much influence on test performance at the activity level (Brouwer, in press). Hence, it is imperative to keep in mind that performance on a practical driving test (or on most tests for that matter) can be influenced by a variety of different factors from possibly different levels and their interactions.

1.4. Consequences
Assessments paying attention to only one (e.g. lower-order visual function) or a few factors, result necessarily in poverty of explaining variability in or in low correlations with practical fitness to drive (Van Zomeren, Brouwer, Rothengatter, & Snoek, 1988; Brouwer, in press). From the point of view of accurately predicting practical fitness to drive, this has at least two consequences. Firstly, only when very specific sub-tasks of the general driving task are considered (e.g. reading signs), the correlations with assessments on the impairment level are increased (Van Zomeren et al., 1988). It is intuitive that for example reading signs or reading licence plates could well be highly related to visual acuity. But then only one aspect of the driving task is considered, and thus practical fitness to drive is only partly addressed. Secondly, when the total driving task is considered (which is actually our aim), the most predictive (neuropsychological) task will have to be equally influenced by the same lower-and higher-order, specific and non-specific factors as the real driving task itself. This test could prove to be difficult to construct and only be approximated (perhaps by e.g. a tracking-task).

1.5. Conclusion
In conclusion, visual function is an important and predominant aspect of the driving task. Visual impairment can thus have clear negative effects on driving performance. It is however of theoretical and practical importance to distinguish and study both lower- and higher-order visual function. Successfully performing the driving task (i.e. being practically fit to drive) entails more than adequate visual function as driving entails a multitude of sub-tasks and appeals to a multitude of functions, all possibly interacting. This is to say that practical fitness to drive is situated at the activity-performance level an can thus possibly be influenced by (a multitude of) impairments, and by individual and non-specific cognitive factors. This has clear consequences for choosing (neuropsychological) tasks when trying to accurately predict practical fitness to drive.

Keeping in mind these general limitations in studying practical fitness to drive, and for the remainder of this discussion, I will focus on visual (dys)function, later narrowing to particularly visual hemi-spatial impairment resulting from brain damage.
2. Visual Function

2.1. General
Changes in visual (and other sensory) structures and lower-order functions may result in a decline of performance on the routine tasks essential to the individual’s daily living including driving. An evenly serious effect can arise from higher-order visual impairment or from a combination of both lower- and higher-order impairments. Visual function was previously conceptualised as incorporating two aspects namely lower-order (sensory) visual function and higher-order (cognitive) visual function, both possibly resulting in limitations. Not being able to quickly overview a visual scene, recognise common objects, faces, words, or signs or failing to notice events on one side of (visual) space, can be further be very restricting. For the remainder, visual field defects (VFDs) and associated higher-order visual impairment will be focussed upon. The associated higher-order visual impairments of our particular interest, are hemi-spatial in nature. The resulting visual limitations may arise as a by-effect or knock-on effect of homonymous visual field loss or may be the direct resultant of brain damage (or both). Behaviourally, the disabilities may appear the same but the causation and perhaps also the rehabilitation might be different. Assessment of visual functioning will thus include tests for both lower and higher-order aspects and, will specifically involve perimetry (i.e. visual field assessment) and visuo-spatial neuropsychological tests. For the remainder, I will try to indicate why and, more specifically, which tests of visual function should be included in a battery used to understand and predict the safety and fluency of driving performance.

2.2. Need and goal of assessment
Studies indicate that general practitioners and occupational therapists as well as clients and their families express the need for standardised and theoretically validated methods for evaluating driver performance (Korner-Bitensky, Sofer, Gelinas, & Mazer, 1998) and thus assessing fitness to drive. As standard procedures do not exist and on-the-road testing is sometimes considered dangerous, often have unknown reliability and objectivity, and are costly in terms of time, money and energy (Galski, Bruno, & Ehle, 1992), it can be desirable to have a set of valid alternative tests closely related to and wishfully capable of predicting practical fitness to drive. Additionally, test results could not only serve the purpose of evaluation but could also guide the therapist as to which components, skills or functions need specific attention in rehabilitation (Brouwer & Withaar, 1997). As such, these results could also help practitioners, researchers, clients and families, to understand why a client is (currently) unfit to drive, perhaps what is the prognosis for further evaluation and development and what are the learning or adaptive potentials. Finally, the accumulated results could yield valuable information about goals and means for improving road and car infrastructure (e.g. additional mirrors) and possible other “personal” adaptations as for example prisms in spectacles.

2.3. Lower-order (sensory) Visual Function

2.3.1. General
Lower-order visual function was previously conceptualised as what is often referred to as visual function in medical and ophthalmic terms. The most well-known of those functions are visual acuity, contrast sensitivity and visual fields. They are usually assessed by a medical expert and measured for each eye separately. Impairments are very often caused by retinal, eye or optic nerve disease but also cortical malfunctioning can be at its basis.
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Visual acuity refers to the ability to perceive details presented with good contrasts and is usually assessed by a letter recognition task (e.g. Snellen chart). Usually visual acuity is not impaired after unilateral post-chiasmatic brain damage, except in cases where also the optic tract is involved (Zihl, 2000). Whether or not reduction in visual acuity leads to limitations, frequently depends on whether further visual impairments (e.g. contrast sensitivity) are present.

Spatial contrast sensitivity is usually assessed by measuring contrast detection thresholds for black-white grating stimuli (e.g. Vistech chart). Patients with impairments in contrast sensitivity, usually complain of “blurred” or “foggy” vision in the presence of normal visual acuity and other visual functions.

However, the present focus is on visual field defects (VFDs). The monocular visual field can be defined as the perceptual space available to the fixating eye. The binocular visual field is the sum of the perceptual spaces available to both fixating eyes. In general, the extent of a normal visual field totals approximately 200 degrees horizontally but is usually measured up until 180 degrees. This extent tends to decrease with age. This age-related decrease is due to a loss of visual sensitivity, which is more pronounced with increasing eccentricity (e.g. Ball, Owsley, & Beard, 1990). Pathological visual field loss can result from ocular and optic nerve disease like macular degeneration, glaucoma and neuritis optica. It can also result from brain damage. Different perimetric techniques and devices can be used to assess the visual fields. They can be automated or manually operated, using static or dynamic, white or coloured targets of different sizes and intensities. Clinically frequently used are the Goldmann and the Humphrey Field Analyzer. Zihl (1994, 1999, 2000) estimates that about 80% of subjects with posterior brain damage suffer from visual field loss. In 89% of cases this loss is unilateral (i.e. affecting only one hemi-field). The most common type of unilateral VFD is HH (65%), followed by quadranopia (16%), hemiamblyopia (11%) and paracentral scotoma (8%). In HH, also termed hemi-field blindness, only (left or right) half of the perceptual space as defined above is available and can therefore be defined as a lower-order visual hemi-spatial impairment. In quadranopia only one quarter of the perceptual space is available, either upper or lower. Hemiamblyopia indicates that light vision is spared but depressed, while colour and form vision are lost. Paracentral scotoma indicate islands of blindness in the parafoveal field region. Following these percentages, approximately 46% of subjects acquiring and surviving posterior brain damage suffer unilateral HH, further referred to as HH.

2.3.2. Lower-order Visual Function and driving(-related) performance

In a recent review article by Owsley and McGwin (Owsley & 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. However, it seems quite intuitive that the importance of intact visual fields or rather the impediments imposed by VFDs should not be underestimated. They can bring about limitations even in the absence of brain damage as is shown by for example Kuyk and co-workers (Kuyk, Elliott, & Fuhr, 1998). These authors studied the relationship between vision and mobility as a function of the subject’s type of vision loss. They assessed 165 visually impaired subjects on many different aspects of sensory and higher-order visual function. Sensory tests included, amongst others, assessments of visual acuity, contrast sensitivity, motion sensitivity, colour confusion and visual fields. The visual fields were measured binocularly using the Goldmann perimeter and associated
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procedures. Higher-order visual functions were assessed by tests of figure-ground discrimination, embedded figures discrimination and scanning reaction time. Also mobility performance was measured on a high-density indoor obstacle course. This route consisted of an indoor track, being 1-1.5m wide and approximately 100m long, passing through several rooms. In addition to the common and usual obstacles in the rooms, 60 objects of different sizes were placed in the travel path. Subjects were instructed to walk through the course at whatever pace they felt comfortable with, to stay within the boundaries, and to avoid colliding with or touching objects. Mobility performance was measured in terms of the course completion time and the total number of contacts made with boundaries and objects. Three types of vision loss were defined: either an acuity loss, a visual field restriction, or a combination of both. All impairments had been caused by ocular or optic nerve disease. Interestingly, it was found that the group with visual field restriction displayed the highest (i.e. better) scores on the higher-order visual perception tests. However, the authors note that the results may have been contaminated by sensory function. The acuity group might have been placed at a disadvantage because the items might not have been equally well visible. More importantly for this discussion, visual field extent and scanning efficiency were found to be the variables most closely related to the mobility results. More specifically, as visual field extent and scanning efficiency decreased, the mobility performance degraded both in terms of completion time and collisions. Further analysis of the mobility task revealed that the acuity-loss group spent less time and made fewer errors than both other groups with VFDs. These results indicate that the size of the visual field can be an important sensory determinant of mobility performance. However, also another aspect of vision, namely visuo-spatial function as measured by the scanning score, appears to be an important factor related to mobility performance.

This has led researchers (e.g. Owsley et al., 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 functions, which they refer to as “central processing skills”. Higher-order visual functions can be argued to have perhaps more face validity to safe driving than visual sensory thresholds (e.g. Shinar et al., 1991). One such higher-order function which appears to be relevant to safe driving appears to be visual speed, sometimes referred to as visual attention. As Owsley and McGwin discuss, assessments of visual processing speed and visual attention as for example assessed with the useful field of view test (UFOV; Visual Resources, Inc., Chicago, IL) appear to be better screening tests than assessments of sensory functions. They further briefly mention that also other higher-order visual processing functions like visual search, sequencing, selective attention, spatial memory and perception of three-dimensional structure from motion are also found to be associated with safe driving. In addition, from the previous discussion on ICF terminology, it should be clear that a combination of visual impairment, and personal and non-specific characteristics and their interactions influence practical fitness to drive. Owsley and McGwin further justly note that these and many other (higher-order) impairments have not been fully explored. The role of eye-movement disorders, motion perception and optic flow phenomena such as heading have indeed a great deal of face validity but have received relatively little research attention. Thus another aspect of “vision” is largely left unexplored namely the higher-order visuo-perceptual, visuo-spatial and visuo-motor processing functions (Owsley et al., 1999). Neuropsychological tests of higher-order visual function 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.
From the previous discussion of lower-order visual function, it emerged that extent of the visual field or presence of VFDs can be an important factor determining practical fitness to drive. Additional evidence for this statement was provided by Hartje and colleagues (Hartje, Willmes, & Pach, 1991) and by Hannen, Hartje and Skreczek (1998), who also addressed the issue of VFDs. The cause of the VFDs in their patient groups differs from the previous reported studies as both studies include brain damaged patients suffering cognitive impairment. A small number of these patients additionally suffered from lower-order visual impairment, namely homonymous narrowing of the visual fields, not caused by ocular or optic nerve disease, but due to post-chiasmal brain damage. Of the patients with the VFDs, hardly any of them passed a practical driving test. As this was not the primary topic in these studies, the authors do not indicate the exact reasons or specific problems associated with the VFDs.

Hartje and colleagues (Hartje et al., 1991) compared performance of 36 aphasic and 29 non-aphasic patients on neuropsychological tests and on a on-the-road driving test. The neuropsychological test battery consisted of visuo-spatial tests, reaction time measures, and an intelligence test. Visuo-spatial functioning is operationally defined as rapid visual orientation, speed of visual perception, visual search, and visual simple and complex reaction times. The practical driving test was a nearly 50 km on-the-road assessment with a representative mixture of varying day-time traffic conditions and levels of driving difficulty. Performance was scored by an experienced licensed driving instructor using a protocol with 280 observational items. Their sample consisted of 45, 7 and 13 subjects with respectively left, right and bilateral brain damage. The sample was unselected in terms of perceptual, motor, and cognitive impairment. Fifty five percent of the patients passed the practical driving examination with the aphasic patients (42%) being less successful than the non-aphasic patients (72%). Only a minority of neuropsychological test scores were significantly related to the outcome of the practical driving test. Those tests that showed a relationship, had visuo-spatial components. In the non-aphasic group only a complex (partly visual) reaction time task proved to be significant. In the aphasic group this test was complemented by a tachistoscopic perception test and a cancellation task. Important in this respect is the observation that hemiparesis nor any other neurological deficit was related to the outcome of the driving test. However, all (eight) patients with VFDs failed the practical driving test. These VFDs were due to a “homonymous narrowing of the visual fields” (as indicated by a not specified perimetric examination) but were not HH, since this was an exclusion criterion.

A comparable negative effect of homonymous VFDs in a brain damaged population on driving performance was found by Hannen, Hartje and Skreczek (1998). They subjected 116 brain damaged patients to a neuropsychological test battery and to an on-the-road driving test. The testing protocol is identical to Hartje et al. (1991), as previously discussed, comprising of visuo-spatial tests, reaction time measures, and a global intelligence test. The on-the-road assessment was a nearly 50 km test-ride with real and representative traffic conditions. Performance was scored using a detailed and extensive protocol. Sixty two percent of the patients had left-sided, 14% right-sided and 24% had bilateral brain damage. Similar to the previous study, 58% of the patients passed the driving test. Also in this study, the same neuropsychological tasks were significantly related to the driving results. These tasks assessed complex information processing (under dual-task conditions) and had strong visuo-spatial components. There were no significant effects of the laterality of the brain damage, nor of
presence of aphasia or hemiplegia. However, 11 of the 13 patients with VFDs failed the test-ride. The type or rather severity of the VFDs is described by the authors as “mild”, and thus are supposedly also due to a homonymous narrowing of the visual fields, but not HHs. In 10 of these 11 patients, the driving instructor was forced to actively intervene during the test-ride to prevent hazardous situations. Again, the presence of VFDs caused by brain damage appears to be a strong indicator of unfitness to drive.

2.3.3. Lower-order visual Hemi-spatial impairment and driving(-related) performance
In the studies by Hartje et al. (1991) and Hannen et al. (1998) it could be observed that homonymous VFDs due to brain damage resulted in nearly all cases in failure on an on-the-road driving test, suggesting clear negative effects of homonymous VFDs on fitness to drive. However, not all literature points inexorably at the devastating effects of such visual impairments on driving or driving-related performance. An early demonstration that HH not necessarily results in unfitness to drive was provided by Vos and Riemersma (1976). This has been confirmed several times by more recent research findings. A similar conclusion was for example drawn in an abstract by Warmink et al. (Warmink, de Jong, & Kempeneers, 1998). In their research, they assessed the driving performance of more than 100 patients with HH. A study by Szlyk et al. (Szlyk, Brigell, & Seiple, 1993) shows clearly that different levels of performance can be observed within the hemianopic patient group and that perhaps age is an evenly important factor for practical driving performance in a brain damaged population. This study will be reported further on in more detail. Racette and Casson (1999) compared retrospectively visual field assessments with an evaluation of an on-the-road driving test in a Canadian sample. They report data from 13 patients with HH and seven patients with homonymous quadranopia. It was found that only 23% of the hemianopic patients were deemed as unsafe drivers. Twenty-three percent were judged to be safe and the remaining patients were referred to be re-assessed. From the quadranopic group, no one was judged to be unsafe and 57% was found to be safe. The remaining patients had to be re-assessed. Clearly, the evidence provided by these reports indicate that homonymous VFDs and HH by itself can not be an absolute and inevitable contra-indication for practical fitness to drive.

A similar positive conclusion was reached by Schulte and co-workers (Schulte, Strasburger, Muller-Oehring, Kasten, & Sabel, 1999). Their subject sample consisted of nine patients with visual field defects, whom were judged to be otherwise neuropsychologically and ophthalmologically intact. They investigated whether driving performance in a driving simulator would be impaired. All patients were found to be without neuropsychological deficits measured by tests of attention, perceptual speed and dyslexia, and had intact foveal vision (macular sparing). Patients had lesions of either primary visual cortex or optic nerve. Visual field assessment was performed with a standard static luminance threshold perimeter, complemented by a qualitative high-resolution campimetry. Three patients presented with HH, two with quadranopia, two with homonymous scotoma, one patient had paracentral defects and one had only monocular (but otherwise intact) vision. The driving simulation consisted of driving a car with automatic transmission. The field of view was 21° (horizontally) by 16° (vertically). Assessments included driving speed, reaction time to a suddenly appearing deer and traffic violations. The test was preceded by familiarisation over a distance of 2.6 km. For the test, the subject was instructed to drive a 5.2 km roadway at 100 km/hr, and to pass slower cars while obeying all traffic rules. Several interesting results emerged from this study. No differences were found between the visually impaired and the age-matched control subjects on any simulator parameter. Larger
field losses tended to be associated with slower driving but the correlation did not reach statistical significance (possibly because of the small number of subjects). Time since onset of the visual impairment did not correlate with any of the simulator performances. Reaction times in moments of danger (a deer suddenly crossing the road) were also found to be identical in both groups. Thus, in this study, no negative effects of VFDs are found with respect to measures of driving performance in this simulator task, suggesting that homonymous VFDs do not necessarily and by definition lead to decline in driving performance. However, by using automatic transmission and simulating a roadway (no intersections), performance-influencing factors other than those caused by the visual field loss (e.g. interference from divided attention) are minimised. Hence, it is important to observe that by the nature of the simulation, the driving task is rather simplified. It could for example be argued that by the rather small used field of view, control subjects could not profit from their available wider field of view.

It is further important to note that these hemianopic patients were reported to be “neuropsychologically intact” and thus this sample is (perhaps) not representative for the wider population of HH patients. A similar critical comment can be made on the study by Warmink et al. (1998). In co-operation with the Dutch Licensing Authority, they officially assessed more than 100 hemianopic patients on an practical driving test. For the vast majority of subjects, the decision by an official driving instructor was positive. Several reasons can be formulated as to why this sample is most likely not representative for the hemianopic population. One of them is that only subjects whom are confident of their performance are likely to volunteer for this official test ride. Since the subjects do not find themselves visually disabled, they are probably also “neuropsychologically intact”.

As presented, this study also warrants against the absolute negative influence of HH on practical fitness to drive. It seems that the sample of hemianopic patients covers several subgroups of patients with different levels of hemi-spatial limitations.

2.3.4. Conclusion

In summary, lower-order (sensory) impairment (e.g. a VFD) as a standard, does not lead to unequivocal decisions about practical fitness to drive. Driving performance -apart from personal characteristics- can also be influenced by impairments at a higher-order level. Perceptual and cognitive disorders are well recognised to accompany brain damage. It is estimated that of persons who suffered a stroke, 75% have residual perceptual-cognitive impairment (Korner-Bitensky et al., 1998) and only 25% are free of these kind of impairments. For most brain damaged patients, cars can be adapted to their new physical requirements, for example automatic transmission and steering knobs for hemiplegia. But these adaptations are of little use for the possible accompanying cognitive higher level, perceptual and spatial impairments. These will be focussed upon subsequently. In the following, I will try to shed some light on the possible role of higher-order cognitive impairment, later specifying to visuo-spatial and hemi-spatial visual impairments, alone or in combination with lower-order hemi-spatial impairment. This will eventually lead to the general aim of the current project, namely to investigate which HH subjects are fit or unfit to drive and what is the cause of this. We will be particularly interested in the limitations typically associated with hemi-spatial impairment.
2.4. Higher-order Cognitive Function
2.4.1. General: Brain damage and Cognitive Function

It seems very intuitive that brain damage can negatively effect a wide variety of activities and performances, including driving. Several studies indicate (e.g. Haselkorn, Mueller, & Rivara, 1998) that not the brain damage in itself is the limiting factor. Only when the brain damage results in higher-order impairment, practical driving performance is negatively affected. For comprehensive and recent reviews on brain damage and driving, I refer to Brouwer and Withaar (1997), Brouwer (in press) and Withaar et al. (2000). They conclude firstly that in the brain damaged population, cognitively impaired subjects perform worse on both neuropsychological tasks and on driving tasks. Secondly, neuropsychological test results can be shown to correlate moderately high with measures of driving performance. Specifically visual speed and measures of divided (visual) attention prove to be more informative than global indicators of severity of illness. However thirdly, the large range in test scores makes it difficult to discriminate between cognitively impaired subjects who are or are not practically fit to drive, purely on the basis of neuropsychological test performance.

2.4.2. Neuropsychological Functioning

As neuropsychological tests are assumed to measure higher-order cognitive functioning and with economic, therapeutic and conceptual reasons in mind, neuropsychological tests have been incorporated into procedures to evaluate and assess (residual) impairment related to driving. In reviewing the relevant literature, it will be noticed that numerous neuropsychological tests have been used in relation to different kinds of performances related to driving. As a result, reports on the validity and reliability of these kinds of tests in relation to any kind of driving performance have been inconsistent and sometimes incomparable. Another possible reason for this is offered by Galski et al. (1992). They question the theoretical basis for the selection of neuropsychological tests. They specifically argue that mostly the tests are not meaningfully related to the behind-the-wheel performance. It can be noticed however that not only a-theoretical selection but also different theories with respect to driving performance have been used.

2.4.2.1. Neuropsychological test scores and driving(-related) performance

2.4.2.1.1. Correlation with driving(-related) performance

A more elaborate discussion for the low to moderate correlations between test scores and driving performance can be found in Withaar et al. (2000). They discuss, amongst other topics, the selection of participants, choice of tests and method of driving assessment. It is suggested that participants are usually too small in numbers and not representative for a general population. The direct relationship between many neuropsychological measures and actual driving performance is questioned. The authors point at the multiple determination of the quality of the driving performance and it is noted that in many studies this has not been taken into account. They further accentuate that the importance of task-specific experience (specifically with respect to driving) may blur the (direct) relationship between neuropsychological function and driving. In addition, it is rightfully commented that the driving task itself can, theoretically as well as practically, be conceptualised in different ways and there has been no consistency in theories used so far. One theoretical approach which has proven to be fruitful, defines the driving task using a hierarchical cognitive structure (Michon, 1971; Van Zomeren, Brouwer, & Minderhoud, 1987) in terms of strategic, tactical, and operational subtasks. However, this and many other theoretical accounts have been used, leading to relative incomparability in studies. Practically, driving, as a dependent variable, can
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and has also been evaluated in many different ways. Assessment can thus take different formats: Subjective and objective reports on accidents (and near accidents), driving frequency, licence renewal, etcetera. can and have been used as an indication of driving performance. The quality of actual and real driving performance can instantly and more directly be assessed on open and closed circuits, with real (and adapted) cars or using driving simulators with different reality similarities. The performance can be evaluated using different protocols and rating scales by different criteria. This variability results in modest comparability between studies and low insights into the subcomponents of the driving task, again moderating possible correlations with other (neuropsychological) tests.

2.4.2.1.2. Specificity

In our opinion a further point can be raised approaching the research from the side of the subject, in this case the patient, rather than exclusively from the side of the (driving) task. Namely, it can be argued that in previous studies, most tests are not specifically assessing the most likely and prominent impairments of the patients under study. This idea originates for example from reports by Galski et al. (Galski, Bruno, & Ehle, 1993). They showed that only carefully selected tests can be used to evaluate fitness to drive. Not all cognitive tests adversely affected or were equally related to driving performance. Additionally, confusion about the relative importance of tests can be created considering the well established observation that tests which successfully discriminate between brain damaged and non-brain damaged patients are not necessarily highly correlated to driving performance (e.g. Van Zomeren et al., 1988). Thus, tests serving one purpose (e.g. patient-group classification), do not necessarily serve another (relationship to driving). This leads to the conclusion, not only that merely very specific tests are useful in neuropsychological assessments, but also that the relatedness of the tests to driving can very well be determined by the specific patient-population (which and) because they exhibit specific limitations. It is not inconceivable that in a population with left-hemisphere brain damage, visuo-spatial tasks will be less revealing and functional than in a right-hemisphere group or that “frontal tests” will be more predictive in a “frontal brain damaged group” than in any other group of patients. Support for this idea is provided by Mazer et al. (Mazer, Kornor-Bitensky, & Sofer, 1998) conducting a study with 84 brain damaged subjects tested on a neuropsychological battery consisting of various mainly visual perceptual tests, and on an on-the-road driving test. The driving test was based on the standard test procedure used by the provincial licensing board in Quebec (Canada) and was evaluated using a 43-item assessment form covering use of controls, manoeuvring, and specific and general driving skills. The score resulted in a pass/fail decision. Logistic regression models were created and it was found that for left and right brain damaged subjects, different perceptual tests were the best predictors of the on-the-road assessment. For right brain damaged subjects, a joint measure of visual discrimination, spatial relations and figure-ground discrimination yielded the best prediction. These tests hold strong spatial components, usually associated with right-sided brain damage. For the left brain damaged group, the Trailmaking Test part B was the best predictor. The Trailmaking Test part B taps multiple conceptual tracking, sequencing, and alternating divided attention. Furthermore, it holds an additional “language component”, typically associated with the left hemisphere.

Summarising this point, we argue that the tests directed towards the typical problems exhibited by the patient population will be most predictive for driving performance. This is in line with a previous general point we made, namely that only when very specific sub-tasks of the driving task are considered, correlations with (specific) neuropsychological tests can be increased. When patients suffer a specific and well isolated impairment, assumed that these
impairments can be neuropsychologically tapped, and these impairments are related to important aspects of fitness to drive, this specific neuropsychological test performance can be highly related to practical fitness to drive.

From previous points, it follows that selectivity in test choice and selectivity in patient population are logically linked. The need for selectivity follows from the conceptualisation of the driving task (what components of the driving task can be adequately measured by neuropsychological tests) and from the specific impairments of a specific patient population. The brain damaged population in general might well be a too broadly defined category to be effective in pinpointing a specific and limited range of impairments relevant to practical fitness to drive. Therefore, specific subgroups of patients should be considered (e.g. well documented HH patients), assessed with specific tests (e.g. visuo-spatial tests).

2.4.2.2. Other (inter-)related general topics: hemispheric differences, selection criteria, and range in outcomes

2.4.2.2.1. Hemispheric differences

As it is not unreasonable to assert that driving has a high visuo-spatial component, it can be expected that right hemisphere brain damaged patients perform worse on both practical driving and visuo-spatial tests than patients suffering from left hemisphere brain damage because of the traditionally assumed hemispheric specialisation of the right hemisphere for spatial function. Brouwer (in press) remarks that most studies indeed show this expected tendency. However, he points at the possible selection bias inherent in many studies. Quigley and DeLisa (1983) notice that although left CVA patients performed better on their visuo-spatial test battery, needed less training sessions (class-room driving instruction and in-car training) and were more successful on a driving test, fewer are in practice referred to driver-training programs. Thus, although some research suggests higher levels of performance of left relative to right CVA patients, fewer actually enrol in (clinical) driver-training programs. It is suggested that left CVA patients have less tendency of actually expressing the desire to continue driving, possibly as a consequence of language impairment to some degree. This is in contrast to right-sided brain damaged patients, who frequently have low insight into their own pathology. These patients do not see at all, why they should not drive or participate in driving-programs. Other reasons for skewness are the possible more prominent limitations for driving caused by right hemiparesis, associated with left-sided brain damage. However, despite of that these limitations can quite easily be diminished with the appropriate technical car-adaptations, frequently right hemiparesic patients decline from driving. These tendencies are likely to skew the proportion of actual left versus right CVA drivers on the road, tempting to inaccurate and biased interpretations when using measures of driving performance as, for example, return-to-driving-after-stroke.

This skewness is also suspected to influence subject selection and inclusion in driving related studies, especially when stringent inclusion criteria are used, as for example minimum of driving experience since the brain damage, and when patients are studied who voluntarily apply for participation. This also might result in exclusion of left CVA patients with relatively high potential and overinclusion of right CVA patients, skewing and biasing overall test-outcomes and hence interpretation. Brouwer (in press) therefore rightfully concludes that precise numbers and conclusions with respect to hemispheric differences should then also be treated with caution. To stress this point, Hannen and colleagues (1998), assessing 116 patients with acquired brain damage, found no significant effects of the laterality of brain damage on an on-the-road driving test. This emphasises the point that hemispheric differences
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with respect to the quality of driving performance, although plausible, are not as yet accounted for by strong evidence. This suggests the need for studies where this kind of patient selection is brought to a minimum.

In the light of topics to be discussed further on, this has important implications, since laterality of brain damage is typically associated with (contra-)laterality of potential HH. The absence of established differences due to laterality of brain damage indicates the potential absence of differences in limitations between left- and right-sided HH patients. This suggests the need for studies including both kinds of patients, with a minimum of additional in- and exclusion criteria. If in such studies differences are to be found, these are not a priori attributable to laterality of brain damage per se, but could be due to specific (visual) problems, typically associated with either left- or right sided HH.

2.4.2.2.2. Selection biases and range in outcomes

From the previous remarks, it should be clear that selection biases can cause caveats with respect to data interpretation. It was shown that possible selection (or exclusion) of patients might influence research outcomes with respect to laterality of brain damage and its relation to driving-related outcomes. In addition, selection biases can also influence the range of test scores. Highly restricting selection can decrease the range in neuropsychological and driving outcomes. In general, narrow ranges are likely to result in low correlational measures and poor predictive powers. To put it extremely simple: if all test performance is at ceiling or floor level, no association between them can be observed. This was for example witnessed in a study by Lundqvist and colleagues (Lundqvist et al., 1997). Several neuropsychological and driving tests (simulator and on-the-road) were subjected to 29 patients. Neuropsychological tests assessed perceptual, cognitive, and executive functioning. The driving simulator consisted of an advanced moving-base system, providing the driver a realistic dynamic impression of a 80-km two-lane road with realistic traffic conditions. During simulator driving, speed, lateral position, complex reaction time, time to collision and distance to collision were recorded. The on-the-road driving was performed over 25-km in actual traffic in the participant’s own car. Speed, manoeuvring, lateral position, attention and traffic behaviour were evaluated. All patients had good recovery from brain damage, no VFDs, no hemiplegia, no deficits as non-fluency and other intellectual impairments. Patients without drivers license or who were not driving at that moment were also excluded. These stringent criteria are very likely to produce skewed outcome ranges to the positive end. In other words, these criteria produce a patient population without (expected) limitations, which is non-representative for a brain damaged population. This is confirmed by the observation that only two of the five simulator driving parameters (speed and lateral position) and three of the five on-the-road driving parameters (speed, manoeuvring and lateral position) showed significant differences between the patient and control group.

The important and striking observation in this study is that the neuropsychological test results were found not to be significantly related to the simulator driving outcomes and that additionally the simulator driving outcomes were not related to the on-the-road driving outcomes. This seems very odd and counter-intuitive, but, as we have argued, it might be as a consequence of very limited ranges in all outcome measures.

The significance of the range of outcome measures is also confirmed in a study by Nouri and Lincoln (1992). It further demonstrates that, if any constriction in driving outcome, it is preferably to the negative end; not to the positive end as in the previously reported Lundqvist et al. (1997) study. The test battery of Nouri and Lincoln (1992) consisted of measures of,
amongst others, spatial function, visual inattention and concentration, reasoning function, and visual memory. These were complemented with typical driving related tests as road sign and hazard recognition. Also, an representative on-the-road driving test was administered. The subjects were first graded into either a pass or fail group by an instructor on the basis of an overall subjective impression of the quality of driving performance. Discriminant equations were then derived from the results of a subgroup of randomly selected patients. Such equations incorporate a profile of neuropsychological test results and produce a predictive value. Two values are obtained per subject, namely a predictive value for whether the subject would pass the driving test and a value whether the subjects would fail. The higher value is taken to indicate the likely outcome. This resulted in 82% correct classifications.

These equations were then applied to the remainder of the subjects to examine their predictive value in another but similar group of patients. These new classification results demonstrated that the predictive equations were approximately equally effective in overall classification (79% correct classifications). But more important for this discussion is the observation that the equations were more effective at identifying those subjects that were to fail the driving test than those who were to pass. Thus, in the light of effectiveness of predicting driving performance, when driving outcomes are biased, this study suggests it preferably to be to the negative end, since it is suggested that failure is more predictable than passing the driving test.

This might explain why in the Lundqvist et al.-study non-significant predictive equations were observed: driving outcomes were strongly biased to the positive end. The preferred bias of driving performance to the negative end does not necessarily have to be problematic since high effectiveness for predicting failure is for screening purposes perhaps a more desired property.

2.4.3. Visuo-spatial Function
It was previously argued that the driving task is comprised of many different aspects on different levels and that the quality of driving performance can thus be influenced by many different factors. In previous discussion we indicated that neuropsychological test choice has to depend firstly on preferably consistent and unified task analysis and model building of the driving task and secondly on the specific population the tests will be applied to, in order to be able to significantly relate outcomes of both types of assessments.

Given that a great deal of information-processing in the driving task is of a visual and spatial nature and that later action is highly dependent on this visuo-spatial information, the specific interest in visuo-spatial functioning is a logical consequence. Additionally, since we specifically limit our focus on patients suffering homonymous VFDs due to post-chiasmal brain damage (and HH in particular) and since this condition is known frequently to accompany, intensify and/or provoke visual-spatial limitation, it follows that the tests of our interest should have prominent visuo-perceptual and visuo-spatial components.

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 is a vital aspect of cognitive functioning as it is a necessary element for successfully performing a wide range of activities of daily living. For instance, it underlies our ability to move around in an environment and orient ourselves appropriately. Visuo-spatial perception is also involved in our ability to accurately reach for objects in visual space and our ability to shift our gaze to different points in space in order to effectively scan and search for objects. Some visuo-spatial impairments are commonly associated with right hemisphere brain
damage. Such impairments could be for example impaired discrimination of complex stimuli, recognition, figure-ground differentiation and visual integration. Other visuo-spatial impairments are defective localisation of points in space, judgement of direction and distance, and topographic disorientation. Subjective complaints as 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 etcetera, are frequently reported by HH patients. These complaints are (at least partly) due to visuo-spatial impairment, resulting in defective visual scanning.

The most severe disabling spatial impairment is the neglect syndrome, usually caused by right hemisphere brain damage. Hemi-spatial visual neglect can be described as a failure to report, respond, or orient to novel or meaningful stimuli, usually on the side of space or objects opposite the side of lesion (e.g. Robertson & Halligan, 1999). This failure is not primarily due to hemi-field blindness although it often co-occurs. It has been estimated that approximately 70% of the neglect patients also suffer from a homonymous VFD (Kerkhoff & Schindler, 1997). However, these percentages have to be treated with caution, since the differential diagnosis can prove to be complex. Due to the severity of the limitations frequently imposed by this condition, it is usually presupposed that this condition in incompatible with safe driving.

Our aim is to study patients suffering HH and patients suffering related impairments which will be inherently visuo-spatial (and specifically hemi-spatial) in nature. We will denote this group of patients as suffering from hemi-spatial visual limitation. Hemi-spatial limitation can be thus caused by lower-order hemi-spatial impairment (i.e. HH), and by higher-order hemi-spatial impairment (i.e. hemi-spatial neglect), or by both. Both types of impairments arise from unilateral (post-chiasmal) brain damage and can be expressed in lateralised visual limitation and restriction, implying more visual problems on one particular side (left or right) of visual space, usually contralateral to the side of brain damage (i.e. contra-lesionally). In the following paragraphs, we will try to highlight studies specifically discussing hemi-spatial impairment and its influence on the quality of driving performance or driving related performance.

2.5. Visuo-spatial impairment and driving(-related) performance

2.5.1. Observational and anecdotal information

We previously alluded to limitations related to visuo-spatial impairment. Examples of such impairments, likely to influence fitness to drive, are visual dysorientation and environmental agnosia. One particular class of visuo-perceptional, visuo-spatial and visuo-cognitive impairment are visual (object)agnosias. Though generally visuo-spatial in nature, these impairments are usually not hemi-spatial in nature and imply difficulty in identifying objects using visual information. This higher-order impairment is not to be explained (fully) on the basis of lower visual impairment. Frequently, these agnosias are category-specific. For a short but comprehensive description of several types of agnosias, we refer to Zihl (2000). In the course of our own research we encountered several types of agnosic patients. Although most of these subjects are quite disabled in some respects, not all of them present a reduction in the quality of driving performance. A prosopagnosic patient (difficulty in visually recognising familiar faces and learning new faces) from our own hemianopic patient sample, had no difficulty at all adequately performing an on-the-road practical driving test. This is not unsuspected, since driving has no relation to recognising faces. Not exactly similar is the case...
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in (pure) alexia. This impairment implies difficulties identifying individual letters and/or constructing words out of the string of letters (“letter-by-letter reading”). Our hemianopic and pure alexic patient expectedly complained of difficulties in following instructions during the test-ride as “on the next crossing, follow the direction to <<placename>>” or follow instructions on information boards due to unexpected deviations. This impairment is obviously more disabling with respect to driving performance, since reading is a small but can be an important aspect for fluent driving. We found visual object agnosia the far most disabling type. Our hemianopic and visual agnosic patient displayed a complete disability in visually identifying and recognising any type of object. Painted markings on the road-surface and crossings with multiple-lane roads, totally confused our subject. During the test-ride, the subject was able to describe most road-signs in terms of colour and shape but was totally unable to identify their meaning, although the symbols (e.g. crossing pedestrians) are very straight-forward to “gnosic” viewers. When a short distance further, a previously and recently explained road-sign was encountered, once again, it was not recognised. When passing through a road-construction area the following happened. Traffic from two opposing lanes was reduced into one lane. This process was supervised by two typically dressed road-construction officials. These visually conspicuous officials (both male, orange uniforms, helmets, and flags) took standard positions at the beginning and end of the one-way lane. At the end of this lane, just before the second official, our subject abruptly stopped the car, making a ‘gentleman-like’ gesture to “let this lady cross the road”. Being “a gentleman in traffic”, he did not have a clue who this person was, what the specific traffic situation was and what all the symbols meant. The test-ride was never considered dangerous by our experienced driving instructor, was sometimes humorous but clearly the impairment is as limiting that quality of driving becomes unacceptable.

By these anecdotes, we indicate that different types of visuo-spatial impairment can result in different levels of limitation. For the remainder, we will specifically focus on hemi-spatial impairment and limitation.

2.5.2. Hemi-spatial visual impairment and driving(-related) performance

2.5.2.1. Legal, ethical and empirical grounds

We previously argued that hemi-spatial impairment can be considered to be a negative indicator for adequate driving performance. This conclusion has not always been based exclusively on objective research findings. Subjective, ethical and legal motives can also be the basis for, for example, withdrawal of drivers licenses. In some studies, such a mixture of matters can be observed as for example in Sundet et al. (Sundet, Goffeng, & Hofft, 1995). Sundet and co-workers investigated whether the judgement concerning fitness to drive (thus not an actual test) by a professional team was related to performance on a neuropsychological screening battery. They investigated 29 left-sided and 43 right-sided brain damaged subjects and decided that respectively 41% and 58% did not meet the fitness criteria for a driver’s license. Results indicated that neither sex, laterality of the lesion nor hemiplegia were of influence on the decision of whether or not the patient was allowed to drive. In predicting the fitness decision, it proved that neuropsychological test results provided a major part of the information used by the team in the decision process. Trailmaking Test part B showed to be the single most potent predicting variable. However, a possible judgement bias might have influenced the observed relationships. When HH and/or hemi-spatial neglect was diagnosed, the conclusion was negative without any exception. The expectation can however be raised that this conclusion was based on legal and ethical grounds rather than on empirical evidence as one can read: “Brain damaged subjects with impairments such as loss of visual field or
significant visuo-spatial inattention, are not allowed to drive. A controlled study designed to compare driving skills between patients with and without hemianopia/neglect is thus neither legally nor ethically advisable”. We would like to notify that decisions whether or not a subject is considered fit to drive has serious social consequences for the subject and safety consequences for the public. Hence these decisions are not to be made on the basis of supposedly common sense, subjective impressions, “clinical feeling”, or historically grown habits. They should be underpinned by clear empirical evidence.

2.5.2.2. Empirical evidence

Other studies do present empirical evidence and from this literature, it is not evident that hemi-spatial impairment necessarily results in negative driving outcomes, suggesting that either lower- or higher-order hemi-spatial impairment not necessarily results in hemi-spatial limitation. As is the case for general higher-order visual impairment (e.g. the agnosias), apparently some forms of hemi-spatial impairment result in a higher degree of limitation. It will for example be argued that hemi-spatial neglect is be much more impeding than HH without other cognitive dysfunction.

To illustrate our points, a (rather limited) number of literature reports can be quoted. In all the following papers, hemi-spatial limitation is apparent. And since hemi-spatial limitation indicates either lower- or higher-order hemi-spatial impairment, or both, these reports are relevant for this discussion. However, not all papers are conclusive about the specific nature and cause of the hemi-spatial limitation. Only a few studies discuss explicitly HH. In these studies, the status of the visual fields has objectively been established. Additionally is reported whether the lower-order impairment are accompanied by higher-order hemi-spatial impairment. Using the impairment as a point of departure, the relationship with limitation is focussed upon. These studies will be highlighted in the next paragraph. Further we will discuss in extent a study using, not the impairment, but the hemi-spatial limitation as the point of departure. In this study, the presence of hemi-spatial impairment can be inferred from the obvious hemi-spatial limitation. Whether it’s nature is of a lower- or higher-order can not simply be resolved. The profoundness of the observed limitations and other information as for example aetiology, leads us to suspect that most patients suffer hemi-spatial neglect. However, the presence of HH, or the combination of both can not be ruled out. In the final paragraph, we mention some studies, not specifically focussing on either hemi-spatial impairment nor hemi-spatial limitation. In these papers, neither constructs were amongst the inclusion criteria and were thus accounted for. The studies rather include brain damaged patients in general. However, some of these studies mention in their discussion section, some presence (in some patients) of hemi-spatial limitation. It is therefore apparent that the patient population under study consist of a "mixed" group. Therefore, although clearly limited, they too can be of some importance for this discussion.

2.5.2.2.1. Homonymous hemianopia and driving(-related) performance

Evidently, not all literature reports are unclear with respect to the presence and classification of visual and/or hemi-spatial impairment. Pitifully, the evidence provided by those papers does not provide simple and clear conclusions about the degree of limitation imposed by these impairments. In a previous paragraph discussing lower-order visual hemi-spatial impairment in relation to driving performance, we already mentioned the studies by Hannen et al. (1998) and Hartje et al. (1991). In these studies, nearly all patients with a homonymous VFD, failed an on-the-road driving test. By these studies, a clear negative relationship with the quality of
driving performance is suggested. In the same paragraph, and in contrast to this suggested negative relationship, we also mentioned the reports by Vos and Riemersma (1976), Warmink et al. (1998) and by Schulte et al. (1999). These reports warrant against an absolute negative influence of HH on practical fitness to drive. Thus with the reports discussed so far, we indicated that, with respect to HH, some authors provide clear negative relationships, whereas others do not find significant differences with controls on practical driving performance or driving-related parameters.

More moderate conclusions are drawn by Szlyk and co-workers (Szlyk et al., 1993). They assessed the driving performance of six older patients in an interactive driving simulator and compared it to performance of seven normally sighted age-matched controls and to a younger control group (31 youngsters). The patients had extended occipital lobe damage resulting from CVAs. Visual field assessment was done by means of a Goldmann perimeter (V4e target) and showed that three and four patients respectively had left and right sided homonymous VFDs (either hemianopia or quadranopia). The authors also report three patients neglecting their missing hemi-field of whom one with left and two with right sided hemi-spatial impairment. Driving was simulated by means of car with automatic transmission (consisting of a seat, steering wheel, acceleration and pedal brakes) in a world provided by three large colour monitors simulating a dynamic and realistic visual environment of 160° horizontally by 35° vertically. Subjects were allowed a 15 min training session followed by a 5 min test course where they were instructed to operate the simulated vehicle as they would normally drive and to obey all traffic regulations. Several challenges were encountered during the test-ride including intersections with crossing traffic, cars passing on the left, a cow approaching and crossing from the right, and cars merging on the roadway. Several simulator indexes were analysed including lateral position, speed, slowing and stopping, and accidents. Results showed worse driving performance by patients relative to the age-matched group suggesting a negative influence of the brain damage and VFDs. This was evidenced on for example lane boundary crossing and variability in lane position. But on other indices as absolute lane position, steering and vehicle angle, average slowing and stopping, speed, acceleration and brake pedal pressure, accidents and eye-movements, no differences were found. Thus on most of the indices, most of the patients performed at levels (nearly) equivalent to age-matched controls. These patients showed greater head-movements than controls, enabling them to compensate for the visual field loss. Thus, as a group, these patients showed relatively little abnormalities, but clearly some specific patients showed marked limitations. One patient with reported left hemi-field neglect, failed to stop at any of the traffic signals. Another patient, with reported right hemi-field neglect had outlier performance on nearly all indices. Hence within the hemianopic patient group, clear differential performance can be observed ranging from normal to highly deficient. Comparing patient and age-matched groups to the younger group revealed strong effects of age. This is, all older individuals (both controls and patients) performed worse than the younger ones. This reveals that not exclusively the brain damage and VFDs negatively effect driving performance but that age is also a significant factor in this simulator task. Szlyk and colleagues (Szlyk et al., 1993) 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, impairment might lead to higher levels of limitation. This is in line with a previous point we made namely that limitation is not exclusively determined by impairment, but that also 'personal characteristics' exert a possible important influence.
2.5.2.2.2. Hemi-spatial Neglect and driving(-related) performance

An interesting study, not starting from the impairment level but from the limitation level, is a study by Webster et al. (Webster et al., 1995). However, although these authors report (severe) hemi-spatial limitation (also in driving-related performance) in their patient group, they do not provide clear indication about its specific cause. In addition to the discussion of hemi-spatial limitation, this paper is also for other reasons relevant for our purposes. Namely, the study specifically addresses the issue of hemi-spatial neglect and the caveats concerning research on fitness to drive with this group of patients. We will therefore first discuss this paper by Webster and colleagues and subsequently complement it with more general findings on hemi-spatial neglect and driving.

Before discussing their results in more detail, we will first describe the included subjects as to justify our interest. Patients were classified in three subgroups on the basis of the severity of hemi-spatial limitation (which is indicative for hemi-spatial impairment) as evidenced in neuropsychological tests (to be specified further on). Lesion analysis of the patients’ (CT or MRI) brain scans (when available) were performed to investigate the possible relationship between lesion location and hemi-spatial limitation. This revealed for nine of the ten subjects in the most hemi-spatially limited subgroup (L-Omit, see further) right inferior parietal lobe and right thalamic damage. The other subject had right thalamic damage. These sites are commonly associated with hemi-spatial neglect (e.g. Vallar, 1993). In a second, modestly hemi-spatially limited, group (R-bias, see further), lesions involved the right parietal lobe (two subjects) and the right frontal lobe and/or right basal ganglia (six subjects). These sites are also suggestive for hemi-spatial neglect (e.g. Vallar, 1993). A third group (non-Neglect, see further) suffered more anterior brain damage, not involving the right parietal lobe (four subjects). On the basis of both hemi-spatial limitation and anatomy, only the latter group can be 'free of suspicions' of suffering hemi-spatial impairment, either lower-, higher-order or both. On the same grounds, the information concerning both former groups is highly indicative for hemi-spatial impairment. It is very plausible to interpret the hemi-spatial limitations as a result of hemi-spatial neglect to a severe or mild degree respectively. In addition, on the basis of frequency of co-occurrence (previously discussed), and on the basis of lesion location and presented hemi-spatial limitation, these patients can also validly be suspected of suffering from left-sided HH.

Hence, this is a relevant study, firstly on the basis of the (severe) hemi-spatial limitations presented by two subgroups of this right hemisphere brain damaged patient group. Secondly, both lower- and higher-order visual hemi-spatial impairment can be expected in at least two of the three patient groups.

Having justified our interest concerning the patients, we further need to account for the reason why, in this study, there is no driving assessment in the format of an on-the-road test. As already mentioned, hemi-spatial neglect might be considered as an extreme case of hemi-spatial impairment resulting in severe hemi-spatial limitation. Therefore, severe neglect is often considered as highly indicative for unfitness to drive. Hence, on-the-road driving assessment is usually considered as very hazardous and alternative testing imposes itself. In this study, a wheelchair mobility task was favoured. This task has clear similarities to a real driving task as equivalent variables as lateral position, speed, (near) accidents etcetera can be observed and evaluated. As a consequence, in spite of severe visuo-spatial limitation, similar visuo-spatial functions, as used in real driving, can be assessed under less dangerous conditions.
Having clarified the reasons for presentation, we can now in more detail discuss the paper and its implications. In this study 55 patients with right sided brain damage were classified into three groups on the basis of performance on two neuropsychological tests. These tests were the Rey-Osterrieth Complex Figure Drawing and a Letter Cancellation Test from which two dependent variables were derived. The first variable considers the number of omitted items. Expressed as left-sided relative to right-sided omissions, this measure indicates differential lateral performance and thus hemi-spatial limitation. For the second measure, task initiation locations (starting points) were recorded. Deviation from the mean starting point displayed by controls, is expressed as a left/right orienting bias. Controls almost always start on the left. Applying these two “lateralisation” parameters, one group was termed the L-Omit group. These 32 patients omitted left-sided stimuli on both tasks and tended to start the tasks more to the right side than controls. The authors note that they preferred to label this group in terms of omissions (limitations) rather than refer to it as the “severe neglect” group (higher-order impairment) because “not all subjects presented all the cardinal features of the traditional neglect syndrome”. This confirms our suspicion that this group indeed not only consisted of what are traditionally called “neglect patients”, but also included patients with lower-order hemi-spatial impairment (i.e. left-sided HH). The same remark holds for the second group (R-bias) which consisted of 11 subjects who showed a rightward orienting bias, namely they exceeded criteria for starting to the right on at least one task, but did not meet the criteria for the left-sided omissions. The third group (Non-Neglect) consisted of 12 patients who showed neither the left-sided omissions nor the rightward orienting bias. The control group comprised of 20 chronic pain patients with no history of brain damage.

Standard hospital incident reports (when available) on all types of falls were reviewed and evaluated. Results show that both L-Omit and R-bias groups fell more than both other groups. Within one week of completing both neuropsychological tests, a 122 m wheelchair obstacle course was traversed and evaluated. The route consisted of six left and six right turns, and 12 obstacles occurring at each side. The path-width was demarcated by a rope and was 81 cm wide (standard door width). Each subject was instructed to propel the wheelchair through the path without striking anything, in a manner that they would usually do, and as safe as possible. They were told they had unlimited time. The control subjects were asked to use only the right arm and leg to propel the wheelchair as to approximate the motor disadvantage experienced by the majority of patients. For evaluation, direct frontal hits and sideswipes (contacts made with the side of the wheelchair) were counted.

In general, the results from the wheelchair obstacle course were in line with the pattern of results of the falls. Both L-Omit and R-bias groups made more left-sided sideswipes than the other groups. However, only the L-Omit group made right-sided direct frontal hits and made also significantly more left-sided direct frontal hits (most severe error) than any other group. Several notable conclusions can be drawn from this study. Firstly, severity of hemi-spatial limitation as measured by neuropsychological tests, by reports of fall-data, and by this visuospatial wheelchair mobility and navigation task, are in concordance. Secondly, the fall-data did not differentiate L-Omit and R-bias groups and showed a clear difference with the Non-Neglect group and controls. In concordance with this are the results of the side-swipes in the wheelchair course. It is thus suggested that, not only “obvious neglect patients” but also patients with similar but less pronounced and “more subtle hemi-spatial tendencies” (R-bias group) are at a greater risk for falls and wheelchair collisions (i.e. side-swipes) than patients without any such symptoms. It could hence be concluded that neuropsychological visuo-
spatial test performance (which was the basis for group assignment), and in particular left-sided omissions and spatial location of the patient’s initial approach to these paper and pencil tests, has clinical significance in that they could be associated with increased accident risk. As already argued, this wheelchair mobility course can be defended to have equivalent components to a real driving task. Though, it would still be interesting to study these relationships with real driving performance. Thirdly, in contrast, the wheelchair course differed from the fall-data in that the L-Omit group (alleged severe neglect group) was the only group that showed right-sided direct hits and had more left-sided direct hits than any other group, including the R-bias group (alleged mild neglect group). This suggests that in the group of patients with hemi-spatial impairment, different levels of limitation can be observed using this ‘ecological’ wheelchair obstacle course.

These points taken together indicate that, when using sensitive neuropsychological visuo-spatial tasks, a continuum can be demonstrated ranging from “severe hemi-spatially limited” to “normal”, with the patients evidencing more subtle hemi-spatial impairment in between. These tasks can still have clinical significance. This suggests that considerable effort should be invested in any (pre-driver) neuropsychological test battery, in prevention of using not sensitive enough measures for quantifying hemi-spatial impairment.

Having described this group-study on relating hemi-spatial neglect to driving-related performance, we would like to complement the discussion with more general remarks on hemi-spatial neglect and driving. Systematic investigations relating hemi-spatial neglect to actual practical driving performance are very scarce, presumably because of safety reasons or because nothing more than a disastrous driving outcome is expected. Occasional case reports have been described which show that visual field defects in association with neglect behaviour can be potentially dangerous for driver and pedestrian (Robertson et al., 1999). Denial of impairment (anosognosia) is a characteristic feature of the neglect syndrome and cases have been described where only after fatal accidents and prolonged court cases cessation of active driving by the patient could be accomplished. Other case reports on hemi-spatial neglect explicitly mention driving problems during everyday driving and are mostly indicated by the partner. In a cognitive rehabilitation study by Rao and Bielaiuskas (Rao & Bielaiuskas, 1983), the partner of the patient reports “accidents caused by misperception of cars approaching from the left side”. In a case study by Barrett and colleagues (Barrett, Schwartz, Crucian, Kim, & Heilman, 2000) showing differential neglect symptomatology in peri- and extrapersonal space, the patient was reported to have a “disturbing tendency to veer to the right towards people or objects present on that side of the road”. In our own work (Tant, Brouwer, Kooijman, & Cornelissen, in press), we observed suboptimal scanning behaviour but also extreme (left) deviant lateral positions, on assessment in a realistic interactive driving simulator in a neglect patient after an otherwise successful rehabilitation program. We too, in case of indication of severe neglect, opted for assessment using a ‘realistic interactive driving simulation’, instead of a the usual practical driving test, because of safety reasons. Our criteria for the diagnosis of severe hemi-spatial neglect are described elsewhere.

In conclusion, although severe hemi-spatial neglect is frequently considered to be a definite contra-indication for practical fitness to drive, overgeneralizations have to be avoided since the relationship has only scarcely objectively been investigated. The study by Webster et al. (1995) shows and confirms that hemi-spatial neglect can be confused with left-sided HH. However, the impairments should be clearly differentiated, both with respect to differential rehabilitation methods and -outcomes, but also on the basis of severity of limitation and hence
its differential implications on practical fitness to drive. Further, since it can be argued that the severity of hemi-spatial limitation can cover a broad range, a (hemi-spatial) neuropsychological battery should be able to differentiate between these different levels. Thus, an adequate screening battery for severe hemi-spatial neglect in addition to a range of sensitive tests for hemi-spatial functioning is in order as to subtly indicate the severity of hemi-spatial limitation.

2.5.2.2.3. Mixed groups and driving(-related) performance

In our introduction, we argued that not all studies relevant for our points, specifically investigated hemi-spatial impairment, but did touch upon this topic indirectly. Since such studies are merely “suspectedly” relevant, they will be dealt with rather briefly. As previously discussed, not all studies are unequivocal with respect to patient selection. Hence, some studies including brain damaged patients are not unambiguous with respect to either presence or measurement of the VFDs in their patient sample. On some occasions the actual perimetric technique is not mentioned or the diagnosis is based on a confrontational technique, for which unquestionably more accurate alternatives can be chosen. In other reports, VFDs are not explicitly mentioned as an exclusion criterion, suggesting that they may be included in the sample. The same caveat holds with respect to higher-order hemi-spatial impairment. The type, severity, and localisation of brain damage and some typical observed behaviours (i.e. hemi-spatial limitations) make it highly likely that some samples did in fact contain (at least some) patients with homonymous VFDs or higher-order hemi-spatial impairment (or both). These samples can thus be suspected to be “mixed” groups as is for example possibly the case in a study by Sivak (Sivak et al., 1981).

In this study, twenty-three persons with brain damage were compared to 10 controls and to eight patients with spinal-cord damage. The brain damaged group consisted of 10 patients with left-sided, six patients with right-sided and seven with bilateral brain damage. Each subject’s performance was evaluated using three sets of tests: a set of 12 perceptual-cognitive neuropsychological tests, a closed-course driving test and an open-road driving test, each assessed on several parameters. The neuropsychological tests were chosen on the basis of expected relatedness to driving performance, involving minimal motor requirements and expected deficiency in a brain damaged population. The closed-course driving test consisted of performing several basic driving tasks on a private parking lot. For the open-road driving test, the subjects drove a 17 km course under different (common) traffic conditions. In general, brain damaged subjects performed worse than controls and than patients with spinal cord damage. In accordance with the dominance of both hemispheres, the authors report worse performance of left brain damaged subjects on tasks with a high verbal component versus worse performance of right brain damage subjects on tasks with high nonverbal and perceptual components. This general pattern of performance was observed in all three sets of tests. Interestingly and making these results relevant for this discussion, in the closed-course driving test, the brain damaged subjects exhibited problems on tracking of the road contralateral to their brain damage: left-sided and right-sided brain damaged subjects hit more cones on the right and left side of the road respectively. Thus, although indicated by hemi-spatial visual limitations, the authors do not provide information whether or not and which of the patients suffered any kind of hemi-spatial impairment.

Having observed hemi-spatial visual limitation and inferred suspected hemi-spatial impairment, we can briefly discuss their further findings. Not all subjects were judged or proved to be competent enough to allow for safe testing conditions in the open-road driving
test. It was completed by thirty-seven subjects. Correlational analyses indicated that, among other indices, age, sex, education, driving experience and time since lesion were not significantly related to the composite driving index (i.e. a measure reflecting overall driving performance). The only difference found was that patients who had driving experience since the acquisition of the brain damage, performed better than those who had not been driving since. When analysed for all subjects simultaneously, most of the neuropsychological tests and closed-course driving measures correlated significantly with the composite driving index. However, the tests which proved to correlate significantly with this overall measure of the quality of driving performance were different for patients with and without brain damage. It was further observed that, for the brain damaged group, none of the closed-course measures correlated with the composite driving index. This is in contrast to the control group, where several of the measures correlated significantly. Both patterns of results might indicate that the nature of the driving task is different in both groups.

Thus, although no conclusive evidence is provided on the presence of homonymous VFDs or other hemi-spatial impairment in this sample, the results could still be relevant, indicated by the specific observation of lateralised visual limitations. Generally, the results confirm our previous point that different patterns of results can be observed for different (patient-)groups indicating different (specific) impairments. It could thus be concluded that the nature of the driving task for patient and control groups might be different and that the closed-course driving manoeuvres might not tap the on-the-road driving-related skills of brain damaged patients. But more to the point for this discussion, is the indication that visuo-spatial functioning, as measured by these neuropsychological tests, is related to driving performance also in this non-specific brain damaged sample (mixed group). This is firstly suggested by the observation that a higher-order visual test of field (in)dependence (Oltman's Rod-and-Frame test) was the best indicator for whether or not patients would perform and complete the open-road driving test. Secondly, the tests which were significantly correlated with the composite driving index, proved to have strong visuo-spatial components. A final note to be made is that the most potent patient characteristic related to the composite driving index was found to be driving experience since the brain damage.

The presentation of this paper, not only has theoretical value (although limited), but is also clinically of importance. It clearly suggests that studying visuo-spatial tasks (i.e. driving) in a non-specified brain damaged population almost inherently yields indefinite conclusions. Especially, since the relatively high occurrence of homonymous VFDs following post-chiasmal brain damage, and the frequent co-occurrence of higher-order hemi-spatial impairment (see previous discussion), this dictates detailed and specific quantification of these deficits. Finally, more positively, it could be inferred that gaining experience with the acquired impairment, can be an important aspect of rehabilitation- or training programs, since subjects who had driving experience since their brain damage performed better. It could be argued that these patients gained more experience in this specific situation, and could thus adapt better to the impairment.

3. Conclusion and Implications

We conceptualised visual function as consisting of two aspects, namely lower-order and higher-order visual function, both possibly resulting in limitations (and restrictions). The lower-order visual impairments of our interest are VFDs, more specifically HH which is a hemi-field loss. Due to it's cause, namely post-chiasmal brain damage, it can be accompanied by higher-order visual impairment, often of a (hemi-)spatial nature. This possible co-
occurrence might explain the variability in research outcomes concerning practical fitness to drive in this patient population. Hence our interest in hemi-spatial impairment. This interest is also fed by the nature of the driving task. The driving task is composed of many different aspects on different levels. It was argued that visual and spatial information-processing are clearly essential. A battery aimed at relating test performance to the quality of driving performance, should include ophthalmological and neuropsychological tests with strong visual hemi-spatial components.

Thus, in our own research, we aim at selectivity in test choice and in patient population. We choose to focus on patients suffering from HH and related hemi-spatial impairment. Therefore we will apply a predominantly visual hemi-spatial test battery to relate ophthalmological and neuropsychological test performance to practical driving performance. Fitness to drive will be evaluated on the basis of practical driving test. An on-the-road test is, in our opinion the best choice for evaluating practical fitness to drive and is the golden standard in the Netherlands. In constructing and selecting our ophthalmological and neuropsychological tests, it has been our aim to be accurate, specific, and detailed with regard to the quantification of the visual (hemi-)spatial impairment, both in terms of lower- and higher-order visual impairment. Standardised perimetric assessments will evaluate the type and extent of the VFD. A visuo-spatial screening should demarcate patients with the most severe hemi-spatial limitations (i.e. severe hemi-neglect patients), since this extreme condition is almost always found to be incompatible with standard and safe on-the-road driving-assessment. The remaining visuo-spatial tasks should be sensitive enough to show the also more subtle hemi-spatial limitations, as to be able to observe a continuum in severity of hemi-spatial limitation and impairment, and relate this to practical fitness to drive.

4. Reference List


Part I: Driving-related Research


Part I: Driving-related Research


A Visuo-spatial test battery

1. General
1.1. Introduction
In the previous chapter, it was argued that the use of cognitive and perceptual tasks can provide significant information about multiple aspects related to driving performance. It was argued that specifically both lower-order and higher-order aspects of visual functioning are relevant in this respect. This focusing is in line with the nature of the driving task and the plausible hemi-spatial visual impairments and limitations displayed by the specific subject group of interest, namely patients suffering homonymous hemianopia (HH) and related disorders. Therefore, our neuropsychological test battery is aimed at assessing visuo-spatial functioning. Visuo-spatial functioning can be expressed in many tasks.

In the previously reviewed studies, many different tests have been subjected to the patients. Additionally, different types of assessment of driving performance have been applied to different and sometimes unclearly defined patient groups. In these studies, only a limited range of visuo-spatial tests were used, which renders it impossible to compare their relative efficiency. Therefore, selection of testing methods, purely on empirical grounds is less obvious. Hence, a broad range of visuo-spatial tests were selected, which have been successfully related to driving performance in previous studies. The selectivity in test choice, for which we argued, is applicable on the class of function assessed, namely visuo-spatial function. The range of visuo-spatial assessments has the further advantage of assessing different aspects of visuo-spatial functioning. Additionally, their interrelatedness can be studied, and by combining their outcomes, a detailed indication can be provided concerning the nature and severity of visuo-(hemi-)spatial impairment.

1.2. Evaluating Visuo-spatial performance
1.2.1. Basic performance: Speed and Accuracy
The selected tests can be evaluated on different aspects, as to increase their efficiency and sensitivity. Speed and accuracy are evident and frequently used dependants to quantify the quality of test performance. Both on theoretical and empirical grounds, it was concluded by Brouwer (in press) that tests of visual speed are moderately correlated to driving performance as assessed in test-rides. In general, this concerns speed of detecting and identifying simple discrete stimuli (e.g. Ball, Owsley, & Beard, 1990) and visual search speed (Withaar, 2000). Thus, to get a reliable indication of this speed component, reaction times (RTs) and completion times on several tests from different visuo-spatial domains are recorded.

Accuracy is also an indicator of efficiency of performance. However, speed and accuracy can be highly interdependent. It is important to appreciate this interrelatedness to fully and adequately interpret the test-results. The interrelatedness of speed and accuracy often results from the nature of the task, the instructions and the preference of the subject. For example, when stimuli are presented for a very limited time, accuracy is actually an indication of speed. This is for example the case in a test where the minimum presentation time (speed component) is determined to identify (accuracy component) simple stimuli. In contrast, when stimuli are presented in a very inconspicuous manner, speed reflects accuracy. A difficult recognition task (accuracy component) might better be analysed in terms of speed, because eventually all subjects would recognise the picture, when given ample time. Also the subject
may voluntarily choose to perform fast and less accurate or vice versa. Our instructions were, unless otherwise specified by formal and official test-instructions, to perform as adequate and fast as possible, in order to approximate an optimal balance of speed and accuracy. Further on, the visuo-spatial tasks and respective methods of analysis will be explained, accounting for this interdependence.

1.2.2. Lateralised performance: the Asymmetry Index
Thus, most tests will be evaluated on one or both of the basic parameters of speed and accuracy. These dependent variables give an indication of visuo-spatial performance in general. But since we are more specifically interested in visual hemi-spatial impairment and limitation, we additionally compute (when possible) a lateralisation score or asymmetry index (AI). This index can be computed from for example differential accuracy or speed measures in the left and right hemi-space, from the location of task initiation, from the (side of) deviation from an expected location, from a preference for either left or right hemi-space etcetera. This AI expresses a lateralised perceptual bias, measured by the degree of differential lateralised performance, independently from general performance. Combined with general performance, the AI distinguishes between a hemi-spatial (and thus lateralised) impairment and a more general spatial, attentional or scanning deficit. In the former there will be a bias in performance on one particular side, resulting in an apparent and high AI. In the latter, the performance level will be more equally distributed across both hemi-spaces, resulting in a low AI. Unless otherwise stated, the AI is calculated as

\[
\frac{\text{right performance} - \text{left performance}}{\text{right performance} + \text{left performance}}
\].

In terms of RTs this would be

\[
\frac{\text{right RT} - \text{left RT}}{\text{right RT} + \text{left RT}}
\].

This formula results in a statistic ranging from -1 to +1. A score of 0 indicates no differential performance. Scores tending to -1 and +1 indicate a relative preponderance of performance on the left and right respectively. Additional information and theoretical considerations on the AI can be found in the chapter “Grey scales uncover similar attentional effects in homonymous hemianopia and visual hemi-neglect” in this dissertation.

1.3. Pre-driver and Driver assessment
In a previous chapter, we discussed the notion of fitness to drive. As it is our aim to study the quality of driving performance, we administer an on-the-road driving test. As such, the driving outcome can be considered an independent variable, as are the neuropsychological outcomes. But since it is our aim to relate performance on the neuropsychological tests to the quality of performance on the driving test, the driving outcome can be considered a criterion. The outcome on the neuropsychological test battery and the ophthalmological screening are then the predictors. As such, neuropsychological and ophthalmological outcomes can be referred to as "pre-driver" assessments.

1.4. Summary
In a previous chapter, we argued for selectivity and specificity in test choice. On the basis of previous research, no specific or limited number of tests emerges which can successfully predict practical fitness to drive. However, the specific patient population of interest, namely HH patients, suffering specific impairment, and the nature of the driving task, both strongly suggest to focus on visuo-spatial functioning.
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. Visuo-spatial perception is further involved in our ability to accurately reach for objects in visual space and our ability to shift our gaze to different points in space in order to effectively scan and search for objects. Impairments in visuo-spatial functioning could be for example impaired discrimination of complex stimuli, recognition, figure-ground differentiation and visual integration. Other visuo-spatial dysfunctions are defective localisation of points in space, judgement of direction and distance, and topographic disorientation. These impairments can result in subjective complaints as 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 etcetera.

In our aim to assess as many relevant aspects, finding a balance between quality and quantity, we chose for a number of 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 the tracking task (Dy). From these tasks (or factors) multiple aspects can be evaluated, namely basic performance in terms of speed and accuracy, and differential lateralised performance in terms of left-right asymmetry. In the following paragraphs, the construction of the visuo-spatial factors will be presented, the tests are described and the associated dependent variables will be indicated. This is visualised and summarised in Table 1.

2. The Visuo-Spatial Factors and Tests
2.1. Factor 1: Basic Visual Scanning and Search (BVSS)
As previously argued, visuo-spatial perception is involved in ability to shift our gaze to different points in space in order to effectively scan and search for objects. This is considered to be a very basic ability as it is frequently described by the patients as "not effectively or forgetting looking around, not simply finding things, failing to notice (visual) events on time, always looking and searching in the same direction, etcetera". Tests from this factor all hold a predominantly simple scanning and/or search component. This component is minimally influenced by other cognitive factors as visual integration, segmentation etcetera. The variety of tests include different types of stimuli (symbols, letters, numbers), under different presentation modes (paper, computer screen, projection screen), requiring different response modes (key-press, pencil, oral), under different conditions (limited or unlimited presentation times). Also, tests which are usually considered as 'visual-attentional' tasks are a part of this factor because of the close relationship of visual-attention and scanning. Thus, clinical visual neglect tests (delineated in the table), such as line bisection and cancellation tasks, are a part of this factor. Also reading is included, since our primary interest in reading is the substantial scanning component.
Table 1. Summary of visuo-spatial factor construction.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Visuo-spatial Test</th>
<th>Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Basic performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Speed</td>
</tr>
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<td>Basic Visual Scanning and Search (BVSS)</td>
<td>Trail Making Test</td>
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</tr>
<tr>
<td></td>
<td>Counting Dots</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Position Discrimination</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>TAP Eye movements</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>TAP Visual Scanning</td>
<td>✓</td>
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<tr>
<td></td>
<td>The Attended Field of View Test</td>
<td>✓</td>
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<tr>
<td></td>
<td>Detection Task</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Reading words</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Reading strings</td>
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</tr>
<tr>
<td></td>
<td>Zihl Dotcounting test</td>
<td>✓</td>
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<tr>
<td></td>
<td>Line bisection</td>
<td>✓</td>
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<tr>
<td></td>
<td>Albert’s line cancellation Test</td>
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<tr>
<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>
<td>The Bells Test</td>
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<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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<td>Representational Drawing test</td>
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<td>Complex Figure Test</td>
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<td>Position Determination</td>
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<tr>
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<td>Blocks</td>
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<tr>
<td></td>
<td>Hidden Figures Test</td>
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</tr>
<tr>
<td></td>
<td>Overlapping Figures Task</td>
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</tr>
<tr>
<td>Dynamic (Dy)</td>
<td>Tracking task</td>
<td>✓</td>
</tr>
</tbody>
</table>

2.1.1. Trail Making Test

Trail Making Test part A (TMTa) (Reitan, 1992) is a test for speed of visual search, attention and motor function. It requires the connection, by making pencil lines, in ascending order between 25 encircled numbers randomly arranged on a page. Trail Making Test part B (TMTb) (Reitan, 1992) is similar to part A, except that the B-version consists of 25 encircled numbers and letters which have to be connected in alternating order. As such, it is also a test for speed of mental flexibility (Spreen & Strauss, 1991). For both parts, basic performance is expressed in terms of the time (in seconds) required to connect all circles.

2.1.2. Counting Dots

This test is subtask 5 from the Visual Object and Space Perception Battery (VOSP) (Warrington & James, 1991). It consists of 10 white cards (150x210 mm²) containing 5-9 black dots (5 mm) randomly scattered. It entails localising and simple scanning as the task is to count the dots (no time limit). Performance is indicated by the number of correctly counted cards.
2.1.3. Position Discrimination
This test is subtask 6 from the VOSP (Warrington and James, 1991). One item consists of two horizontally aligned black squares (80x80 mm$^2$). Each square contains one black dot (5 mm). Only one of the dots is positioned exactly in the centre of its square. The task is to find and indicate the centre-dot (no time limit). Performance is scored as the total number of correctly answered items (max 20).

2.1.4. TAP Eye movements
This task is a subtask of the Testbattery for Attentional Performance (TAP) (Zimmerman & Fimm, 1994). It measures the speed of an overt orienting response, namely a saccadic eye-movement. Stimuli consist of small white squares (15x15 mm$^2$) on a black background. In the target stimulus, the square has an opening on top. Stimuli are randomly presented on three possible positions (horizontally aligned): centre of the screen, left and right. The peripheral stimuli were 135 mm separated from the centre position. Viewing distance was approximately 450 mm. The subject pressed a button when the target stimulus appeared. Basic performance is the overall RT. The difference in RT between central and (left or right) peripheral targets gives an indication of lateralised performance (and is indicated by an AI).

2.1.5. TAP Visual Scanning
This task is a subtask of the Testbattery for Attentional Performance (TAP) (Zimmerman and Fimm, 1994). It gives an indication of speed and strategy of visual search. One item consists of a 110x110 mm$^2$ matrix of (5x5) white squares. The squares measure 15x15 mm$^2$ and all have one discontinuous (i.e. open) side. The target stimulus holds the open side on top. In each matrix, there is only one target, if any. The task of the subject is to indicate whether or not the target stimulus was present by pressing one of two buttons (present vs not present). Basic performance is scored in terms of the overall reaction time (RT) and the number of correct decisions. Correlational analysis (RT by position) results in row- and column-correlations, indicating the method and direction of search (top to bottom or vice versa, and left to right or vice versa). The column correlation gives an indication of lateralised performance.

2.1.6. The Attended Field Of View Test
This visual search task (AFOV) is extensively described by Coeckelbergh (Coeckelbergh, Cornelissen, Brouwer, & Kooijman, submitted). After central fixation, a display of 31 circles is presented. The positions of the circles are organised in three elliptical rings subtending 60° by 24°. One circle (target) has a gap. The task of the subject is to indicate the direction of the gap (left, right, up or down). The presentation time of the display is adjusted by a staircase procedure determining 75% correct identifications of the gap-direction at that particular location. Performance is scored in terms of speed and efficiency of distribution. In the appendix of this dissertation, a detailed description of the method of scoring of the AFOV is described in “Assessing visual search in the AFOV test”.

2.1.7. Detection Task
In this scanning task, digits (1-9) or symbols (X or O) are singly and randomly presented in one of 48 different positions (4 rows x 12 columns) on a large projection screen (approximately 100° horizontally and 60° vertically). The stimulus software is developed and described by Pizzamiglio and colleagues (e.g. Pizzamiglio et al., 1992). We adapted the original procedure by using a voice-key which registers the naming/detection latency. The
mean RT is taken as a measure of speed. The standard deviation is a measure of consistency of search. An AI is calculated based on the differential RTs and STDs on left and right side of the projection screen.

2.1.8. Reading

2.1.8.1. Word version
In the reading test, 90 unrelated Dutch words are presented over 16 lines on a A4 sheet of paper in landscape orientation. Words are printed in bold Arial 20 point font. Mean word length is 8.2 letters and varies from 2 to 18 letters. Longer words usually are compositions (e.g. sunflower). The mean number of words per line is 5.6 and varies from 3 to 8 words. The left and right margins are varied, as is the spacing between the words, resulting in a irregular type page.

We started with two different reading tests and constructed parallel versions of each one, changing the words but keeping their positions and approximate lengths. Not all words were changed completely: in some words only the first or last composite part was replaced (e.g. sunflower into cauliflower).

We record reading time and accuracy. We calculate the mean reading speed per word by dividing the total reading time by the number of words actually read. For accuracy, we consider the number and type of errors. Errors are scored on two dimensions: the word level and the line level. A word-error is committed when part of a word is not read. Not reading a complete word is scored as a word-omission. We also note the number and location of words read more than once (word-repetitions). A line-error is committed when the subject does not start or end reading respectively at the first or last letter on that line, and is scored as a left- or right-sided line error, respectively. The location of the error within the word (left or right part) is noted as is the location of omissions and repetitions on the line. Reading accuracy is operationally defined as the sum of the proportion of all errors. From the accuracy measures, an AI is deduced.

2.1.8.2. Letter-string version
To investigate the influence of the direction of gaze during reading and to minimise the effect of word recognition, we devised also an alternative ‘reading’ test, based on the previous word-reading test. This alternative test was constructed by again replacing all the words while keeping the positions. All words were replaced by strings of random letters and numbers of equal length as the words they replaced. The subjects were asked to read all the strings character by character, first as they would read a normal page (i.e. from left to right in the word and starting from the leftmost string on the page, proceeding rightwards). Subsequently they were asked to do the same but in reversed order on the word level thus ‘reading’ the strings backwards but again starting with the leftmost word on the line (i.e. from right to left in the string, but left to right on the line). Performance is scored in the same manner as the word-reading tests.

2.1.9. Zihl Dotcounting test
Zihl (e.g. 1995) presented a task to assess the presence (if any) and quality of a compensatory scanning strategy displayed by HH patients. This test consists of one trial in which 20 dots are presented on a computer screen and have to be counted. We adapted the work of Zihl by using more dot patterns and varying the distribution and the total number of dots. We presented in total 29 trials. The total number of dots in a particular trial was 5, 7, 9,11 ,13 ,15,17, 19, 20 or
21 dots. The screen dimensions were 36° and 27° horizontally and vertically respectively. The dot size was 1°. Dots were white on a grey background. Subject are instructed to count and to report verbally the number of dots presented as quickly and accurately as possible. We compute the mean response time as speed measurement and the mean absolute error as accuracy measurement. The response time is the time between presentation of the trial and verbal response. The absolute error is the unsigned value of the difference between the actual number of dots and the reported number. For a more elaborate discussion of the dotcounting task, we refer to the relevant chapter in this dissertation (part III: Hemianopic Visual Field Defects elicit Hemianopic Scanning).

2.1.10. Clinical Neglect tasks
The neglect battery (marked in the table) is the collection of the following tests, which are clinically frequently used to diagnose (visual) hemi-spatial neglect. The battery is used not only to quantify (parts of) visual scanning and search, but also to diagnose severe neglect as this was an exclusion criterion for the actual HH-project. Hence, these tests are part of both the pre-driver and the screening assessment. The rationale for exclusion is described in the screening section of the chapter addressing “Driving and Visuo-spatial Test performance in Homonymous Hemianopia” in this dissertation. Used as screening tests, the performance is scored with reference to cut-off scores. As pre-driver assessment tests, performance is scored in more detail, as will be described. At this point, only five of the six clinical neglect tests are presented. The representational drawing test will be described when addressing the VCO-factor.

2.1.10.1. Line bisection
The line bisection task (Schenkenberg, Bradford, & Ajax, 1980) consists of an A4 sheet of paper (landscape orientation) with 20 horizontal lines. Eighteen of the lines are organised in three sets of six lines, so that one set is situated primarily on the left, one set on the right and one in the middle of the page. Each set contains lines of 100-200 mm, with 20 mm increments. The order of the lines is random with respect to line length and position, and are vertically distributed across the page. Two 150 mm centre lines are added at top and bottom of the page for instruction purposes and are not included in the analysis. Scoring is achieved as described in Schenkenberg and colleagues (1980) and entails the computation of an average percent deviation score. The absolute value of this deviation score gives an indication of basic performance. The average percent deviation score is comparable to an AI.

2.1.10.2. Cancellation tasks
We will first specify the four cancellation tasks we selected, after which the scoring procedure will be described as the rationale is identical for all four of them. We chose to select cancellation tasks of different difficulty levels and different stimuli. Both the Albert's line test and the Mesulam's test are of a moderately difficulty level as there are respectively few and unambiguous targets or he position of the stimuli is structured, promoting structured search. Both other tests are unstructured, have many targets, have different types of stimuli (symbols or letters), and have different page orientations (landscape or portrait).
In each cancellation task basic performance is scored in terms of completion time and accuracy. The completion time is the time from presentation of the sheet until indication by the subject of being finished. The completion time was not measured in the modified Albert’s
Part I: A Visuo-spatial test battery

Lines test. Accuracy is expressed by the number of omissions. Using left- and right-sided omissions, an AI is calculated.

2.1.10.2.1. Modified Albert’s line cancellation Test
This line-cancellation task (Albert, 1973; Halligan & Marshall, 1989) is a test frequently employed for diagnosing severe visual neglect. The task consists of an A4 sheet of paper in landscape orientation, with an array of 40 variously orientated black lines. These lines, each of 25 mm, are pseudorandomly distributed in six columns of six lines each, and one central column of four lines. The purpose of the test is demonstrated by the examiner by crossing out the four central lines, leaving 36 lines to cancel for the subject (18 on the left and 18 on the right).

2.1.10.2.2. Mesulam Structured Shape cancellation
This cancellation task was introduced by Weintraub and Mesulam (1988). In their study they examined the effect of stimulus material on the severity of neglect. They varied several stimulus dimensions as for example the type of material (letters vs geometric shapes) and stimulus array (random vs structured). We opted only for the structured–shapes version. The stimuli are displayed on an A4 sheet of paper in landscape orientation. There are 60 black targets to be found and circled. These targets can be described as "an open circle with radiations and a single slanted line". They are equally divided over the four quadrants of the page and are interspersed with 300 distracters in total. The stimuli are linearly organised in rows and columns (structured) and the targets are in symmetrical locations with respect to the horizontal and vertical axes of the page.

2.1.10.2.3. The Bells Test
The Bells Test (Gauthier, Dehaut, & Joannette, 1989; Vanier et al., 1990) consists of 315 figures pseudorandomly distributed on an A4 sheet of paper (landscape orientation). All figures are black silhouettes of familiar objects and are about 0.7 cm$^2$ in size. Of these 315 figures, 35 are bells (targets) and 280 are distracters (guitar, house, key etc.). The positions of the bells are organised into seven columns (five bells per column). The purpose of this test is to find and circle all the bells.

2.1.10.2.4. Search for O's
In this cancellation task (OZO) the subject is presented with an A4 sheet of paper in portrait orientation. This sheet contains black letters pseudorandomly distributed. There are 40 target letters (“o”), ten in each quadrant and 430 distracter letters (all the other letters of the alphabet). The purpose of this cancellation task is to find and circle all the o's. To our knowledge this test is not publicly available, but is however widely used for diagnostic purposes in the Netherlands.

2.1.11. Grey scales
The Grey Scales task was originally described by Mattingley and colleagues (Mattingley, Bradshaw, Bradshaw, & Nettleton, 1994). Initially, it was designed to assess the early, automatic orienting of attention towards the ipsilesional side of space, frequently supposed in neglect patients. This test proved to assess this chronic attentional bias in neglect by expressing it as a lateral preference (or lateral bias). Our version contains 26 items. An item consists of an A4 (landscape orientation) white sheet of paper with two vertically aligned rectangular grey scales of equal length. A grey scale is a
Part I: A Visuo-spatial test battery

rectangular strip with a thin black border. Its dimensions are 20 mm in height and 20 to 260 mm in width with 20 mm increments. This rectangular is filled-in by a semi-continuous scale of different grey shades varying between black and white. This filling-in is achieved by defining 33 strips of different grey shades. The width of these band is adjusted according to the length of the rectangular. Grey scales are thus presented in pairs (and vertically aligned) so that one grey scale is the mirror reverse of the other. Hence, one of the grey scales is black on the left and white on the right. The other is exactly the opposite. Each item is presented once with top/bottom position counterbalanced resulting in 26 items. The subject is asked to judge which of the two grey scales (top or bottom) appears overall darker. The subject is encouraged to make a judgement based upon spontaneous and rather immediate apprehension rather than on prolonged and detailed inspection but is told that there is no time limit. This test results only in an AI based on the number of items judged with a rightward and leftward bias. For a more elaborate discussion we refer to the chapter “Grey scales uncover similar attentional effects in homonymous hemianopia and visual hemi-neglect” in this dissertation.

2.2. Factor 2: Visuo-Constructive and Organisational tasks (VCO)

The nature of this type of visuo-spatial functioning is (partly) different from the previous factor, in that in the present tests "spatial insight" is predominant. This function is mainly expressed in spatial constructions and spatial organisations. To acquire, use and maintain this spatial cognition, basic visual scanning and search are a prerequisite though not sufficient. We opted for tests with and without time limits, always minimising the memory component since this is not our primary interest.

2.2.1. WAIS-R Block Design Test

This test is a subtest of the Wechsler Adult Intelligence Scale Revised (Wechsler, 1981) and involves having the subject duplicate specific designs using blocks with different coloured sides. The designs are presented (two dimensional) on a small booklet. The subject uses a prespecified number of blocks in order to duplicate the design in a limited amount of time. Standard procedures for instruction and scoring are used. The raw score is used as the measure of basic performance.

2.2.2. Matrix Copy test

This test is based on a part of a training method for neglect as mentioned in for example Pizzamiglio et al. (Pizzamiglio et al., 1992). An item consists of a A4 sheet of paper in landscape orientation, containing two matrices separated by a thick black line in the middle of the page. A matrix is a set of structurally ordered black dots. In one of both matrices, the dots are connected by lines (i.e. the stimulus), forming a pattern. The successive items (and thus patterns) are of increasing difficulty. The first dimension used to increase difficulty is the size of the matrix. The first set of matrices is composed of 2x2 dots, followed by 2x3, 3x3, 4x4, 4x5 and 5x5. Within each set, the difficulty level is increased by increasing the number of connected dots, the length of the lines and the number of line crossings. The first three sets consist of three items each, the latter three sets contain each four items, adding up to 21 items in total. The task for the subject is to copy the line pattern onto the empty matrix, as quickly and accurately as possible. No instructions or limitations are imposed except for the starting point (dot marked by a small square). Items are presented one at a time with the stimulus matrix on the same side as the visual field defect. The test is ceased when at least one error is made on three consecutive items. Performance is expressed by the total number of errors (i.e.
faulty line segments) divided by the maximum number of faulty line segments, given the number of items attempted. This error-proportion takes into account both number of errors and number of items attempted.

2.2.3. Representational Drawing test
This drawing task is part of the Behavioral Inattention Test (BIT) (Wilson, Cockburn, & Halligan, 1987) and belongs to both screening and pre-driver evaluation, as it is a clinical method for diagnosing (visual) hemi-spatial neglect (described earlier). For each drawing the subject is presented with a blank A4 sheet of paper in landscape orientation with the centre of the page positioned directly in front of the sagital midline of the body of the subject. The subject is first asked to draw a clock face with numbers. They are also invited to set a time at own preference. Next they are urged to draw a simple man or woman and finally to produce a simple sketch of a butterfly. For each drawing, a new sheet of paper is used.

The scoring system provided by the manual of the BIT was applied for screening purposes, but was found to be too basic for our assessment purpose. Therefore, the basic quality of the drawings is scored using a self-constructed system taking both global form and details into account. The reported scores are the average of two independent raters. Scoring also results in an AI based on the absence/presence of (a)symmetry in the drawings.

2.2.4. Rey-Osterrieth Complex Figure Test
In this test the subject is presented with the Rey-Osterrieth figure (Osterrieth, 1944) and is asked to copy it on a sheet of paper, as accurately and quickly as possible. We did not include reproductions from memory. For scoring basic performance, we use the Boston Qualitative Scoring System (BQSS), which provides a global score for accuracy and organisation (Stern et al., 1999). We additionally recorded the completion time. For evaluating asymmetry, we use accuracy scores for left- and right-sided items as suggested by Rapport, Dutra, Webster, Charter, and Morrill (1995).

2.3. Factor 3: Visuo-Integrative tasks (VI)
In contrast to the previous factor, tasks from this factor do not mainly hold constructional and more active spatial components. In the previous (VI-)factor, the more passive, receptive and apperceptive spatial functions are envisaged as visuo-spatial comprehension and understanding, figure-ground separation, field-(in)dependence etcetera. For adequate performance, many different high and low level visuo-spatial information has to be integrated and fused. Basic visual scanning and search can again be considered a prerequisite, but not sufficient for successful visuo-spatial integration. We opted for minimal involvement of memory and motor components.

2.3.1. Position Determination
This test is subtask 7 from the VOSP (Warrington and James, 1991) and consists of 10 items. One item contains two vertically aligned black squares (62x62 mm$^2$). The top square contains numbers (1-9) at randomly placed positions. The bottom square contains one black dot. Its position matches the position of one of the numbers of the top square. The task is to find the matching number. Standard procedure for administration is used and as such there is no time limit. The total number of correctly answered items is taken as indication of basic performance.
2.3.2. Blocks
This test of interpreting two dimensional depictions of a three dimensional object, is subtask 8 from the VOSP (Warrington and James, 1991). It enquires the perception of complex spatial relations. The tests consists of 10 in-perspective drawings of a spatial construction of blocks. The difficulty level is systematically increased as the total number of blocks increases (5-10) and the number of 'hidden blocks' increases (0-3). The task is to count the number of blocks the construction consists of. Standard procedure for administration is used and as such there is no time limit. Basic performance is scored as the total number of correctly answered items.

2.3.3. Hidden Figures Test
This hidden figures test consists of 51 Gottschaldt-like figures partitioned over four parts and is based on Thurstone's Hidden Figures Test (Thurstone, 1944). For each part, the task is to find and trace a stimulus figure which is embedded in a more complex figure. A coloured felt-tip is used for the tracings. The first part consists of 37 pairs of items. Each pair consists of a simple stimulus figure (on the left) which is embedded and has to be marked in the complex figure on the right. The second part consists of seven complex figures in which a (one and thus always the same) given stimulus figure is embedded. The third part is similar to the second part in that again seven (different) complex figures are presented. But instead of one, two stimulus figures are offered. Thus one of both stimulus figures is embedded in each complex design. The fourth part is identical to the third part (two different stimulus figures), only it offers 10 complex stimuli which are also more complicated. Instructions were to mark the hidden figures as quickly and accurately as possible. For each part a maximum time was set at 10 minutes. As a measure of basic performance, we divide the total number of correctly marked items by the total completion time.

2.3.4. Overlapping Figures Task
The Overlapping Figures task (OFT) was constructed using the principles mentioned by Gainotti and colleagues (Gainotti, D'Erme, Monteleone, & Silveri, 1986). Our version has eight stimulus and response cards. Each stimulus card (A4 sheet, landscape orientation) has five black line drawings of common objects all belonging to the same category. We use five clearly nameable themes: both small and large elements from both the categories of utensils and animals, and transportation means. The three other categories are less nameable: upper, and lower case Greek letters, and symbols from flow charts. The stimulus cards are composed of two figures transparently overlapping on the left, two transparently overlapping on the right, and a fifth larger figure in the centre of the card transparently overlapping both left and right pairs. Each composition is approximately 100x130 mm$^2$ in size. Each response card (A4 sheet, portrait orientation) contains eight drawings vertically aligned across the page in a counterbalanced order. Four of them (targets) are identical to the four lateralised figures on the corresponding stimulus card. Each target is matched with a visually similar distracter belonging to the same category.

To explain the test to the subject, an instruction item is used. This stimulus card contains only three drawings. This card is not used in the analysis. Cards are placed in front of the subject, with the centre of the pages aligned with the sagital midline of the body. The response card is placed below the stimulus card. Subjects are asked to point, on the response card, to the identical figures they could recognise on the stimulus card. There is no time limitation. When subjects indicate being finished, the examiner asks if they pointed to all the figures they could recognise.
Completion time and number of correct identifications are measures of basic performance. An AI is derived from the number of lateralised omissions. A second AI is based on the strategy. This AI indicates the tendency to preferentially first explore one side of the composition. For this we record in each composition the side (left or right) of the first object identified.

2.4. Factor 4: Dynamic Tracking task (Dy)
As it has previously been suggested, more dynamic aspects of visuo-spatial processing, in relation to driving performance, have received relatively little research attention. Yet, motion and optic flow perception do have a great deal of face validity in this respect, since driving essentially implies also movement. We therefore chose not to include exclusively static but also a dynamic visuo-spatial task. The task in question calls for multiple visuo-spatial functions as scanning, construction and integration, in a moving environment. Hence, by its underlying components, but also by its implementation, it simulates in some aspects (visuo-spatially) the real driving event.

The tracking task aspires to assess two basic skills closely related to driving, namely lane keeping and detection of peripheral events. The experimental set-up is partly described in Brouwer, Rothengather and van Wolffelaar (1992). It consists of a central (20 inch) screen, flanked by two peripheral screens. A steering wheel, in which press-buttons are incorporated, is placed in front of the central screen. The central screen represents a (straight) road-scene as seen through the windshield of a car. Both peripheral screens present (peripheral) targets, i.e. triangular traffic signs in which black arrows can appear. This set-up covers approximately 75° of visual angle.

In the first phase of this task, using only the central screen, the subject tries to keep the car on course, in the middle of the right lane, while a distortion signal is imposed on the steering signal. This distortion signal is referred to as an "unpredictable sidewind" and causes unpredictably being pushed out of course. By compensatory steering, the lateral displacement is to be corrected for. For each subject, a computer routine adapted the signal-amplitude, in 15s intervals, until a stable course of 90% of the time is reached. The individually attained sidewind-factor provides an indication of the ability of psycho-motor tracking (Brouwer, Rothengather, & Wolffelaar, 1992) and is the first measure of basic performance. In the second phase, the average lateral position on the road (LP) and the average standard deviation of the lateral position (STDLP) of the car are determined, while keeping lane with the individually achieved sidewind factor. The LP provides a second basic measure of performance. The LP, expressed as a deviation from its ideal (middle of the right lane), provides an indication of lateralisation, comparable to an AI. The STDLP is a measure of variability and can be interpreted as a measure of swing i.e. how well subjects can keep course. This measure should be similar at this stage for each subject as all subjects drive with their individually attained sidewind factor. In the third phase, only using the peripheral screens and the press-buttons in the steering wheel, stimuli are presented randomly on left and right peripheral screens. The subject does not have to keep lane, but only reacts on detection (pushes buttons on the steering wheel). The overall reaction time (RT) is taken as a basic measure of detection. The RTs on left and right sided stimuli provide an AI. During the final phase, both tasks (lane keeping and peripheral detection) are performed at the same time (dual-task condition). The same dependent variables as in both single task conditions, are computed in this dual task condition.
3. Driver Assessment

3.1. The Practical Driving Test

We previously discussed driving performance with reference to fitness to drive. Traditionally, fitness to drive is defined in medico-legal terms. We however use a different conceptualisation, namely practical fitness to drive, which is to be located at the activity-performance level and is hence assessed accordingly. Also from previous discussion, it appeared that numerous kinds and formats of driving tests have been applied (e.g. open and closed circuits, on-the-road and in realistic simulated environments etc.) and we argued for more universal and comparable formats. Therefore, driving will be evaluated on-the-road as we consider this to be the primary and most direct method for determining practical fitness to drive. Our practical driving test is as close to real-life as possible. It is identical (except for the scoring system) to the "practical 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. Hence, the test-ride is not a regular on-the-road driving examination, as applied for obtaining a drivers' licence. Such a conventional test-ride is meant to get an overall impression of driving skill. The practical test-ride we apply, is used to assess driving competence on the level of activity-performance. Its aim is therefore to evaluate how an impairment is manifested and compensated for during driving. Thus, during the test-ride, specific and potentially problematic situations are focussed upon.

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 impairment, of the individual patient. Possible adaptations were for example automatic gears, reverse pedal control, steering knobs, etcetera. The examiner, who conducted the behind-the-wheel assessment, was not blind to the perceptual status of the subjects. Because of safety reasons, it was found to be unreasonable to let the examiner ignorant of the subject's perceptual deficits. Hence, the examiner could and did seek circumstances which taxed the subjects potential weaknesses in order to observe if, and how well, these could be compensated for by the subject. During the driving test, difficulty levels (in terms of speed, busyness and complexity) were systematically increased when judged to be safe. When fully administered, the driving test took approximately one hour and was representative for real and average day-time traffic.

3.2. Evaluating Practical Fitness to Drive

The prognostic validity of even a practical driving test cannot be taken for granted. In principle, a practical driving examination does not necessarily yield an objective measurement of driving competence. The judgment given by a driving instructor or traffic expert is subjective in nature. Therefore, to judge the performance while driving and in an attempt to try to reduce effects of rater bias, a structured protocol, with predetermined observational items, was used.

The structured protocol (Test Ride for Investigating Practical fitness to drive, i.e. TRIP) is a checklist of different aspects of the driving task. Previous versions were used by for example Withaar (2000) and De Raedt (2000). We added some items which specifically asked for visual and visually related performance. Our version contains 55 items asking for specific qualities and behaviours during driving scored on a 4-point scale (1-4). In case of suboptimal performance, the examiner is asked to provide a clarification of the problem or situation. At
the end of the protocol, both a global impression and end-verdict are provided, based on all (subjective) observations.

From the 55 items, separate subscales or factors were constructed, based on a priori considerations. The visual factor (VIS) joins all items in which predominantly visuo-perceptual behaviour is reflected. This includes visual scanning, visuo-spatial, and visuo-integrative aspects like assessment of eye- and head-movements in different situations, perception of traffic signals, visual communication with other traffic participants etcetera. This factor holds 25 different items. The operational factor (OPER) joins 8 items and reflects fluency of instrumental and psycho-motor aspects of driving like handling the brakes and shifting gears. The tactical factor (TACT) reflects all aspects in which (tactical) choices, anticipation, and adaptation are represented. This factor is comprised of 15 items. Some items are represented in more than one factor. The global impression (GLOB) is the combination of three items, each scored on the same 4-point scale, namely a global impression of practical fitness to drive, technical execution, and traffic insight. These factors are expressed proportional to the maximum factor-score for ease of intercomparison. The end-verdict indicates whether or not the subject would be declared fit to drive (pass or fail).

4. Conclusion
Using the proposed visuo-spatial neuropsychological test battery, and applied and analysed in the proposed way, we hope to be able to qualify and quantify in detail the visuo-spatial limitations in our patient group. It is our intention to relate these measures to (aspects of) driving performance. We are aware that, especially for the new and adapted tests, detailed information about their psychometric properties is lacking.

5. Reference List


