Driving and visuospatial performance in people with hemianopia


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Practical fitness to drive was studied in 28 patients with homonymous hemianopia (HH). More specifically, visual performance during driving and neuropsychological visuospatial test performance were compared and related. Visuospatial tests were a priori classified in four visuospatial sets, and were evaluated on three measures, namely laterisation, speed, and accuracy. Driving safety and fluency was assessed by means of a practical test-ride and scored using a structured protocol. It was concluded that HH cannot be considered a definite contraindication for holding a drivers’ licence since not all patients failed the test-ride. The most frequent remark made by the driving expert was a lack of stability in steering. It was found that visual performance during driving was significantly related to visuospatial test performance, operationally defined as a function of typical visual HH disability. A specific combination of the laterisation, speed and accuracy measures of the visuospatial sets explained 77% of the variance in visual performance during driving.

For deciding which type of mobility rehabilitation goal is feasible in HH, our results suggested administering the Grey Scales task, the Trailmaking test, the Bells test and a Hidden Figures test.

INTRODUCTION

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

Owsley and McGwin (1999) addressed the relationship between driving habits, performance and safety, and various eye conditions. They concluded that visual acuity, although the most commonly used visual screening test for driving licensure, was only very mildly associated with driving safety. This has led researchers (e.g., Owsley & McGwin, 1999; Sivak et al., 1981) to conclude that visual perception during driving, or any other complex task for that matter, is not exclusively dependent on visual sensory function and physiological optics, but also on higher-order visual functions. Neuropsychological tests, assessing these higher-order visual functions, could thus also and perhaps more successfully serve the purpose of screening, evaluating, and understanding fitness to drive and guiding possible rehabilitation and adaptation.

Traditionally, fitness to drive is either ill defined or defined in medicolegal terms (e.g., Brouwer, 2002), based exclusively on impairments as defined by the WHO (ICF) classification. However, a different conceptualisation could be used, namely, “practical fitness to drive”, considered to be situated at the activity level. Therefore, driving fluency and safety has to be evaluated on the road, giving special emphasis to the present impairments and their limiting consequences.

Neuropsychological test performance has previously been related to practical fitness to drive. Concepts of visual search, visual speed, visual and divided attention, and visuospatial impairments were frequently put forward as important determinants (e.g., Brouwer, 2002; Shinar & Schieber, 1991). Visuospatial perception is one component of cognitive functioning that globally refers to the ability to move around in an environment and orient ourselves appropriately. It is not unreasonable to assert that driving holds a considerable visuospatial component, and that ongoing and related action is highly dependent on this visuospatial information.

Homonymous hemianopia (HH) is a visual field defect (VFD) in which, for both eyes to the same extent, half of the visual field is blind. This condition is known frequently to accompany, intensify and/or provoke visuospatial limitation (e.g., Zihl, 2000). Owsley and McGwin (1999) concluded that the presence of VFDs can be an important factor determining fitness to drive. In studies by Hartje and colleagues (Hartje, Willmes, & Pach, 1991), and Hannen and colleagues (Hannen, Hartje, & Skreczek, 1998), it was reported that homonymous VFDs due to brain damage resulted, in nearly all cases, in failure on an on-the-road driving test. However, there is also evidence that indicated that homonymous VFDs and HH cannot be an absolute and inevitable contraindication for holding a drivers’ licence. An early demonstration was provided by Vos and Riemersma (1976) and was confirmed by Warmink and colleagues (Warmink, de Jong, & Kempeneers, 1998). Further, studies by Szlyk and colleagues (Szlyk, Brigell, & Seiple, 1993) and Racette and Casson (1999)
showed clearly that different levels of driving performance can be observed within the hemianopic patient group. An even more optimistic conclusion was reached by Schulte and co-workers (Schulte et al., 1999). In their study, no negative effects of VFDs were found with respect to measures of driving performance in a driver simulator task.

The current research focused on two main questions. The first concerned practical fitness to drive in patients with HH. Therefore, effort was invested in differentiating HH from hemispatial neglect. Hemispatial neglect might be considered as an extreme case of hemispatial dysfunction resulting in severe hemispatial limitation. By excluding patients with hemispatial neglect, we aimed at studying visual and visually related disabilities, rather than primarily attentional disabilities. As a consequence, no differences in limitations between left and right HH patients were expected, since both groups suffer equal (but inverse) visual impairment.

The second question concerned relating visual performance during driving to other characteristics. As already mentioned, low acuity and VFDs cannot be the sole cause of practical unfitness to drive as not every such patient proves to be (practically) unfit to drive. Other personal characteristics such as age, time since lesion, driving experience, macular sparing, and subjective visual complaints will therefore also be explored.

Our primary interest was however in relating higher-order visual function to practical driving performance. Focus was on visuospatial functioning, both in neuropsychological tests and during driving. From previous research, no specific or limited number of tests emerged which showed a consistently high correlation with practical fitness to drive. Therefore a small selection of testing methods, purely on empirical grounds, was not obvious. Hence, a broad range of visuospatial tests, which had been moderately correlated to practical driving performance in previous studies, were selected. These tests were classified a priori in different visuospatial domains or aspects (henceforth termed “sets”), and were evaluated on different measures, namely lateralisation, speed, and accuracy.

The model predicting visual performance during driving by these sets and measures was strongly bound by a priori considerations. First, it was assumed that a homonymous VFD can result in relatively poor visual performance on the side of the blind hemifield (i.e., differential lateralised performance). This lateralisation was assumed to be typical for hemianopic disability, possibly and most likely affecting all other visual behaviour. It is intuitive that highly differential lateralised performance leads in general to more difficulties in constructing an accurate mental spatial representation which is essential in visuospatial tasks. This then leads to more time consumption and/or less accurate performance. As effective compensation for the HH is assumed to be a prerequisite for practical fitness to drive, the extent of differential lateralised performance was the first measure to be forced in the prediction model.
Second, HH is caused by brain damage. It is commonly observed that brain damage results in mental slowness. In addition, it has been argued that the mere visual effects of HH primarily result in more time consumption during visual tasks (Tant, Cornelissen, Kooijman, & Brouwer, 2002a; Zihl, 1999). Therefore speed was forced as the second measure in the model. Third and finally, accuracy was entered. In support of this conceptualisation of HH viewing behaviour, higher (i.e., worse) laterisation scores were expected to be associated with worse performance in terms of speed and/or accuracy. Additionally it was investigated which visuospatial sets were most important in relation to visual performance during driving and which specific tests could be chosen to represent them.

To conclude, more light was shed on the relationship between visuospatial disability and visual performance during driving. It was hypothesised that not all HH patients are practically unfit to drive and that visual performance during driving is related to visuospatial test performance.

**METHOD**

**Patients**

_General._ Thirty-two brain-damaged patients were referred because either the carer or the patient had expressed the desire for the patient to be assessed on fitness to drive. All patients had a binocular optically corrected acuity of 0.8 or better and contrast sensitivity within normal ranges. All had complete or incomplete homonymous hemianopia (HH) as confirmed by automated perimetry using the Humphrey Field Analyser (Full Field 246 screening program, age corrected, 3-zone strategy). One patient, with left HH, only had (right) monocular vision. Three patients were excluded on the basis of severe hemispatial neglect (see further). One patient with left HH suffered severe object agnosia. As several tests proved not to be applicable and/or resulted in extremely deviant performances, inclusion of this patient would have highly distorted group analyses. As a consequence and as severe object agnosia is not considered to be typical for HH, this patient was also excluded from the analyses. Hence, 28 patients participated in this study. Table 1 provides some relevant patient characteristics.

Number, gender, driving continuation, and aetiologies were equally distributed across both left and right HH groups, range \( \chi^2 = (.048, 2.45) \) n.s. Also _T_-tests failed to reveal differences in age, macular sparing, time since injury, or driving experience before injury between both HH groups, range \( t = (-.122, .427) \) n.s.

_Neuropsychological screening._ Prior to the visuospatial and driving assessments, all subjects were assessed on standardised tests to exclude
dementia, aphasia, and apraxia. For each individual patient, there was no indication of global cognitive decline as assessed by the Cognitive Screening Test (CST; De Graaf & Deelman, 1991) and the Mini Mental State Examination (MMSE). For assessing aphasia, two subtests from the SAN test (Deelman, Liebrand, Koning-Haanststra, & van der Burg, 1987) were administered. There was no indication of receptive aphasia in this sample. Ideational and ideomotor apraxia was assessed using a modified version of a method by De Renzi (De Renzi, Faglioni, & Sorgato, 1982). No impairments were found. Further, all patients performed within the normal limits on a form discrimination screening test (VOSP), confirming adequate general lower-order aspects of visual function.

In order to exclude patients with severe hemispatial visual neglect, a battery of six clinical tests was used. Four cancellation tests were included, namely Albert’s Line Cancellation test with a cut-off of two omissions (Halligan & Marshall, 1989; Vanier et al., 1990), Mesulam Structured Shape cancellation
(Weintraub & Mesulam, 1988) with a cut-off of three omissions, the Search for Os, which is not publicly available but clinically widely used in The Netherlands (cut-off of three omissions) and the Bells test with a cut-off of four omissions (Gauthier, Dehaut, & Joanette, 1989; Vanier et al., 1990). The other two tasks in the neglect battery were the Line Bisection test, which was scored as a function of omitted lines (cut-off = 2) (Schenkenberg, Bradford, & Ajax, 1980; Soukup, Harrell, & Clark, 1994; Van Deusen, 1984) and the Representational Drawing test (cut-off = 2) (Wilson, Cockburn, & Halligan, 1987).

For each task, an additional “lateralisation-requirement” was imposed in order to make a distinction between a general inattention deficit (resulting in a general scanning deficit), and hemi-inattention (resulting in a lateralised scanning deficit). The requirement held that for a “neglect score” (as opposed to a “general attention deficit score”) the difference between left-sided and right-sided omissions should also be equal to or exceed the cut-off score (i.e., there should be a clear lateralisation). When applicable, the laterality was labelled as either “left” or “right” depending on the side of the anomalies. It was decided that, using this battery and cut-off criteria, a patient was considered to suffer severe hemispatial visual neglect, if at least four (of maximally six) neglect scores were obtained and if these scores were identical in laterality. As mentioned previously, three patients were excluded on the basis of these neglect criteria.

Test procedures

Driving assessment. The practical driving test was (except for the scoring system) similar to the “test-ride for assessing practical fitness to drive” as conducted by the Dutch Licensing Authority (Department of Adaptations) and was conducted by a certified and official driving examiner. The cars used for the on-the-road test had dual operation and could be adapted to the needs imposed by motor impairments.

To assess driving performance in a detailed manner, a structured protocol with predetermined observational items was added to the procedure. This protocol (Test-ride for Investigating Practical Fitness to Drive, i.e., TRIP) was a checklist of different aspects of the driving task and had to be completed by the expert after the test-ride (see also De Raedt, 2000; Withaar, 2000). It contained 55 items judging specific driving qualities and behaviours. These items were scored on a 4-point scale, ranging from 1 to 4 (respectively indicated as “inadequate”, “dubious”, “adequate”, and “good” performance). Based on a priori considerations, separate subscales (henceforth referred to as “sets”) were constructed with these 55 items. The visual set (VIS) was constructed by joining all items in which predominantly visuoperceptual behaviour was reflected. This included visual scanning, visuospatial and visuointegrative aspects such as assessment of eye and head movements in
different situations, perception of traffic signals, visual communication with other traffic participants, etc. This set held 25 different items. The operational set (OPER) joined eight items and reflected fluency of instrumental and psychomotor aspects of driving such as handling the brakes and shifting gears. The tactical set (TACT) reflected all aspects in which (tactical) choices, anticipation, and adaptation were represented (15 items). Some items were represented in more than one set. The sum of the scores on all 55 TRIP items were indicated by the TOT set.

At the end of the evaluation, the expert provided both a subjective global impression (GLOB) and an end verdict. The GLOB set indicated a subjective evaluation on three aspects, namely practical fitness to drive, technical handling and execution, and traffic insight, each scored on the 4-point scale. All these TRIP sets (VIS, OPER, TACT, TOT, and GLOB) were expressed proportional to their respective maximum score for ease of inter-comparison and will subsequently be referred to as “TRIP set scores”. As a consequence, a TRIP set score of 0.25 indicated performance at the “inadequate” level. Scores of 0.50, 0.75, and 1.00 indicated performance at respectively “dubious”, “adequate”, and “good” level. By definition, the minimum level for passing was the “adequate” (i.e., 0.75) level. The end verdict indicated whether or not the subject would have been declared fit to drive (pass or fail).

Whenever the driving expert scored an item as inadequate or doubtful, he also indicated the cause and reason for the specific inadequacy. This provided some qualitative indications of the driving performance.

Visuospatial assessment

Cerebral visual disorder (CVD) questionnaire. The quality of the subjective reports of the visual (field) impairments and limitations can be considerably improved by using a structured protocol with specific items assessing specific disabilities (Zihl, 2000). The (translated) Cerebral Visual Disorder questionnaire (Kerkhoff, Schaub, & Zihl, 1990), modified by Dittrich (1996, version E1.1, personal communication) was used. Eight visual disabilities were scored as absent or present (0–1) (Kerkhoff et al., 1996) and 12 specific situations on a 5-point scale, ranging from “no problem” (0) to “mostly a problem” (4) (Dittrich, personal communication). Again, the summed scores for both parts were expressed relative to their respective maximum score (i.e., the respective proportion disability scores). The reported subjective disability score was the average of both these proportions and indicated the severity of the subjective visual complaints as measured by this questionnaire.

Visuospatial tests: Set (measure) scores. In our aim to assess different visuospatial aspects, finding a balance between quality and quantity, a battery of tests was chosen (see Table 2). These tests were a priori classified into four
domains of visuospatial functioning (henceforth referred to as “sets”), namely basic visual scanning and search (BVSS), a visuocostructive and organisational set (VCO), a visuo-integrative set (VI), and a dynamic set (Dy). The details on the construction of the sets are discussed elsewhere (Tant, 2002) but are summarised in Table 2. When possible, the tests were evaluated in terms of lateralisation, speed, and accuracy (Table 2). Lateralisation expressed the nature and degree of differential lateralised performance, independently of general performance (speed and accuracy).

When necessary and possible, transformations were enforced on the raw test data, following suggestions by Stevens (1996, p. 246), to approximate normal distributions of these scores. The data were then normalised for intercomparison. The respective measures of the different tests were then averaged by set,
providing a set measure score. Visuospatial test performance was hereby operationally defined by four visuospatial sets, which respectively were evaluated in terms of lateralisation, speed, and accuracy. There was no accuracy measure in the dynamic set (Table 2).

RESULTS

Practical driving test

Twenty eight HH patients performed the test-ride, after which the TRIP protocol was completed by the driving expert. The comments were listed. Protocols were tagged whether the comment was present or not. Lack of stability in steering was the most frequent comment (11 protocols). This deficiency was especially evident in complex situations, such as busy traffic, difficult road design, distraction by conversation, or an upcoming manoeuvre. Unsteadiness was more apparent in the left HH group. Extreme unsteadiness, labelled as unacceptable lateral deviations, were reported in eight protocols. There was no relationship with the side of the HH. These large lateral deviations (and their corrections) led to unacceptable “drifting over the road”. This was most apparent on broad roads with minimal markings and low traffic. In five protocols the driving instructor commented that the patient could not adequately overview a complex traffic scene (e.g., large intersection) and as a consequence chose a wrong lane. Viewing behaviour was variable or inconsequent in seven protocols, five pertaining to right HH patients. The speed was too high in eight protocols, equally distributed across both HH groups. Too low speeds were also frequently observed (10 protocols), in city and in rural areas. In seven protocols, driving behaviour was too uncertain, sometimes despite adequate viewing behaviour. These patients decreased their speed, which made them an obstacle for other traffic. Driving too close to the right-hand side of the road and taking right turns too widely was commented upon in four and five protocols respectively, all pertaining to right HH patients.

MANOVA analysis was performed entering the TRIP set scores (VIS, OPER, TACT, TOT, and GLOB) as dependents and the side of hemianopia as between-subjects factor. This revealed no significant effect of hemianopia side, $F(5, 22) = 0.737$, n.s., neither when tested univariately. Chi-square analysis on the end-verdict data revealed that significantly more patients failed than passed, $\chi^2 (1, N = 28) = 14.286, p < .001$, but the distribution was equal in both groups, $\chi^2 (1, N = 28) = 0.862$, n.s. The TRIP set scores were summarised in Table 3.

Finding no interactions with the side of the hemianopia, that data from both HH groups were pooled to increase the sample size and hence the power of subsequent analyses.
To situate the value of the TRIP set scores, one-sample *T*-tests were performed. All set scores were significantly below “adequate” (i.e., 0.75) level, range *t*(27) = (–7.3, –4.0), all *p* < .001. All set scores were significantly above “dubious” (i.e., 0.50) level, range *t*(27) = (3.3, 5.6), all *p* < .005, except the VIS, *t*(27) = 1.5, n.s., and GLOB set, *t*(27) = 1.1, n.s.

The correlations between the different TRIP sets were all highly significant and ranged from .71 to .98 (all *p* < .001). For the remainder of the analyses, only the VIS score was considered (and predicted) as the specific interest was in visual performance during driving. The end-verdict was not used as the to-be-predicted score, since far more failures than passes were observed and logistic regression resulted in 86% correct classifications without any sets in the model. Any other set (measure) score failed to add significantly to this model.

**Visuospatial tests**

Since the intercorrelations between the “Kerkhoff et al. part”, the “Dittrich part” and the subjective disability score proved to be significantly high, *r* range .56, .93, all *p* < .001, only the subjective disability score, which is the mean of both parts, was used.

The visuospatial sets were constructed on an a priori theoretical basis (see Table 2 and Tant, 2002). To indicate that the various sets were acceptable representatives for their constituent tests, the respective set measures were correlated with their constituent test scores. For accuracy, care was taken that higher scores indicated better performance. The results are summarised here but were reported in detail elsewhere (Tant, 2002).

The speed measure of the BVSS set was correlated with the speed scores of its constituent tests. All correlations (but one) were significant and ranged from .48 (*p* < .01) to .82 (*p* < .001). The accuracy measure of the BVSS set
was correlated with its constituent accuracy scores. All but two correlations were significant and ranged from .38 \((p < .05)\) to .78 \((p < .001)\). Similarly, the lateralisation measure of the BVSS set was correlated with its lateralisation test measures. Significant correlations ranged from .40 \((p < .05)\) to .82 \((p < .001)\). Five lateralisation correlations did not reach significance.

There was only one speed test score in the VCO speed measure. The accuracy measure of the VCO set was correlated with the accuracy scores of its constituent tests. All test scores correlated significantly with it. Correlations ranged from .38 \((p < .05)\) to .79 \((p < .001)\). The lateralisation measure of the VCO set correlated significantly with its constituent lateralisation test measures and ranged from .38 \((p < .05)\) to .87 \((p < .001)\).

There was only one speed test score in the VI speed measure. The accuracy measure of the VI set was correlated with the accuracy scores of its constituent tests. All correlations (but one) were significant and ranged from .52 to .72 \((all \; ps < .05)\). There was only one lateralisation test score in the VI lateralisation measure.

The Dynamic set had only one speed test score, no accuracy score, and one lateralisation test score.

The respective speed, accuracy, and lateralisation set measures were inter-correlated. All four speed set measures intercorrelated significantly (and positively), and ranged from .41 \((p < .05)\) to .74 \((p < .01)\). For the accuracy measures, the correlations between the BVSS and VI set did not reach significance \((r = .37, \text{n.s.})\). The other correlations were .69 \((\text{BVSS} \times \text{VCO}, p < .01)\) and .57 \((\text{VI} \times \text{VCO}, p < .01)\). None of the correlations between the lateralisation measures reached statistical significance.

Finally, the respective speed, accuracy, and lateralisation measures of the four different sets were averaged into global measure scores. A negative correlation between global speed and global accuracy \((r = -.46, p < .01)\) was observed. As we pooled data from left and right HH patients, with qualitatively comparable but quantitatively opposite lateralisation scores (Tant et al., 2002b), the unsigned values of the lateralisation scores were used for correlation. Global lateralisation was not significantly correlated with either global speed \((r = .32, \text{n.s.})\) or global accuracy \((r = -.34, \text{n.s.})\).

**Associations with visual performance during driving**

**Patient characteristics.** Associations of patient characteristics with the TRIP visual set score (VIS) are shown in Table 4. High negative correlations of VIS with age and driving experience were found. Since age and driving experience were highly correlated \((r = .90, p < .001)\), the correlations with the VIS set were recomputed controlling for age. These partial correlations are also displayed in Table 4. All characteristics, except gender, correlated significantly
Visuospatial assessment. The correlation between the subjective disability score (CVD questionnaire) and the VIS set score proved not to be significant ($r = -.12$, n.s.).

The model predicting visual performance during driving (VIS) by visuospatial set measure scores was strongly bound by a priori considerations: First, lateralisation was entered, followed by speed and accuracy. A regression analysis predicting the VIS set using the three global measure scores as predictors resulted in an $R^2$ of .58, $F(3, 24) = 11, p < .001$; $R^2$ adj. = .52. Each measure added significantly to the increase of variance explained. When age

with the VIS set. Driving experience and macular sparing correlated positively, time since injury negatively.

Entering the four continuous data sources of patient characteristics in a stepwise regression analysis with the VIS set as dependent, yielded a model with age, sparing and driving experience as significant predictors explaining 67% of the variance, $F(3, 24) = 16, p < .001$. Time since lesion was not included in the model (Table 5).

### Table 4

<table>
<thead>
<tr>
<th>Patient characteristics</th>
<th>VIS score</th>
<th>VIS × Age Correlation$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-.70**a</td>
<td></td>
</tr>
<tr>
<td>Time since injury (months)</td>
<td>-.13$^a$</td>
<td>-.41**a</td>
</tr>
<tr>
<td>Macular sparing</td>
<td>.41**a</td>
<td>.47**a</td>
</tr>
<tr>
<td>Driving experience before injury (years)</td>
<td>-.50**a</td>
<td>.41**a</td>
</tr>
<tr>
<td>Gender</td>
<td>.02$^b$</td>
<td>.14$^b$</td>
</tr>
<tr>
<td>Driving continuation</td>
<td>.50**b</td>
<td>.45$^a$</td>
</tr>
<tr>
<td>Aetiology</td>
<td>.26$^c$</td>
<td></td>
</tr>
</tbody>
</table>

$^*$ correlation is significant at .05 level (2-tailed), ** correlation is significant at .01 level (2-tailed) ($N = 28$). $^a$ Pearson correlation, $^b$ point-biserial correlation, $^c$ Eta statistic. $^1$ Association when controlled for VIS × Age.

### Table 5

Statistics from stepwise regression analysis entering continuous data sources from the patient characteristics with VIS set as dependent

<table>
<thead>
<tr>
<th>Variables entered</th>
<th>$R^2$ (Adj. $R^2$)</th>
<th>$R^2$ change</th>
<th>Change statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>.49 (.47)</td>
<td>.49</td>
<td>$F(1, 26) = 24, p &lt; .001$</td>
</tr>
<tr>
<td>Sparing</td>
<td>.60 (.57)</td>
<td>.11</td>
<td>$F(1, 25) = 7, p &lt; .012$</td>
</tr>
<tr>
<td>Driving experience</td>
<td>.67 (.62)</td>
<td>.06</td>
<td>$F(1, 24) = 4, p &lt; .045$</td>
</tr>
</tbody>
</table>
was forced into the model after these three measures, it did not add significantly to the $R^2$ increase, $F(1, 23) = 2$, n.s.

The primary aim was however to relate specific (rather than global) neuropsychological test performance to visual performance during driving. Therefore a regression analysis was performed using the 11 set measure scores to predict the VIS score. The respective measure scores were again entered in a blockwise manner (lateralisation—speed—accuracy). Within these respective (measure) blocks, the method was stepwise for set determination. This procedure produced four models. The final model explained 77% of the variance, $F(4, 23) = 19, p < .001; R^2$ adj. = .73. The retained sets from the respective measures and the model parameters can be seen in Table 6.

For each retained set measure, we chose the test with the highest correlation as its best representative. These were respectively the Grey Scales task ($r = .81$), the Trailmaking test (part B) ($r = .80$), the Bells test ($r = .78$), and the Hidden Figures test ($r = .72$) (all $ps < .001$). Post hoc regression analysis, substituting these specific test performances for their set measures, resulted in 60% of the variance explained, $F(4, 23) = 9, p < .001; R^2$ adj. = .53.

### DISCUSSION

The practical driving test differed from a regular driving examination in that specific situations and occurrences were sought and observed in which the visual impairment was thought to be a hampering factor. Since patients with expected visuospatial limitations were studied, focus was on the visuospatial performance during driving.

Although the left HH group tended to perform slightly worse, no significant differences in driving performance between left and right HH groups were found. This suggested that we were successful in selecting HH patients with comparable impairment and disability. In this sense, the left and right HH groups in the current study were not unselected and hence the finding did not
imply that overall left and right sided brain damaged patients perform equally well.

The different TRIP sets (VIS, OPER, TACT, GLOB, TOT) differentiated different aspects of the driving task. Their high intercorrelations were not surprising, since some of the TRIP items were included in more than one TRIP set. Focus was on the VIS set, as visual and visuospatial problems were expected. Indeed with respect to practical driving performance, the VIS set was found to be worse than the other TRIP sets. Namely, the VIS set score proved not to be statistically different from (i.e., above) “dubious” level, while the other sets (OPER, TACT, and TOT) were.

The overall quality of the practical driving performance was generally low. First, this was suggested by the global subjective appreciation of the driving expert (GLOB score), not being different from the “dubious” level. Second, none of the TRIP set scores reached the “adequate” level. This indicated that, whatever driving aspect was measured, it was (on average) never rated as the minimum level for passing. Finally, only four patients in our group actually passed the driving test, as indicated by the end-verdict (Table 3). This overall negative driving outcome was in clear contradiction with some reports (Schulte et al., 1999; Vos & Riemersma, 1976; Warmink et al., 1998) but could at least partly be explained by our selection methods and criteria. The current population were HH patients without severe hemineglect, requesting the possibility of re-evaluation of the safety of their driving participation. The outcome was in most cases expected or feared to be negative, since this was the reason for referral. Contrary, in the Warmink et al. (1998) study (personal communication) most of the patients volunteered for an official (and hence decisive) driving evaluation. These patients were possibly encouraged by others or by their own experience of a likely positive outcome. This would suggest a self-selection bias (to the positive end) in their population, accounting for the high number of patients passing the driving test. Schulte et al. (1999) also suggested an absence of driving-related disabilities in HH patients. However, they used a driver-simulator task, which was inherently a simplification of a real-world driving situation (i.e., automatic transmission, no intersections, etc.). Further, their nine patients were reported to be “neuropsychologically intact”, also suggesting a positive bias. These positive biases were not present in the current study, nor this simplification of the driving test and hence the current results could be more indicative of the performance level in the HH (without hemineglect) patient population.

Most patients showed at least some form of (occasional) compensation for their HH and this activity possibly resulted in an unsteadiness in steering, which was more apparent in complex situations. Further, in situations where creating an overview was rendered difficult, either by complex road design, large to-be-viewed area, or absence of road markings, patients tended to show spatial limitation, expressed as deviant lateral positions, misinterpretation of
road design, and choosing a wrong lane. Another type of compensation was to dramatically reduce speed. Although apparently safe, it resulted in being an (unacceptable) obstacle for other traffic participants. Finally, it appeared that typical lateralised anomalies were only observed for the right HH group, as indexed by driving too close to the right side of the road. This observation was most likely induced by the fact that in The Netherlands one drives on the right side of the road. Quantitatively similar lateralised anomalies for the left HH group would have resulted in driving too closely to the left side of the lane, approaching or crossing the midline, or driving dangerously near traffic coming from the other direction. This oncoming traffic was a source of feedback and correction for the (deviant) lateral position.

Despite evidence of the high predictive value of the CVD questionnaire (i.e., subjective complaints verified by objective tests; Kerkhoff et al., 1990), no significant correlation with the VIS set was found. Possible causes of this absence are first, that the CVD questionnaire did not include any questions related to driving, and second, the questions were formulated in terms of simple disabilities. In contrast, driving is a complex task and performance could be influenced by a variety of different factors.

Lower-order (sensory) impairment (e.g., a visual field defect) is not unequivocally related to practical fitness to drive. Practical driving performance can also be influenced by impairment at a higher-order level (e.g., Owsley & McGwin, 1999). Higher-order function can be assessed by neuropsychological tests and has been reported to correlate only moderately with measures of driving performance (e.g., Brouwer, 2002). In previous studies, most tests were not targeted at specific driving-related abilities, nor at specific dysfunctions in specific patients. In the current study, a specific group of patients (HH patients without hemineglect) was assessed with specific tests (visuospatial tests) as visuospatial limitation was expected and driving is highly dependent on this ability.

From the significant intercorrelations of the four speed measures it could be concluded that speed, with which visuospatial tasks were completed, was a prominent and robust variable in all visuospatial sets. Brouwer (2002) had previously argued that visual speed emerged as a crucial factor of neuropsychological test performance, and that it was associated with safety and fluency of driving as assessed by test-rides. Contrary to both other measures, the lateralisation measures were not significantly interrelated. This supported previous literature on perceptual asymmetries that, across tasks, only low to modest intercorrelations are observed (Nicholls, Bradshaw, & Mattingley, 1999).

In general the expected relationships between speed, accuracy, and lateralisation were present. The interrelation was expressed as a speed–accuracy trade off, indexed by the negative correlation between the two measures. Although speed and accuracy were not statistically related to
lateralisation, the trend was as expected: Worse performance tended to be related to higher (i.e., worse) lateralisation scores. The statistical insignificance could question our assumption, that asymmetry in visual performance (lateralisation) is the basic measure of HH disability, influencing speed and accuracy. Alternatively, both measures were influenced by other factors (e.g., brain damage) and high associations were not to be expected.

Predicting visual performance during driving

A combination of age, macular sparing, and driving experience significantly predicted visual performance during driving (67% of the variance explained, Table 5). Age alone accounted for 49%. When performing regression analysis on the basis of neuropsychological information, using the global lateralisation, speed, and accuracy measure, 58% of the variance was explained. Hence, global visuospatial neuropsychological information was less predictive than information from patient characteristics, but more predictive than age. This suggested that a simple age criterion, apart from being morally, ethically, and politically incorrect, was less predictive for visual performance during driving. Further analysis suggested that age no longer provided additional information after considering the global neuropsychological data. This relatively high age-dependency was not a new finding. Szlyk et al. (1993) suggested that, beside the effects of visual field loss, age was an equally important factor in their HH population. They concluded that age-related losses, when compounded by brain damage-associated impairments, may further increase the on-the-road risk of the older hemianopic patients. This suggested that with increasing age, equal impairment might lead to higher levels of limitation. Hence, age is to be considered a “carrier” or a “covariate” rather than a factor on its own, as its interaction with other factors is most important. Limitations were not exclusively determined by impairments, but also by “contextual factors”. Examples of such contextual factors were driving experience and macular sparing. The logic of the former in compensation for driving is obvious, the influence of the latter was surprising. Although it is generally agreed that macular sparing is crucial for comfortable reading (e.g., Kerkhoff, 1999), it is less obvious how it could be so important for visual performance while driving. However, this visual performance was dependent on using a spatial representation by creating a global overview of the (visual) situation. Macular sparing was not expected to be a crucial factor for this. Using this spatial representation also implied specifying (e.g., identification of objects) and updating, requiring constant scanning. For this, macular sparing could be important, since it could reasonably be assumed to be (positively) associated with the ease of identification of individual objects and hence (negatively) with the amount of compensational effort to be invested. It was previously argued that compensational effort could
be associated with unsteadiness in steering, hence accounting for the association of macular sparing and visual performance during driving.

The regression analysis resulted in a model retaining four set measures explaining 77% of the variance in the VIS set, which was more effective than prediction on the basis of the patient characteristics or age alone (67% and 49%, respectively). The model included the lateralisation measure of the BVSS set, the speed measure of the BVSS set, and the BVSS and VI accuracy measures (Table 6).

In order to reduce the number of tests, but with the ability to reproduce significant information about the measures and taking availability of norms in mind, the Grey Scales task (for lateralisation), the Trailmaking test (part B) (for speed), the Bells test, and the Hidden Figures test (for accuracy), explained 60% of the variance in VIS. By administering these four tests, the prediction obtained was better than only using age (49%), which has, as already mentioned, practical (and political) implications.

Logistic regression analysis predicting pass/fail scores was statistically futile, as only four patients passed. However, for rehabilitation purposes, it could be desirable to differentiate which patients approximate practical fitness to drive from those who are dramatically unfit to drive. It could be argued that for the former group, specific rehabilitation for driving could be attempted, while for the latter group other or more modest mobility goals should be formulated. Therefore, to present some tentative indications, a near-fit group was defined as being represented by the patients with a VIS score in the upper quartile. This revealed that in this group, the Grey Scale lateralisation scores were not more extreme than −.69, +.54, the longest completion time in the Trailmaking test (part B) was 196 s, the worst performance on the Bells test was five omissions and the lowest score on the Hidden Figures test was .03 (number of correctly marked items per second). The combination of scores representing worse performances could be considered a negative indication for adaptive visual performance during driving and for success of driving rehabilitation.

CONCLUSION

A minority of the HH patients passed the driving test. This confirmed that HH should not be an absolute contraindication for practical fitness to drive. It also justified the current investment of effort in studying fitness to drive in HH and hopefully future investment of improving fitness to drive and/or specific visual rehabilitation for HH.

We confirmed that visual performance during driving was significantly related to visuospatial test performance. A specific combination of the lateralisation, speed, and accuracy measures derived from different visuospatial sets explained 77% of the variance. Substitution of the retained set measures by their respective most representative tests was done using the Grey
Scales task, the Trailmaking test, the Bells test, and the Hidden Figures test. These tests could be used for deciding whether or not rehabilitation efforts should be invested with respect to driving or, alternatively, that other or more modest mobility rehabilitation goals should be determined.

The results and conclusions have to be interpreted in the light of the relatively low number of patients and therefore extension of the sample is suggested. Despite this caveat, visuospatial performance appeared to be indicative of visual driving performance and therefore this higher-order (cognitive) function deserves further attention.

REFERENCES


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