

Part III: Additional findings in patients with HH and related impairments

Grey Scales uncover similar attentional effects in homonymous hemianopia and visual hemi-neglect*

1. Abstract

Multi-component models of visual hemi-neglect have postulated that visual hemi-neglect is characterised by various attentional deficits. A Grey Scales-task has been developed to quantify the early, automatic, (perhaps obligatory) ipsilesional orienting of visual attention, frequently assumed as the first of these attentional deficits. Explanations for this attentional imbalance are up until now mainly formulated in terms of right hemisphere activation. This lateral attentional bias has also been demonstrated in controls, in whom it is expressed as a leftward perceptual asymmetry. We reproduced previous literature findings on a Grey Scales-task, considering controls and neglect patients. Three patients with neglect showed an extreme ipsilesional lateral bias. This bias did not change during or after cognitive rehabilitation. Additionally, we presented this Grey Scale-task to 32 patients with left- and right-sided homonymous hemianopia (HH). Homonymous hemianopia is the loss of sight in one visual hemi-field. The HH patients had no clinical signs of impaired lateralised attention. Results revealed that HH patients showed a similar ipsilesional bias, albeit to a lesser degree than in neglect. Left-sided HH patients presented a quantitatively similar, but qualitatively opposite bias than the right-sided HH patients. We suggest that sensory effects can be an alternative source of attentional imbalance, which can interact with the previously proposed (right) hemispheric effects. This suggests that the perceptual asymmetry in the Grey Scales-task is not necessarily an indicator of impaired right hemisphere attention. It rather suggests a pattern of functional cerebral asymmetry, which can also be caused by asymmetric sensory input.

2. Introduction

Several authors (e.g. [16, 11, 23]) suggested that the clinical syndrome of unilateral visual spatial neglect (UN) can be described/explained as a series of successive attentional events beginning with (1) an early, automatic, chronic, perhaps obligatory, orienting of attention toward the ipsilesional half space, followed by (2) a deficit in disengaging attention from that side in order to reorient it toward the contralateral half space. In addition to these two deficits, (3) a generalised (i.e. directionally non-specific) reduction in attentional-information processing capacity is assumed. The first component underlies an anomalous lateral preference. The second component gives rise to the clinical signs of UN (e.g. left-sided omissions on cancellation tasks) [23]. Karnath [16] proposed that this second component (reorienting) recovers faster than the other two, and this has been confirmed by several authors (e.g. [28, 23]). Mattingley and colleagues [23] concluded that the apparent recovery of UN constituted of the restitution in reorienting of attention, but that the early ipsilesional orienting remained. They further postulated this (residual) attentional bias to be characteristic of right hemisphere dysfunction, and posed that it could be predictive of persistent neglect-type behaviours.

This attentional bias has been demonstrated in right hemisphere patients, not only using RT paradigms (e.g. [3]), but also under more naturalistic free viewing conditions. It has been demonstrated using several indexes and tasks. Gainotti et al. [11] operationally defined it as a "position preference", namely as the tendency to identify first (and consistently) those parts of a composite diagram lying on the right or on the left of its centre. As a result of the early,

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automatic orienting of attention, UN patients frequently start scanning on the right side of a given composite stimulus (i.e. show a rightward bias). A further frequently used index expressing this lateral orienting bias is an Asymmetry Index (AI) derived from mainly paradigms using chimeric stimuli. For example, Mattingley et al. [24, 23] concluded that this lateral preference is expressed (in UN) by a tendency to choose or prefer the right side of a composite image (rightward bias). In a face-matching task by Mattingley et al. [23], subjects were required to indicate which of two bisymmetrical composites (one composed of the two left halves of an original face, the other composed of the two right halves) more closely resembled the (inherently asymmetrical) original. Patients with UN tended to judge the faces composed of the two right halves as more similar to the original one than the face composed of two left halves (rightward bias). In another chimeric faces task, presented by the same authors, patients were required to judge which face of a given pair appeared "happier". The faces were composed of two half-faces of the same person, one half smiling, the other in a neutral expression. In one pair, the smiling face was on the left, in the other on the right. Again, UN patients tended to judge the face with the "right-smile" as happier. This rightward bias was also demonstrated using Grey Scales [24]. In this task, the patient was required to compare two vertically aligned rectangular bars and indicate which one appears overall darker. The bars consisted of scales of semi-continuous shades of grey, ranging from white on one end to black on the other. Both bars were identical, but mirror-reversed. Patients with UN tended to choose the bar which was black on the right side as the darker one.

Lateral biases have also been demonstrated in healthy subjects using identical or comparable paradigms (e.g. [27, 24, 23, 21]). Contrary to patients with UN, healthy subjects exhibit a significant leftward bias. Since this bias is displayed by healthy subjects, and hence is considered to be "normal", it is often termed as a "perceptual asymmetry" instead of a "bias" (which suggests deviation from normality).

This left perceptual asymmetry in healthy subjects has been demonstrated using face-stimuli (judgements of emotions, similarity, and femininity) [24, 23, 21], using Grey Scales (e.g. [24]), and using stimuli asking for comparisons of dot numerosity and roundness (e.g. [21]), and size (e.g. [27]). The leftward bias occurs in all these tasks in more or less comparable intensities. Despite of the similar levels of perceptual asymmetry, only low to modest intercorrelations are observed. Nicholls and colleagues [27] suggest that these tasks do not index one single common factor, but tap a set of attentional processes, some of which are overlapping, and others which are task-specific. The communality is suggested to consist in the common right hemisphere involvement.

Summarising the explanations provided in the literature, in healthy subjects the lateral bias is explained as the result of more right hemisphere activation due to the visuo-spatial nature of the stimuli [21,22, 23,28]. It is argued that the differential activation of the right hemisphere generates a bias of attention to the left hemispace, creating an attentional imbalance. In UN patients, the lateral bias results from disturbed right hemisphere function. It is suggested [19,20,24,23] that each hemisphere controls a contralaterally directed attentional vector. Damage to one hemisphere results in dysfunction of the associated vector and gives rise to an ipsilesional bias. In all accounts, the perceptual asymmetry is explained in terms of functional cerebral asymmetry and more specifically in terms of differential attentional right hemisphere activation. One other alternative account was proposed by Nicholls et al. [27]. They suggested the possibility that the asymmetry may be related to effects of directional scanning. In support

of this proposal, they report a study by Sakhuja et al. [29] who found that readers of Hindi (left-to-right) showed the expected leftward bias, whereas readers of Urdu (right-to-left) showed the opposite bias. Nicholls and colleagues argue that the preferred directional scanning habit may lead to an over-representation of one side (i.e. ipsi-directional) of the stimulus and hence can influence the nature of the perceptual asymmetry. This conceptualisation, namely as a lateralised over-representation, also can be interpreted as an attentional account. It suggests an alternative nature or cause of attentional imbalance.

In our opinion, further alternative causes of the attentional imbalance can not be ruled out on the basis of previous experiments. Mattingley et al. [23] demonstrated that patients no longer showing classical signs of UN, continued to show the ipsilesional attentional bias. The authors interpreted the persisting ipsilesional attentional bias in terms of a higher-order attentional right hemisphere dysfunction. However, five of the 13 patients also had visual field defects (VFDs), i.e. either homonymous hemianopia (HH) or quadrantanopia. Hence, the observed residual (group-)effects (in terms of the bias) could be attributable, not to a higher-order right hemisphere attentional problem, but alternatively to effects of the (lower-order) left-sided VFDs.

It is well recognised that visuo-spatial perception can be impaired in “pure” hemianopic patients (i.e. in patients with HH and without UN) [39]. Hemianopic patients have been reported to show impaired visuo-spatial exploration, especially in the hemianopic hemi-field [40]. Also a deviated subjective midline or subjective straight-ahead in visuo-spatial judgements has frequently been reported [e.g. 18, 2, 8]. Karnath and Ferber [17] discuss reports which show that misperception of horizontal space (hemimicropsia) exists in (some) pure hemianopic patients. It is thus apparent that a homonymous VFD can give rise to lateralised visual impairments. Hence it is not inconceivable that HH, which results inherently in a chronic differential lateralised visual input, also gives rise to an imbalance in processing efficiency of the visual space. We thus suggest that an attentional imbalance is not necessarily the result of a higher-order attentional right hemisphere dysfunction, but also can arise by the presence of a lower-order VFD.

It is hence our aim to investigate what is or can be the cause of the attentional imbalance resulting in the observed lateral biases. As argued, hemispheric specialisation for visuo-spatial processing, hemispheric specificity with respect to directional attentional vectors and reading habits or scanning direction have been suggested as underlying mechanisms. We investigate if homonymous VFDs (i.e. HH), resulting in asymmetric visual input, can also be added to the list of mechanisms or factors producing attentional imbalance. If so, it should do so both in left-sided and right-sided HH, but in opposing directions (i.e. both contralaterally to the side of the VFD). If this is confirmed, previous explanations of the attentional imbalance stressing exclusively higher-order right hemisphere involvement may have to be revised.

3. Method

3.1. Participants

3.1.1. Controls

Sixty-three control subjects participated in this study (25 females, 38 males). All participants were naive as to the aims and expected outcomes of the study and reported to be right-handed. They all had normal or corrected-to-normal visual acuity. Their mean age was 47 years, ranging from 17 to 86 years.

3.1.2. Patients

Prior to testing, we administered a screening battery to exclude dementia [5, 9], aphasia [7] and apraxia [6]. No impairments were found. All patients performed within the normal limits on the form discrimination screening test [36] confirming perceptual functions to be adequate for form discrimination. The nature and extent of the VFD was determined using the Humphrey Field Analyzer, which is a clinically widely used automated perimeter. We used the Full Field 246, age corrected, 3-zone strategy, screening program.

In order to identify patients with severe UN, we constructed a battery of clinical UN tests, namely, four clinical cancellation tasks, and a line bisection task. For Albert's line cancellation Test the cut-off score is two omissions [13, 35]. For the Mesulam Structured Shape cancellation this was three omissions [38], for The Bells Test four omissions [12, 35], and three omissions on the Search for O's. This last unstructured cancellation task is not publically available, but very frequently used for diagnostic purposes in the Netherlands. Also the Line bisection task was scored as a function of omitted lines (cut-off = 2) [30, 34,31].

For each task, we additionally imposed more stringent criteria. This was done in order to make a distinction between a general inattention deficit resulting in a general scanning deficit, and hemi-inattention resulting in a lateralised scanning deficit. We therefore imposed an additional "lateralisation-requirement", namely that for a "UN-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. For example, if the cut-off score for a particular test is three omissions, a UN-score is obtained only if also the number of omissions on either side exceeds the other side by at least three. Two left-sided omissions and one right-sided omission hence would not result in a UN-score, although it is indicative of a general attention and scanning deficit.

We decided that using this battery and cut-off criteria, a patient is considered to suffer severe UN if at least three (of maximally five) UN-scores are obtained and if these scores are identical in laterality (i.e. reach the lateralisation-requirements of the respective tests due to omissions on the same side).

3.1.2.1. UN patients

Three patients were classified as UN patients using our criteria. They were all males and suffered a right-sided stroke, resulting in UN and left-sided HH. One patient underwent extensive clinical rehabilitation in a clinical setting before participating, but the UN persisted. The other two patients were referred by their ophthalmologists because of "peculiar visual behaviour". Their mean time since lesion was 16 months. Their visual acuity and contrast sensitivity were within normal limits. Their mean age was 64 years. Additional clinical information is provided in table 1. On average they omitted 13 items (SD = 9) on the Albert's line cancellation Test, 23 items (SD = 22) on the Mesulam Structured Shape cancellation, 17 items (SD = 9) on The Bells Test, 17 items (SD = 14) on the Search for O's, and three lines (SD = 3) on the Line bisection task.

Table 1. Clinical data for the brain-damaged subjects

	Age/ Gender	TSL ^a	type of HH ^b and macular sparing	Location ^c and cause ^d of lesion	Other remarks
<u>UN group</u>					
1	50/M	34	C-I, no	<u>Right-sided brain damage</u> T-O-P IC, CVA	extensive clinical rehabilitation
2	74/M	7	C-C, no	O dS, CVA	left leg hemiparesic
3	70/M	7	C-C, no	O-P, CVA	
<u>Left-sided HH group</u>					
1	76/M	13	I-I, yes	<u>Right-sided brain damage</u> T-O-P, CVA	
2	69/M	12	I-C, yes	O-P, CVA	
3	53/M	24	I-C, yes	O-P, CVA	
4	56/M	9	I-C, yes	O, CVA	
5	49/M	18	I-I, yes	O-T, tumor	blindsight
6	29/M	9	I-, yes	oC, CHI	right eye blind
7	36/F	107	I-C, yes	O, CVA	
8	56/F	157	C-C, no	O-T, CVA	left hemiplegic
9	73/M	6	I-I, yes	O-P, CVA	
10	31/M	12	C-C, yes	O, CVA	
11	70/M	13	I-C, no	O, CVA	
12	34/M	64	I-C, yes	O-P-F, CHI	left hemiplegic
13	54/M	24	I-C, yes	T-O-P Th, CVA	left hemiplegic, agnosia
14	53/M	11	C-C, no	O, CVA	letter-by-letter reading
15	37/M	12	I-C, yes	O-P, tumor	
16	67/M	47	C-C, no	O-T, CVA	left hemiparesic
<u>Right-sided HH group</u>					
1	50/M	390	C-C, yes	<u>Left-sided brain damage</u> O, tumor	
2	51/F	57	C-C, yes	O, CVA	
3	50/M	28	I-I, no	T-O-P, CHI	word finding difficulties
4	39/F	142	I-C, yes	O, CVA	
5	66/M	123	I-I, yes	O, CVA	
6	18/M	225	I-I, yes	O-P*, hydrocephalus	mild balance problem
7	43/F	60	C-C, yes	O-T, CVA	letter-by-letter reading
8	52/M	6	I-I, yes	Nd, CVA	
9	64/F	10	I-C, yes	O-T, CVA	
10	65/M	32	I-C, yes	Na, CVA	
11	48/F	11	I-I, yes	O-P, CVA	
12	53/M	22	C-C, yes	O-T, CVA	
13	56/M	14	I-I, yes	O-T Th, CVA	left hemiparesic, blindsight
14	68/M	25	I-I, no	T-O-P, CVA	word finding difficulties
15	24/M	63	C-C, no	Nd, CHI	
16	57/M	3	C-C, no	O, CVA	word finding difficulties

^aTime Since Lesion in months

^bComplete (C) versus Incomplete (I) – Congruent (C) versus Incongruent (I) Homonymous Hemianopia

^cO: occipital, T: temporal, P: parietal, F: frontal, Th: thalamus, IC: internal capsula, oC: optic chiasm, dS: diffuse subcortical damage, Nd: no abnormalities detected on CT, Na: no CT available.

^dCVA: cerebrovascular accident, CHI: closed head injury

* Patient refused to give permission for scan inspection. Localisation is based on clinically motivated assumption and verbal description.

3.1.2.2. HH patients

Thirty-two patients with HH participated in this study. Their mean age was 51 years. The mean time since lesion was 55 months (SD = 80). Sixteen patients had left-sided HH (16

males, 2 females). Sixteen patients had right-sided HH (11 males, 5 females). All patients had normal or corrected-to-normal visual acuity and normal contrast sensitivity. For additional clinical data, see table 1. None of these patients fulfilled the aforementioned UN criteria. Neither of them had ever been treated for or diagnosed with UN. They omitted no items on the Albert's line cancellation Test and on the Line bisection task, on average three items (SD = 9) on the Mesulam Structured Shape cancellation, three items (SD = 4) on The Bells Test, and one item (SD = 3) on the Search for O's.

3.2. Stimuli

We used Grey Scales as described in Mattingley et al.[24]. 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 lengths. A Grey Scale is a rectangular bar with a thin black border (see fig. 1). 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 at the extremes. 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 identical to, but the mirror reverse of, the other. Each item is presented once with top/bottom position counterbalanced, resulting in 26 items.

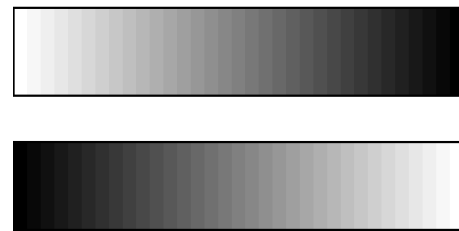


Fig. 1. Example of an item in the Grey Scales task. Upper and lower bar are identical but mirror-reversed.

3.3. Procedure

A booklet containing the 26 items is placed and remains in front of the subject at reading distance. The subject is asked to judge which of the two Grey Scales appears overall darker. The choice is indicated by saying "top" or "bottom" after which the page is turned and the next item is presented. The subject is encouraged to make a judgement based upon spontaneous and immediate apprehension rather than on prolonged and detailed inspection but is told that there is no time limit and hence can view freely. Most patients responded fluently and confidently. Many controls, on the other hand, felt they were making arbitrary choices. In addition to this standard procedure, on a second occasion, we asked the UN patients to touch the left side of each bar, prior to judging, to ascertain the perception of the full length of the bars.

3.4. Scoring

Scoring is achieved as in Mattingley et al. [24]. For each stimulus, a response is defined as left-bias or right-bias respectively if the subject chose the Grey Scale with the black side on the left and right side respectively as the darker one. The Asymmetry Index (AI) was calculated as the number of items with a rightward bias, minus the number of items with a leftward bias, divided by the total number of items. This AI varies between -1 and +1, representing an extreme leftward and rightward bias respectively. An AI of zero indicates no bias.

4. Results

We firstly checked whether we were able to replicate previous findings with control subjects. The mean AI was -0.3370 ($SD = .4304$) which is significantly different from zero ($t(62) = -6.215$, $p < .0005$). This confirms a significant leftward bias in control subjects. Secondly, we confirmed the extreme lateral bias displayed by our three UN patients. All AIs were equal to one (mean = 1, $SD = 0$), also on the second occasion, when both left ends of the bars had to be touched.

We then performed a one-way ANOVA, with both left-sided and right-sided HH groups and control subjects as a between-subjects (group) factor. This revealed a significant group effect ($F(2, 92) = 40.757$, $p < .0005$). The mean AI for left-sided hemianopic patients was $.6317$ ($SD = .3725$) and for right-sided hemianopic patients $-.5417$ ($SD = .3967$). Post-hoc comparisons with Bonferroni correction revealed the HH groups to differ from each other ($t(30) = 8.6$, $p < .0005$) and the left-sided HH patients to differ from the control group ($t(77) = 8.2$, $p < .0005$). There was no significant difference between the right-sided hemianopic patients and control subjects ($t(77) = -1.7$, ns). The patients with UN were not included in the ANOVA analysis because of the low number of patients and the absence of variation in their AIs. To test whether the AIs by the left-sided HH patients significantly deviated from the AIs by the UN patients, we performed a one sample T-test on the data by the left-sided hemianopic patients with the AI from the UN patients (i.e. 1) as test value. This analysis revealed a significant difference ($t(15) = -3.956$, $p < .001$). With the same type of analysis but with the absolute value of the AI by the right-sided HH patients as the test value, we confirmed that the strength of the AI by both HH groups did not differ from each other ($t(15) = .966$, ns).

In the control group, we found no effects of educational level, nor of age. However, in the pooled HH-group, the effect of age was marginally significant as indicated by a Pearson's correlation of age with the absolute value of the AI ($r(32) = .338$, $p < .059$). Further, time since lesion proved to correlate significantly with the absolute value of the AI ($r(32) = -.436$, $p < .05$). Time since lesion and age did not correlate in this sample ($r(32) = -.283$, ns). None of the measures of the clinical UN battery correlated significantly with the absolute value of the AI.

We further had the opportunity to test 15 HH (7 left-sided and 8 right-sided) patients on two different occasions (one week interval, same standard procedure). The AIs on both occasions correlated significantly ($r(15) = .968$, $p < .0005$), and a paired T-test comparison showed no significant difference ($t(14) = -1.662$, ns) between the means.

5. Discussion

We replicated previous findings confirming (left) perceptual asymmetries under free viewing conditions in control subjects. Our AI ($-.337$) clearly is in line with the AI reported by Mattingley et al. [24] using similar Grey Scales ($-.323$). It is also well within the range of other AIs, using different types of chimeric stimuli ranging from $-.208$ to $-.450$ [27, 24, 23, 21]. In controls, we found no effect of age, nor of educational level, suggesting the lateral bias to be a fairly robust phenomenon.

We secondly observed an extreme right-sided bias (AI = 1) in patients with UN. At first hand, our AIs might appear to be more extreme than those reported by Mattingley et al. [24] (AI = $.849$ for the Grey Scales). However, the authors report that four (of the twelve right-sided brain damaged) patients did not have UN. Removing those four patients from their results

would increase their observed AI, since three of the four lowest scores on the Grey Scales are by a non-UN patient. Not including these non-UN patients would result in all AIs (except one) to be above .9.

One of our patients with UN participated in a cognitive rehabilitation program based on the principles mentioned in Pizzamiglio et al. [28] and was relatively successfully trained [32]. His AI, after rehabilitation, remained at its extreme. This confirms claims made by Mattingley et al. [23] that the AI represents a strong ipsilesional attentional bias which is insensitive to rehabilitation. We further confirmed the persistency of the lateral bias by, additionally and on a second occasion, asking our left-sided hemianopic UN patients to touch the left side of each bar separately before judging which one appeared darker. In order to touch the left side of each bar, the patients have to fixate the left side of it (as a consequence of their left-sided HH). This brings the total bar in the right (and normally perceiving) visual hemi-field, ascertaining us that, at least once, both bars have been fully perceived. Also in this condition, all AIs remained at their extremes. This suggests this bias to be a chronic, very early (low-level) component in the visuo-attentional process, not subjected to effects of behavioural compensation. Previously made claims that this ipsilesional bias represents a relatively early, automatic, chronic, perhaps even obligatory orienting of attention [23] are hereby strengthened.

We previously summarised present accounts of the attentional imbalance. Mattingley and colleagues [23] and Luh [22] suggested that the observed perceptual asymmetry in controls is the result the selective activation of the right hemisphere, as it is specifically dedicated to processing visuo-spatial stimuli. In line with this, Luh et al. [21] previously had argued that there is a great deal of evidence that the performance of cognitive tasks for which one hemisphere is specialised, does result in an asymmetric activational pattern. This had already been recognised very early on by Trevarthen [33]. He further suggested that one hemisphere could be differentially activated by many conditions such as electrical stimulation of one hemisphere and unilateral brain damage.

Similarly, Nicholls and colleagues [27] discuss an activation model of perceptual asymmetry presented by Milner et al. [26]. This model suggests that the asymmetry can be conceptualised as an attentional imbalance between resources allocated to the left and right hemispaces. Activation of the right hemisphere generates a bias of attention to the left hemisphere, increasing the salience of stimuli located there. And since the right hemisphere is specialised for judgements of brightness [4], numerosity [25] and shape [10], performing the above discussed perceptual asymmetry tasks specifically activates the right hemisphere, resulting in a leftward bias. Nicholls et al. [27] argue that this activation model can account for numerous observations in controls (e.g. the relatively low intercorrelations between the different, but equal in size, asymmetry scores), but fail to explain how this model could account for the rightward bias in right hemisphere brain damaged patients.

As already briefly mentioned, other authors have attempted to explain the rightward bias present in UN patients and also stressed the involvement of the right hemisphere. Mattingley et al. [24] suggest that the lateral bias reflects a gradient in perceptuo-attentional processing efficiency and note that the observed rightward bias is consistent with a model of spatial attention suggested by Kinsbourne [19, 20] which stresses the directional nature of space-related behaviour. It is argued that each hemisphere controls a contralaterally directed attentional vector. The net effect of both vectors gives rise to an attentional gradient (which

can be conceptualised as processing efficiency) imposed on the attentional field. Damage to one hemisphere results in dysfunction of the associated vector and hence results in an ipsilesional bias. As such the attentional field is characterised by a gradient which allocates "more weight" or processing efficiency to the ipsilesional side. A unilateral lesion would also release the opposing hemisphere from inhibition, and thereby further inducing a pathological ipsilesional bias. A second critical element in Kinsbourne's vectorial model is that the strength of the attentional vectors controlled by either hemisphere can be modulated by the activation of that hemisphere.

Hence, Kinsbourne's vectorial model in combination with the assumed hemispheric specialisation for visuo-spatial events, accommodates the rightward bias in UN and the leftward bias in controls (attentional/hemispheric account). By this view, the perceptual asymmetries reflect patterns of differential functional cerebral activity and specifically stress that right hemisphere activity is a key concept. This right hemisphere predominance is considered to be exclusively based on its own internal properties i.e. its directional attentional nature or its specialisation for visuo-spatial stimuli or tasks. We however argue that, in addition to this hemispheric influence, also differential sensory input can be of influence. Several indications are provided by our results.

Firstly, we found differential performances within the right hemisphere brain damage group. Namely, all our UN patients presented extreme rightward biases, while the patients with left-sided HH were significantly less extreme, though clearly in the same direction and significantly different from no bias and from controls. The difference in performance, within the right hemisphere damage group, suggests that mere right hemisphere involvement (as suggested by previous accounts) can not be the sole explanation for the observed rightward bias. However, since we did not have access to detailed neurological information, we cannot rule out the possibility that the size of the right hemisphere lesion can account for the observed difference. A second confounding factor in our data is the marked difference in time since lesion between both right hemisphere brain damage groups. This difference could thus also, at least partly, account for the differential performance within this group. Hence, our data show differential performance in the right hemisphere brain damage group, suggesting other factors to be at hand than mere right hemisphere involvement. But alternatively, size of, and time since the right hemisphere lesion can not be ruled out as valid determinants.

However, secondly, we showed that right- and left-sided HH patients present a quantitatively similar, but qualitatively opposite pattern of results. Both HH groups are virtually identical, but suffer a mirror-reversed visual dysfunction and present an identical but also reversed lateral bias. The side of the attentional imbalance is clearly linked to side of the HH. We hypothesise, conceptually in line with the previously mentioned "reading habit" assertion, that the VFDs lead to an over-representation of the ipsilesional hemi-space. It is commonly assumed that visual attention has two aspects, namely exogenous (stimulus-induced) and endogenous (voluntary). Stimulus-induced attention is considered to be very dominant [15, 14] and this directing of attention is thought to be guided by the saliency of (visual) objects. In patients with HH, objects from the non-perceiving hemifield cannot attract attention (i.e. have no saliency). All stimulus-driven capturing of attention is exclusively and consistently in the ipsilesional direction. We conceptualise that this bias leads to an over-representation of the ipsi-lesional hemi-space, and hence an attentional imbalance. Our results suggest that

these effects in the HH group are conceptually different from attentional/hemispheric effects, as traditionally conceptualised, since none of the clinical UN measures correlated with the AI.

We hence argue that the sensory effects can be another source of attentional imbalance, which can interact with the hemispheric effects. In controls, the (normal) leftward bias is due to right hemisphere specialisation for visuo-spatial events. This bias seems enhanced by the sensory effect of a right-sided VFD. This enhancement did however not reach statistical significance in our sample. Damage to the right hemisphere removes the (hemispheric) leftward bias, and induces a rightward bias. Right hemisphere brain damage can disrupt typical visuo-attentional and directional processes, thought to be typical in UN. But a similar rightward bias can also be elicited by left-sided VFDs, for the same (i.e. sensory) reason as with right-sided VFDs. In our study, we cannot dissociate the sensory and attentional/hemispheric components, but it was shown by Mattingley et al. [24] that UN patients without VFDs, all showed an extreme AI on the Grey Scales task. In our patients with UN (and left-sided HH), both sensory and hemispheric components are combined, leading in all cases to extreme and persistent rightward biases. In our left-sided VFD patients, only the sensory component is present (with possibly a minor hemispheric component). The bias is qualitatively similar to the UN patients, but less extreme. Warranted, as already argued, by the possible size and time since right hemisphere lesion effects, this suggests the sensory component to be less dominant.

Firstly, this would strengthen the claim that UN is more severe when it occurs simultaneously with HH (e.g. [1,37]) since this condition entails both sensory and attentional/hemispheric components. Secondly, this would underpin our claim that one symptom of UN behaviour (namely the lateral bias) can also be displayed by non-UN patients, namely also by HH patients. This suggests, at least at the behavioural level, a continuum in disability, giving rise to the notion “subclinical neglect”. This term would indicate subtle indications of UN(-behaviour), without objective clinical signs or evidence of UN.

In previous literature, it was not clear whether the attentional imbalance was considered to be the cause of UN (as suggested by Kinsbourne's model) or whether it resulted as a consequence of another dysfunction (e.g. a contralesional attentional deficit in UN, or a VFD as in HH). Previous literature had shown that, in pure UN (UN without VFDs), an ipsilesional bias could be demonstrated (e.g. [23, 24]), suggesting an attentional/hemispheric component. We found that HH also gives rise to a qualitatively similar bias, suggesting a sensory component. We therefore conclude that the attentional imbalance can be multiply influenced and is hence a consequence rather than cause. This has the further implication that an attentional imbalance is not necessarily and unequivocally to be associated with UN.

We feel that the Grey Scales task has strong clinical potential. Firstly, as was suggested in previous literature, the AI can be considered a sensitive measure of attentional imbalance, with UN as its extreme. Secondly, the AI can give the clinician a clear indication of the possible presence and side of a homonymous VFD. Namely, in our brain damaged patient group with homonymous VFDs, we observed a sensitivity and specificity of .94 and .88 in predicting the side of the HH, given the direction of the AI. Thirdly, contrary to most cancellation tasks or other tasks clinically used to diagnose differential lateral performance, almost any patient can perform the Grey Scales task, because it has no identification component. We hence successfully applied this test to a patient with complete object-agnosia,

while all cancellation tasks appeared unachievable. Finally, although not extensively investigated, we feel that the AI can also have some practical significance. In a larger study investigating practical fitness to drive in patients with HH (to be published), we found evidence that the AI was significantly related to visual performance during driving ($r(29) = -.510, p < .005$), while AIs from other tasks were not or significantly less strongly related. This suggests the Grey Scales task to have some practical significance to at least this type of activity of daily living.

In conclusion, we do not refute that perceptual biases reflect a pattern of functional cerebral asymmetry. But the imbalance can not be uniquely related to specialisation of the right hemisphere for visuo-spatial attentional function, since left- and right-sided hemianopic patients, with right- and left-sided brain damage respectively, show similar but inverse lateral biases. Asymmetric activation of one hemisphere can be the result of asymmetric sensory input, caused by the HH.

To further understand the nature and cause of the different components which can give rise to the attentional imbalance, future research could concentrate on patients with left- and right-sided brain damage, without clinical signs of UN and without VFDs. This could elucidate the possible differential hemispheric involvement. Further, other types of homonymous VFDs could also contribute to the insight into the involvement of the sensory influences. In bilateral superior and inferior quadrantanopia (i.e. missing a lower and upper hemifield respectively) and with the Grey Scales items 90 degrees rotated, the attentional imbalance should result in a quantitatively similar upper and lower bias respectively. We also envisage experiments where different types of homonymous VFDs can be simulated on (non-brain damaged) controls using sophisticated eye-movement equipment. In these kinds of paradigms, the observed asymmetries (if any) are unconfounded with respect to VFDs and brain damage. Finally, for clinical and practical use, the relationship with performance during activities of everyday life should be further investigated and confirmed.

6. References

- [1]Agrell, B M, Dehlin, O I, Dahlgren, C J. Neglect in elderly stroke patients: a comparison of five tests. *Psychiatry and Clinical Neuroscience* 1997;**51**:295-300.
- [2]Barton, J J, Behrmann, M, Black, S. Ocular search during line bisection. The effects of hemi-neglect and hemianopia. *Brain* 1998;**121**:1117-1131.
- [3]D'Erme, P, Robertson, I, Bartolomeo, P, Daniele, A, Gainotti, G. Early rightwards orienting of attention on simple reaction time performance in patients with left-sided neglect. *Neuropsychologia* 1992;**30**:989-1000.
- [4]Davidoff, J B. Hemispheric differences in the perception of lightness. *Neuropsychologia* 1975;**13**:121-124.
- [5]De Graaf, A, Deelman, B G. *Cognitieve Screening Test*. Lisse: Swets & Zeitlinger, 1991.
- [6]De Renzi, E, Faglioni, P, Sorgato, P. Modality-specific and supramodal mechanisms of apraxia. *Brain* 1982;**105**:301-312.

-
- [7]Deelman, B G, Liebrand, W B G, Koning-Haanstra, M, van der Burg, W. SAN test. Lisse: Swets & Zeitlinger, 1987.
- [8]Ferber, S, Karnath, H O. Parietal and occipital lobe contributions to perception of straight ahead orientation. *Journal of Neurology, Neurosurgery and Psychiatry* 1999;**67**:572-578.
- [9]Folstein, M F, Folstein, S E, McHugh, P R. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research* 1975;**12**:189-198.
- [10]Fontenot, D J. Visual field differences in the recognition of verbal and nonverbal stimuli in man. *Journal of Comparative and Physiological Psychology* 1973;**85**:564-569.
- [11]Gainotti, G, D'Erme, P, Bartolomeo, P. Early orientation of attention toward the half space ipsilateral to the lesion in patients with unilateral brain damage. *Journal of Neurology, Neurosurgery, and Psychiatry* 1991;**54**:1082-1089.
- [12]Gauthier, L, Dehaut, F, Joannette, Y. The Bells Test: A quantitative and qualitative test for visual neglect. *International Journal of Clinical Neuropsychology*. 1989;**11**:49-54.
- [13]Halligan, P W, Marshall, J C. Is neglect (only) lateral? A quadrant analysis of line cancellation. *Journal of Clinical and Experimental Neuropsychology* 1989;**11**:793-798.
- [14]Hikosaka, O, Miyauchi, S, Shimojo, S. Focal visual attention produces illusory temporal order and motion sensation. *Vision Research* 1993;**33**:1219-1240.
- [15]Hikosaka, O, Miyauchi, S, Shimojo, S. Voluntary and stimulus-induced attention detected as motion sensation. *Perception* 1993;**22**:517-526.
- [16]Karnath, H O. Deficits of attention in acute and recovered visual hemi-neglect. *Neuropsychologia* 1988;**26**:27-43.
- [17]Karnath, H O, Ferber, S. Is space representation distorted in neglect? *Neuropsychologia* 1999;**37**:7-15.
- [18]Kerkhoff, G. Displacement of the egocentric visual midline in altitudinal postchiasmatic scotomata. *Neuropsychologia* 1993;**31**:261-265.
- [19]Kinsbourne, M. Mechanisms of unilateral neglect. In: Jeannerod, M, editor. *Neurophysiological and Neuropsychological Aspects of Spatial Neglect*. Amsterdam, North-Holland, 1987:69-86.
- [20]Kinsbourne, M. Orientational bias model of unilateral neglect: Evidence from attentional gradients within a hemispace. In: Robertson, I H, Marchal, J C, editors. *Unilateral Neglect: Clinical and Experimental Studies*. Hove: Lawrence Erlbaum, 1993:63-86.

-
- [21]Luh, K E, Rueckert, L M, Levy, J. Perceptual asymmetries for free viewing of several types of chimeric stimuli. *Brain and Cognition* 1991;**16**:83-103.
- [22]Luh, K E. Line bisection and perceptual asymmetries in normal individuals: What you see is not what you get. *Neuropsychology*. 1995;**9**:435-448.
- [23]Mattingley, J B, Bradshaw, J L, Bradshaw, J A, Nettleton, N C. Residual rightward attentional bias after apparent recovery from right hemisphere damage: implications for a multicomponent model of neglect. *Journal of Neurology, Neurosurgery, and Psychiatry* 1994;**57**:597-604.
- [24]Mattingley, J B, Bradshaw, J L, Nettleton, N C, Bradshaw, J A. Can task specific perceptual bias be distinguished from unilateral neglect? *Neuropsychologia* 1994;**32**:805-817.
- [25]McGlone, J, Davidson, W. The relation between cerebral speech laterality and spatial ability with special reference to sex and hand preference. *Neuropsychologia* 1973;**11**:105-113.
- [26]Milner, A D, Brechmann, M, Pagliarini, L. To halve and to halve not: an analysis of line bisection judgements in normal subjects. *Neuropsychologia* 1992;**30**:515-526.
- [27]Nicholls, M E, Bradshaw, J L, Mattingley, J B. Free-viewing perceptual asymmetries for the judgement of brightness, numerosity and size. *Neuropsychologia* 1999;**37**:307-314.
- [28]Pizzamiglio, L, Antonucci, G, Judica, A, Montenero, P, Razzano, C, Zoccolotti, P. Cognitive rehabilitation of the hemineglect disorder in chronic patients with unilateral right brain damage. *Journal of Clinical and Experimental Neuropsychology* 1992;**14**:901-923.
- [29]Sakhuja, T, Gupta, G C, Singh, M, Vaid, J. Reading habits affect asymmetries in facial affect judgements: a replication. *Brain and Cognition* 1996;**32**:162-165.
- [30]Schenkenberg, T, Bradford, D C, Ajax, E T. Line bisection and unilateral visual neglect in patients with neurologic impairment. *Neurology* 1980;**30**:509-517.
- [31]Soukup, V M, Harrell, E H, Clark, T. Right hemispace presentation and left cueing on Raven's Coloured Progressive Matrices among right brain-damaged neglect patients. *Brain Injury* 1994;**8**:449-455.
- [32]Tant, M L M, Brouwer, W H, Kooijman, A C, Cornelissen, F W. Evaluation of the effectiveness of a hemi-neglect rehabilitation program and generalization to driving: a case study. In: Gale, A G, Brown, I D, Haslegrave, C M, Taylor, S P, editors. *Vision in Vehicles VIII*. Amsterdam: Elsevier, in press.
- [33]Trevarthen, C. Brain bisymmetry and the role of the corpus callosum in the behavior and conscious experience. In: Cernacek, J, Padivinsky, F, editors. *Cerebral hemispheric relations*. Bratislava: Slovak Academy of Sciences, 1972.

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- [34]Van Deusen, J. Normative Data for Ninety-Three Elderly Persons on the Schenkenberg Line Bisection Test. *Physical and Occupational Therapy in Geriatrics* 1984;**3**:49-54.
- [35]Vanier, M, Gauthier, L, Lambert, J, Pepin, E P, Robillard, A, Dubouloz, C J, Gagnon, R, Joannette, Y. Evaluation of left visuospatial neglect: Norms and discrimination power of two tests. *Neuropsychology* 1990;**4**:87-96.
- [36]Warrington, E K, James, L. *The Visual Object and Space Perception Battery*. Bury St. Edmunds: Thames Valley Test Company, 1991.
- [37]Webster, J S, Jones, S, Blanton, P, Gross, R, Beissel, G F, Wofford, J D. Visual scanning training with stroke patients. *Behaviour Therapy* 1984;**15**:129-143.
- [38]Weintraub, S, Mesulam, M M. Visual hemispatial inattention: stimulus parameters and exploratory strategies. *Journal of Neurology, Neurosurgery, and Psychiatry* 1988;**51**:1481-1488.
- [39]Zihl, J. *Rehabilitation of Visual Disorders After Brain Injury*. Hove, East Sussex: Psychology Press Ltd, 2000.
- [40]Zihl, J, von Cramon, D. Visual field recovery from scotoma in patients with postgeniculate damage. A review of 55 cases. *Brain* 1985;**108**:335-365.

Hemianopic Visual Field Defects elicit Hemianopic Scanning*

1. Abstract

Previous explanations for the variability in success of compensating for homonymous hemianopia (HH) has been in terms of extent of the brain injury. In using on-line eye movement registrations, we simulated HH in 16 healthy subjects and compared their scanning performance, on a dot counting task, to their own “normal” condition and to real HH patients’ performance.

We evidenced clear parallels between simulated and real HH, suggesting that hemianopic scanning behaviour largely is visually elicited, namely by the visual field defect, and not by the brain damage. We further observed age-related processes in compensating for the HH.

2. Introduction

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 results from unilateral post-chiasmal brain damage. Nearly 80% of patients with unilateral post-chiasmal brain damage acquire a homonymous VFD (Zihl, 1994). Common causes are cerebrovascular accident, traumatic brain injury and tumours (e.g. Kerkhoff, 1999; Zihl, 2000).

Visual field defects often lead to visually related complaints and dysfunctions. Patients complain for example about having a limited overview, bumping into obstacles or persons and experience their vision as being too “slow”. These disabilities are related to the degree of compensation for the visual field loss. For comprehensive reviews we refer to Kerkhoff (1999) and Zihl (2000). Oculomotor compensation, i.e. adaptive visual scanning behaviour, can be assessed by recording eye movements (e.g. Zihl, 1995, 1999, 2000; Zangemeister, Meienberg, Stark, & Hoyt, 1982; Zangemeister & Oechsner, 1996).

A paradigm to objectively and quantitatively assess oculomotor compensational behaviour was introduced by Zihl (e.g. 1995, 1999, 2000) and consisted of inspection of a dot pattern. The stimulus display consists of 20 randomly arranged dots projected onto a screen. Subjects are asked to fixate the centre of the screen, after which the dot pattern is presented and eye movements are recorded. Subjects subsequently scan the pattern and silently count the number of dots. Upon completion they report the number of dots. The relatively simple stimulus display was chosen to restrict visual scanning to the process of visual sampling without any further identification component (Zihl, 1999), or the primary involvement of other complex higher-order visual functions. Using this paradigm, it was found that in HH typical defective oculomotor scanning behaviour is characterised by longer scanning times and scan paths, higher number of fixations and re-fixations, and, at least in part, longer fixation durations and shorter saccadic amplitudes (e.g. Zihl, 1995, 1999, 2000). These findings are in concordance with other reports (e.g. Kerkhoff, 1999; Zangemeister & Oechsner, 1996; Meienberg, Zangemeister, Rosenberg, Hoyt, & Stark, 1981; Chedru, Leblanc, & Lhermitte, 1974; Ishiai, Furukawa, & Tsukagoshi, 1987; Neetens, 1994; Zangemeister et al., 1982).

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In large, it was found that about 40% of the HH patients spontaneously compensate effectively for their VFD (Zihl, 1995, 1999, 2000) and that the subjective visual complaints by HH patients were substantiated by eye movement recordings during the dot counting task, confirming its practical relevance. Interestingly, it was concluded (Zihl, 1999, 2000) that the presence, time since, and severity of the VFDs could not sufficiently explain the observed scanning deficit and that additional factors are crucial for explaining the impaired oculomotor scanning. Zihl suggested that the extent of the brain injury is a crucial factor and that occipitoparietal and posterior thalamic brain injury may be responsible for inefficient compensation.

Nevertheless, there are some peculiar aspects in the results, which cast doubt on the provided explanation for the individual differences in the efficiency of compensation for HH. Firstly, it was noted by Zihl (1999) that the scanning (e.g. in terms of scanning time) was found to be impaired in this very simple visual sampling task. Hence, even in a task, in which complex higher-order (i.e. brain related) functions are not involved, a disability appears. This calls into question the crucial importance of the integrity of the brain for the visual disability. Zihl therefore cautions against the (mis)interpretation of the results in term of “unspecific” cognitive slowing, suggesting in our view, an interpretation in terms of mere visual slowing. He suggested that the “slowness of vision” may, at least in part, be explained by the use of hypometric saccades which are provoked by a homonymous VFD.

Secondly, it was found that the side of the VFD (and therefore the side of the brain lesion) was not a crucial factor. Zihl (1999) comments this observation to be surprising, because of the assumed specialisation of the right (posterior) hemisphere for visuo-spatial function, including the spatial guidance of eye movements. If predominantly higher-order visual (i.e. brain related) functions were involved, one would have expected left-sided HH patients (with right-sided brain damage) to perform worse, due to hemispheric specialisation and the inherently visuo-spatial nature of the dot counting task.

Both observations suggest that the deficit in visual exploration is perhaps not predominantly related to additional brain damage, but is merely a knock-on effect of the lower-order dysfunction, i.e. the hemianopic visual field loss. In order to preclude the effects of brain damage, we simulated HH in healthy subjects and compared the visual exploration to their own ‘normal’ condition. By simulating the hemianopic visual field loss, we ‘create’ subjects with the lower-order visual dysfunction, but without higher-order dysfunctions caused by brain damage. The observed disabilities (if any) during simulation result from the visual limitation only and do not require a further explanation in terms of brain damage. If visual exploration deficits in real HH are predominantly provoked by the VFD, the visual exploration behaviour, displayed in simulated and real HH, should be comparable, including the variability in performance between individuals. Our primary research question hence concerns the influence of the pure visual component on hemianopic visual exploration during a dot counting task. We also included real HH patients in this study to compare the patterns of performance with simulated and real HH.

A secondary question concerns the explanation of individual differences in the efficiency of compensating for HH. Apart from differences in extent and site of brain injury in patients, in healthy subjects there are large individual differences in higher-order visual and cognitive abilities, for example differences in visual speed and other components of intelligence. Some

of these abilities are highly dependent on age, for example perceptual speed and spatial orientation (Schaie & Willis, 1993) and fluid intelligence (Rybash, Roodin, & Hoyer, 1995). As was also suggested by Szlyk and colleagues (Szlyk, Brigell, & Seiple, 1993), it is quite conceivable that such age-related abilities play an important role in the efficient compensation of HH. To investigate the effect of ageing on the efficiency of compensation, we included both younger and older adults in the study. It is predicted that the older subjects will have significantly more problems in coping with HH.

In summary of the research questions, we expect to find typical HH scanning performance in healthy subjects with a simulated hemianopic VFD, since we hypothesise that HH scanning is primarily generated by the VFD and not by brain damage. To fully compare and characterise HH scanning performance, we will perform, in addition to general analysis, also directional, hemispace, and trend analysis (see further). Secondly, we expect to find the disabilities to be more pronounced in an older age group, since we assume that individual differences in perceptual and intellectual abilities, which tend to decrease with age, are important factors governing the compensation process.

3. Methods

3.1. Subjects

Sixteen healthy subjects participated in this study (seven males, eight females). Their mean age was 40 years (range 16-71). Two age groups were included: a younger group with a mean age of 21 years (range 16-23) and an older age group with a mean age of 60 years (range 46-71), each consisting of eight subjects. They showed no signs of cognitive decline (CST; De Graaf & Deelman, 1991), reported to be right-handed, and had normal or corrected-to-normal visual acuity. They declared to have no visually related complaints.

Twenty-nine patients were included (23 males, 6 females). They showed no evidence of cognitive decline (CST; De Graaf & Deelman, 1991 and MMSE; Folstein, Folstein, & McHugh, 1975), aphasia (SAN; Deelman, Liebrand, Koning-Haanstra, & van der Burg, 1987) or apraxia (De Renzi, Faglioni, & Sorgato, 1982). Neither of them showed severe unilateral visual hemi-neglect (UN) or visual agnosia. The selection procedure for UN is described elsewhere (Tant, Brouwer, Kooijman, & Cornelissen, submitted). All patients had a binocular optimally corrected acuity of 0.8 or better and contrast sensitivity within normal ranges. All had complete or incomplete HH as confirmed by automated perimetry using the Humphrey Field Analyzer (Full Field 246 screening program, age corrected, 3-zone strategy). Fourteen patients had left-sided HH. Their mean age was 54 years (range 29-76), the mean time since lesion was 32 months (range 6-157), and the mean macular sparing subtended 3 degrees (range 0-10). All were victims of stroke, except two patients, who were surgically operated for tumour. One patient, with left-sided HH, only had (right) monocular vision. Fifteen patients had right-sided HH. Their mean age was 50 years (range 17-68), the mean time since lesion was 80 months (range 3-390), and the mean macular sparing subtended 3 degrees (range 0-8). One patient was surgically operated for hydrocephalus, and one for tumour. Two patients suffered closed head injury. The remaining patients were victims of stroke.

3.2. Dot counting Task and Apparatus

Our dot counting task is based upon the work of Zihl (e.g. 1995). We presented in total 29 patterns of dots. The screen dimensions were 36° and 27° horizontally and vertically respectively. The dot size was 1°. Dots were white (luminance 25 cd/m²) on a grey

background (50% contrast). The viewing distance was 52 cm. We presented five different patterns consisting of 19, 20 and 21 dots each (i.e. 15 trials). The spatial distribution of the dots in these patterns was random but fixed over subjects. Additionally we presented patterns consisting of 5-17 dots (two-dot increment), which each were presented twice (i.e. 14 trials). Their spatial distribution was randomly generated on each presentation. The 29 trials were presented in a random order. Before each trial, a fixation dot (1.5°) was presented in the centre of the screen. Upon stable fixation, the trial was initiated. The subject was asked to count the number of dots. When the subject verbally indicated being finished, the trial was aborted, and the answer registered.

During the experiment the eye movements were recorded using an EyeLink Gaze tracker (SensoMotoric Instruments GmbH, Teltow, Germany) which registers real-time gaze at 250 Hz. When simulating HH, a window, with the same properties as the background, continuously and completely blanked one side of the screen with reference to the current gaze position. This could either be left or right of fixation in order to simulate left- or right-sided HH respectively. Prior to the experiment, the equipment was calibrated using a nine-point grid. The initial central fixation dot, prior to each trial, was also used for drift correction which may result from slips of the EyeLink's headset. Small head-movements were allowed (and corrected for) during the experiment. This equipment allows for relatively normal free viewing conditions.

3.3. Procedure

The healthy subjects performed the task on two different occasions. On each occasion, they firstly performed the task in a non-simulation (i.e. normal) and subsequently in a simulation condition. During the task in a simulation condition, the side of the simulated homonymous hemianopia (sHH) was fixed. On the second occasion, the side of the sHH was changed for each subject. During simulation, half of the subjects had a macular sparing of 2.7° on both occasions. The patients performed the task once. Obviously, no simulation was imposed.

3.4. Statistical analysis

The oculomotor parameters are number and duration of the fixations, number and amplitude of the saccades, and the length of the scanpath, which is sum of the saccadic amplitudes. When both number of fixations and number of saccades are used in the same analysis, only the number of fixations are reported. As a saccade typically follows a fixation, both parameters are logically linked and hence the number of one or the other provides no additional information. We further report the absolute error in counting the dots (henceforth referred to as error) and the search time. Additionally, we perform directional and hemispace analysis. Since the healthy subjects suffered no actual brain damage, directions and side of the hemispace are defined with respect to the side of the VFD. "Ipsilateral" and "contralateral" hence refer to "in or towards" the affected and intact visual hemifield respectively. Directional analysis is performed on the amplitudes and number of saccades. Hemispace analysis is applicable for the fixation parameters. The hemispace is defined in terms of the centre of the screen, which is also the start of exploration in each trial. To further characterise the scanning performance, we perform a trend analysis using the errors, search time, number of fixations, and length of the scanpath to investigate how the difficulty of the task (operationally defined by the number of dots in each pattern) influences performance in each subject group.

To analyse the data by the healthy subjects, we performed a MANOVA on a doubly repeated measures design. When significant multivariate effects were observed, the univariate effects were inspected. When necessary, we additionally performed simple-main-effects analysis, to untangle the interaction-components. For this last type of analysis, only p-values will be reported. The design is graphically depicted in Fig. 1. We included the factors of age (Young/Old), macular sparing (yes/no), and sequence (A/B) as between-subjects factors. The sequence factor represents whether subjects were first imposed with a left- (A) or right-sided sHH (B). Within-subject factors were measurement (first or second occasion) and mode (Normal/simulated HH). The measurement-, mode- and age-factors are interpretable as main-effects factors. Since the sparing factor has no relevance in the normal mode and can only exert effects during simulation, a main effect of sparing will arise as a mode x sparing interaction. Effects of the side of the sHH are inferred from simple-main-effect analysis on the measurement x mode x sequence interactions. Namely, a significant measurement x sequence interaction, within the simulation mode, reveals differential performances by left- and right-sided sHH subjects. When observed, further analysis and inspection of the means will then reveal the nature of the effects of the side of sHH and the consistency of the difference between left- and right-sided sHH in both sequences. Absence of this 2-way interaction indicates no difference in left- versus right-sided sHH. Although statistically interactional, the effects of both sparing and side of the sHH will be reported as main-effects. The patient data conform to a repeated measures design with side of the HH as a between-subjects variable. We analysed the same parameters as for the healthy subjects.

Figure 1. Graphical depiction of the healthy subjects design. Between-subject factors are Sequence, Age, and Sparing. Within-subject factors are Measurement and Mode.

Sequence	Age	Sparing	Measurement		Second occasion	
			Mode	First occasion	Normal	Simulation
A	Y	no	N	left-sided sHH	N	right-sided sHH
		yes				
	O	no	N	right-sided sHH	N	left-sided sHH
yes						
B	Y	no	N	right-sided sHH	N	left-sided sHH
		yes				
	O	no	N	left-sided sHH	N	right-sided sHH
yes						

4. Results

4.1. General analysis: Multivariate

MANOVA failed to reveal significant multivariate main effects of measurement and age, suggesting that nor repetition of the experiment or age did have any overall influence on the data. There was a significant mode-effect ($F(7,2) = 147, P < .007$), suggesting an overall effect of the simulation. We observed no effect of sparing, indicating that macular sparing did not lead to better performance in sHH. We found no measurement x mode interaction, confirming the absence of learning effects in both modes. Age, however, did interact significantly with mode ($F(7,2) = 62, P < .016$). The age effect will be explored further. We observed a significant measurement x mode x sequence interaction ($F(7,2) = 27, P < .036$), suggesting a possible influence of the side of the sHH. Simple-main-effect analyses will be performed to reveal the nature of these effects and interactions.

4.2. General analysis: Univariate

In the simulation mode (compared to the normal mode), subjects took more time and made more errors in counting the dots. They fixated more and the mean fixation duration was longer. Also the scanpath was prolonged (Fig. 2). All parameters showed significant differences, except the saccadic amplitudes (F -range: 11-184, P -range: .011-.0001).

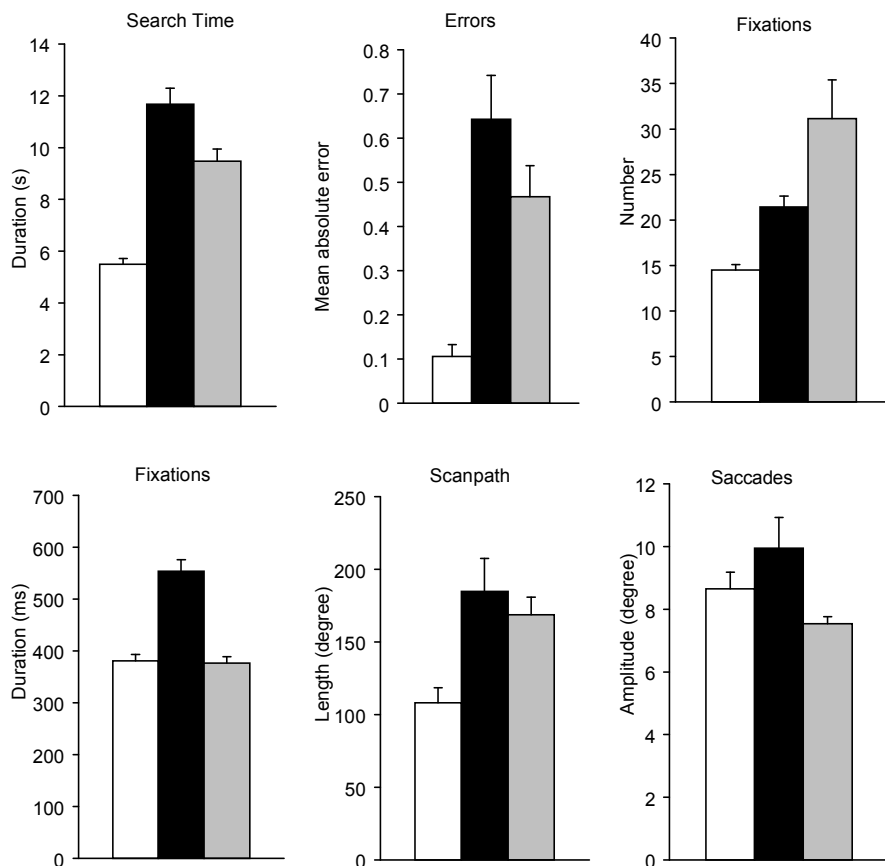


Figure 2. Simulated HH (black) provokes longer search times, more errors, more fixations, longer fixation durations, and longer scanpaths than in normal conditions (white). Patient data (hatched bars) for comparison. Error bars are 1 standard error.

In comparison to right-sided sHH, subjects with left-sided sHH made more errors ($F(1,8) = 13, P < .007$) and presented a longer search time ($F(1,8) = 11, P < .01$) (Table 1). Simple-main-effects analysis had revealed that none of the parameters produced significant differences in normal modes. Significantly worse performance by left-sided HH was also observed in the patient group, but only for the errors ($F(1,27) = 9, P < .005$) (Table 1).

Table 1. Effects of the side of the VFD in simulated (sHH) and real hemianopia (HH). Left-sided sHH subjects take more time and make more errors than right-sided sHH. Left-sided HH patients make more errors than right-sided HH. The difference between left- and right-sided HH was not statistically significant for the search time. Standard errors between brackets.

		Side of the VFD	
		left	right
Errors	sHH	.95 (.11)	.34 (.11)
	HH	.68 (.10)	.25 (.10)
Search Time (s)	sHH	13.2 (.83)	10.2 (.83)
	HH	10.1 (.67)	8.8 (.65)

The effect of age was apparent in the search time ($F(1,8) = 19, P < .002$) and number of fixations ($F(1,8) = 19, P < .006$). The increase for both parameters in the simulation mode was greater for the older age group (Fig. 3). Exploratory, we plotted the search time per dot (i.e. relative search time) in function of the trial order, and observed that, although always present, the age effects are especially evident in the beginning of the task (Fig. 4). We observed similar age effects in the patient population, as evidenced by the Pearson's correlation of age with search time ($r(29) = .38, P < .05$) and number of fixations ($r(29) = .42, P < .05$).

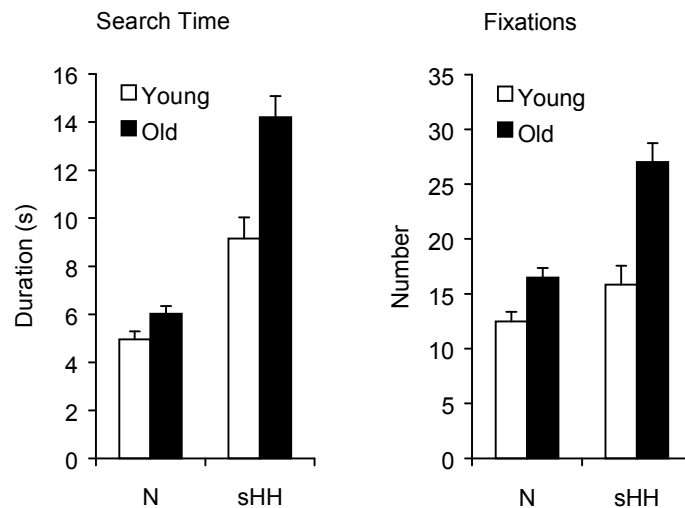


Figure 3. Subjects from the older age group had longer search times and made more fixations (and saccades) in the simulated conditions. N: Normal condition, sHH: simulated condition. Error bars are 1 standard error.

4.3. Directional analysis

Multivariate directional analysis on the healthy subjects data, including the number and amplitude of the saccades, was significant ($F(2,13) = 4, P < .05$) for the mode x direction interaction. The saccadic amplitudes in either direction did not differ in the normal mode, but there was a significant directional effect in the simulation mode ($F(1,14) = 5, P < .05$). Namely, ipsilateral saccadic amplitudes were smaller than contralateral amplitudes (Table 2). There was no effect of the side of the sHH, indicating that the amplitudes of saccades into the blind hemifield are smaller than into the seeing hemifield, for both left- and right-sided sHH. This pattern of results was paralleled in the patient group. Multivariate analysis failed to reveal any effect of the side of the HH, but presented a significant directionality effect ($F(2, 26) = 11, P < .000$). Inspection of the univariate analysis showed the saccadic amplitudes to be smaller in ipsilateral than in contralateral direction ($F(1, 27) = 19, P < .000$) (Table 2).

4.4. Hemispace analysis

A multivariate hemispace analysis was performed on the number and durations of the fixations by the healthy subjects. A multivariate mode x field interaction was found ($F(2,13) = 11, P < .002$).

Univariate analysis showed a significant effect of fixation duration ($F(1,14) = 9, P < .010$). This effect was however not apparent in the simulation condition. In the normal mode, the durations proved to be longer when they occurred on the right side of the screen than on the left side (352 ms and 411 ms for left and right hemispace respectively, $P < .004$). Tentatively, in the simulation mode, inspection of the

means would suggest ipsilateral fixation durations (577 ms) to be longer than contralateral ones (533 ms), but this difference proved not to be significant.

There was also a significant effect of hemispace on the number of fixations ($F(1,14) = 8, P < .012$). In the normal mode, there were as many fixations in either left or right hemispace, but clearly more fixations in the ipsilateral hemispace in the simulation mode ($P < .009$) (Table 2). There was no interaction with the side of the sHH, indicating that, in both left- and right-sided sHH, subjects fixated more on the same side of the screen as their VFD.

This pattern of results was paralleled in the patient group. We observed a multivariate effect of hemispace ($F(2,26) = 55, P < .000$) and no effect of side of the HH. Both left- and right-sided HH patients fixated more in the ipsilateral hemispace ($F(1,27) = 93, P < .000$) (Table 2).

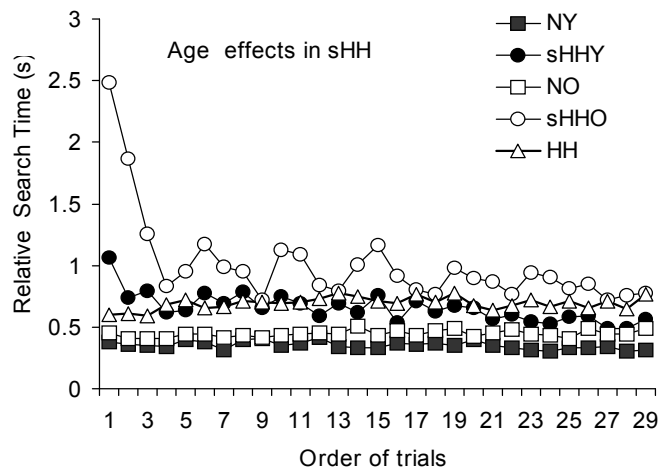


Figure 4. The age effects in sHH are especially evident in het beginning of the experiment. N: Normal condition, sHH: simulated condition, Y: Younger age group, O: Older age group, HH: patient group.

Table 2. Directional and Hemispace analysis. Saccadic amplitudes are smaller in ipsilateral than in contralateral direction in simulated (sHH) and real hemianopia (HH). In the normal condition (N), there were no differences in amplitudes between saccades to the left or to the right (in table termed ipsilateral and contralateral receptively). In both HH groups, there are more fixations in ipsilateral than in contralateral hemispace. We observed no such difference in the normal condition. Standard errors between brackets.

		Ipsilateral	Contralateral
Saccadic Amplitude (degree)	N	8.4 (.59)	8.7 (.55)
	sHH	9.08 (.96)	10.81 (1.2)
	HH	7.00 (.18)	8.2 (.31)
Number of Fixations	N	7.3 (.39)	7.2 (.41)
	sHH	12.5 (1.2)	8.9 (1.1)
	HH	15.7 (.94)	9.1 (.48)

Table 3. Trend Analysis assessing the influence of the number of dots for the normal (N) and simulated condition (sHH) and for the patients (HH). # indicates presence of higher-order trends. ns: not statistically significant.

		Trends	
		Linear	Quadratic
Error	N	F(1,15) = 13, p<.002	ns
	sHH	F(1,15) = 19, p<.001	F(1,15) = 5, p<.046
	HH	F(1,27) = 38, p<.000	#
Search Time	N	ns	ns
	sHH	F(1,15) = 15, p<.001	ns
	HH	F(1,27) = 5, p<.026	F(1,27) = 15, p<.001
Number of Fixations	N	F(1,15) = 24, p<.000	ns
	sHH	F(1,15) = 42, p<.000	F(1,15) = 8, p<.012
	HH	ns	F(1,27) = 7, p<.015 #
Length of Scanpath	N	F(1,15) = 11, p<.004	ns
	sHH	F(1,15) = 50, p<.001	ns
	HH	F(1,27) = 56, p<.000	F(1,27) = 29, p<.000 #

4.5. Trend analysis

To assess the relative difficulty level of the patterns, induced by the number of constituent dots, we expressed the errors, search time, number of fixations, and length of the scanpath as relative measures in dividing them by the number of dots in the patterns. These parameters hence indicate the performance per dot. We then performed a trend analysis by way of polynomial contrasts, separately for the normal and simulation mode. If the dot counting task functionally is performed in the same manner in both groups (N and sHH), the same trends should appear. If different or additional trends appear, the number of dots assert a different influence on the performance, suggesting functionally different subcomponents or processes. The results are summarised in Table 3. For all but one parameter, at least one additional trend was present in the simulation mode compared to the normal mode. For the length of the scanpath, only linear trends were present in both modes, but in simulation mode being far more distinct (as evidenced by the *F*-value being almost five times higher). This overall pattern was observed to be continued for the patient data, except that occasionally also additional higher-order trends were present (Table 3). For illustrative purposes, we plot the search time per dot in function of the number of dots (Fig. 5). It can be observed that in (s)HH, there is relatively more time

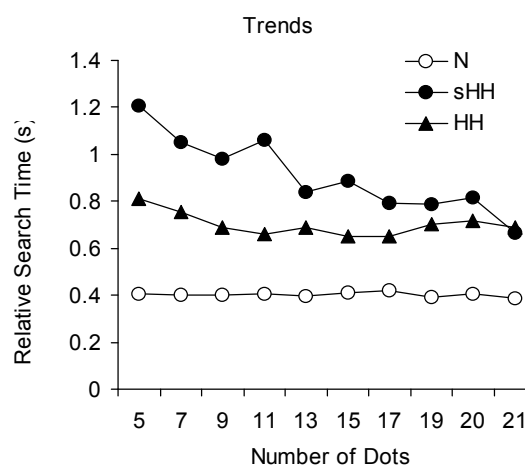


Figure 5. Trends for relative search time in function of number of dots. In the normal condition (N) no trend is present. In the simulated condition (sHH), a linear trend was found. For the patients (HH), both a linear and quadratic trend was present. Different trends suggest different functional components.

consumption for the patterns with less dots, as evidenced by the linear trends. We similarly observed relatively increasing number of fixations and the length of the scanpaths with decreasing number of dots. The reverse pattern was found for the errors (not in Figs).

5. Discussion

We did observe hemianopic scanning behaviour in healthy subjects without brain damage with an imposed HH. This suggests that hemianopic scanning behaviour largely is visually elicited, namely by the VFD. The parallels between simulated and real HH are evidenced by several findings. Firstly we found elevated search times, errors, number and duration of fixations and length of scanpath (Fig. 1) in sHH compared to the normal condition. We did not observe a main effect of saccadic amplitude. These findings are in perfect concordance with previous findings reported by Zihl (1995, 1999, 2000) for real HH patients and confirmed by our own patient data (Fig. 1). In sHH, we also found in general longer fixation durations, which was not observed in our patient data (Fig. 1). Zihl (1999) reported the mean fixation duration to be longer in some (“impaired”) and shorter in other (“unimpaired”) HH patients. We did not create these subgroups, and hence are likely to have a pooled patient population in this respect. This could account for the total null-effect of fixation duration in our patient group (compared to the normal condition, Fig. 2). The finding that we do observe fixation duration increase, fortified by the elevation of the other parameters, suggests that, in many respects, our sHH subjects resemble the “impaired” HH patients. The observation that, for most parameters, the performance in sHH is more deviant (from the normal condition) than in HH, is agreement with this suggestion. Alternatively, the HH patients did have (more) time to adapt to their VFD, while for the sHH subjects, the acquisition of the VFD was very recent.

The second parallel between real and simulated HH concerns the side of the VFD, which was previously reported not to affect any oculomotor parameter in real HH patients (Zihl, 1999). This was confirmed by our patient data. We did however find left-sided HH patients to count less accurately than right-sided HH patients (Table 1). Zihl did not observe this difference. In his paradigm, only one pattern (one trial) was presented and subjects made no errors. Since we presented 29 trials, we were more likely to observe errors, and hence our data are not optimally comparable in this respect. The absence of effects of the side of the VFD in oculomotor parameters and the worse error performance in left-sided HH was paralleled in sHH (Table 1). We did additionally find a longer search time in left-sided sHH. Hence, the results in sHH parallel the results in HH in that the side of the VFD does not differentially influence oculomotor performance. Left-sided sHH subjects however tend to make more errors and need more time than subjects with right-sided sHH. This was also the case with respect to the errors for the HH patient group.

Thirdly, directional and hemispace analyses further confirm the same pattern of results in sHH and HH (Table 2) and are in concordance with previously reported findings. Differential hemifield distribution of the fixations has previously been reported (e.g. Zihl, 1995, 1999, 2000; Kerkhoff, 1999; Zangemeister & Oechsner, 1996; Meienberg et al., 1981; Chedru et al., 1974; Ishiai et al., 1987). Also in our data, both sHH and HH fixated more in the ipsilateral hemispace. Saccadic dysmetria and more specifically ipsilateral hypometric saccades are considered typical for hemianopic scanning (e.g. Zihl, 2000; Neetens, 1994; Zangemeister et

al., 1982; Chedru et al., 1974; Ishiai et al., 1987; Meienberg et al., 1981, Zangemeister & Oechsner, 1996). Our data, both for sHH and HH, confirm saccadic amplitudes in ipsilateral direction to be smaller than in contralateral direction. As in previous studies (e.g. Zihl, 1995) no effects of the side of the VFD were found.

Hence, all aspects known to be typical for hemianopic scanning behaviour we were able to replicate with simulated HH. These healthy subjects did not suffer brain damage, but were imposed with a simulated homonymous hemianopic VFD. It follows that the typical HH scanning behaviour is largely due to the VFD (i.e. visually elicited) and not to concomitant brain damage. To further explore underlying components in the scanning behaviour, we performed the trend analysis in function of the number of dots (Table 3). We assume that functionally different components will result in different trends. In the normal condition, we observed linear relationships between the number of dots and the errors, number of fixations and length of the scanpath per dot. The search time per dot did not seem to be influenced by the number of dots. These same trends appeared in sHH, suggesting the same underlying mechanisms. However, in nearly all parameters, also other (higher-order) trends were observed, suggesting additional components. It is reasonable to assume that these additional trends are brought about by the simulated VFD, since this was the only difference with the normal condition. These additional trends are suggested to be visually elicited. We already argued that the scanning behaviour displayed in sHH is in many respects identical to real HH. This was partly confirmed, by the trend analysis, in that most trends present in sHH, also appeared in HH (Table 3).

Upon visual inspection of the trends, a paradox appeared. Fig. 5 shows that relatively, the search time increases with decreasing number of dots. A similar pattern was observed for the number of fixations and the length of the scanpath. We suggest that this pattern can be explained as the time cost and effort for (s)HH to check the whole visual field. When healthy subjects, in the normal condition, fixate the centre of the screen, they can parafoveally perceive the whole screen and spatially represent the dot pattern as to effectively and economically organise their scanning pattern. They will cluster neighbouring dots and devote more attention and time to densely crowded parts of the screen and no attention to empty parts. This immediately available spatial representation is not available in (s)HH. In addition and as a result, even (eventually apparent) empty parts of the screen require visual exploration. It follows that, as the result of the VFD, apparently easier configurations lead to more dysfunction in (s)HH. In such a configuration, a priori clustering and identification of unimportant parts of the screen, leads to gain in effectivity in the normal condition, contrary to (s)HH. We suggest that this is partly at the basis of the visual slowness reported in HH: a visual slowness brought about by the absence of an immediately available spatial representation and the need to standardly fully explore all parts of the screen, also when this is, as ultimately appears, not necessary.

However, the additional trends in HH, compared to sHH (e.g. quadratic in Fig. 5), suggest that still additional components are into play in real HH scanning. Although different subjects comprise the sHH and HH groups, and hence are not ideally comparable, this suggests that also brain damage functionally influences the scanning behaviour. More dots most likely summon more visuo-spatial, memory and organisational functions. Brain damage is likely to affect (some of) these functions, which are likely to interact reciprocally with adequate visual exploration and proper cerebral representation of space, hence resulting in the appearance of

additional trends. Alternatively, the appearance of the additional trends could be statistically induced by generally better performance by the HH subjects (compared to sHH). As a result, HH subjects sooner perform at their maximal effectivity, inducing flattening of the (relative) performance curve, which will appear as additional trends. With this statistical alternative in mind, we would like to indicate that the additional trends can at least be suggestive for the additional impact of brain damage on the HH scanning behaviour, but also that psychometrically fully comparable data is needed to support our suggestion.

In summary, we can conclude that HH scanning behaviour is largely visually elicited, namely by the VFD. We further suggest that subtle interplay of brain-related functions and the VFD complete real HH scanning.

Our interest in the effects of age were aroused by Szlyk et al. (1993) who suggested that age-related losses, when compounded by CVA-associated impairments, significantly influenced visuo-spatial performance i.c. driving related skills. Such an age-related loss could be fluid intelligence, defined as the ability to new-problem solving. Our healthy subjects were exposed to a new experience (sHH) for which adaptive behaviour was required. We found this compensation indeed to be worse for the search time in the older age group. This age effect remained when the log-transformed values were used, as suggested by Cornelissen and Kooijman (2000). Clear differences were also observed for the number of fixations, in that the increase in the sHH condition was far greater in the older age group (Fig. 3). These findings were paralleled in the patient group. Hence, becoming (simulated) hemianopic seems more disabling for older subjects. It would follow that on second simulation, these effects would weaken, since it then is no longer a new situation. The absence of a learning effect seems to contradict this, but since on both occasions the side of the sHH was changed, it can not be considered a valid test for our hypothesis. We therefore explored the compensation effects within the simulation conditions by trial order. The rationale is that the sHH is very new at the first trial, but less with increasing trials. If the older age group is less capable of new-problem solving, it should be most prominent during the first trials. This is exactly what we observed (Fig. 4). This pattern, although still very prominent, was slightly reduced on second occasion for the older age group (not in Fig.). For the younger age group, patterns on both occasions were identical (not in Fig.). We therefore conclude with Szlyk and colleagues that age-related processes are related to hemianopic compensation, but we add this to be the case even if the disabilities are merely visually elicited and hence are not specific for brain damaged subjects.

In conclusion, HH scanning behaviour, as assessed by eye movement recordings during a dot counting task, can largely be accounted for by the VFD. It follows that most typical HH oculomotor dysfunctions, as for example ipsilateral hypometric saccades, do not result from the brain damage but are visually elicited. Age-related processes, i.c. worse compensation to these visually elicited disabilities were apparent. The implication of this study is that at least some typical HH disabilities and complaints as for example slowness of vision and prolongation of scanpaths, can no longer be merely associated to brain damage, as they also do appear in subjects with sHH. A further implication would be that these visually elicited impairments can be most pronounced during (seemingly) the simpler situations.

This can have also ramifications for both for rehabilitation and diagnosis. Firstly, these results suggest that, at least for some HH patients, more emphasis can be devoted to visual than to cognitive components in rehabilitation. Secondly, diagnosing higher-order visuo-spatial impairment can only occur in the light of concomitant lower-order visual impairment.

6. Reference List

- Chedru, F., Leblanc, M., & Lhermitte, F. (1974). Visual searching in normal and brain-damaged subjects. *Cortex*, *9*, 94-111.
- Cornelissen, F. W. & Kooijman, A. C. (2000). Does age change the distribution of visual attention? A comment on McCalley, Bouwhuis, and Juola (1995). *Journals of Gerontology Series B Psychological Sciences and Social Sciences*, *55*, 187-190.
- De Graaf, A. & Deelman, B. G. (1991). *Cognitieve Screening Test*. Lisse: Swets & Zeitlinger.
- De Renzi, E., Faglioni, P., & Sorgato, P. (1982). Modality-specific and supramodal mechanisms of apraxia. *Brain*, *105*, 301-312.
- Deelman, B. G., Liebrand, W. B. G., Koning-Haanstra, M., & van der Burg, W. (1987). *SAN test*. Lisse: Swets & Zeitlinger.
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*, 189-198.
- Ishiai, S., Furukawa, T., & Tsukagoshi, H. (1987). Eye-fixation patterns in homonymous hemianopia and unilateral spatial neglect. *Neuropsychologia*, *25*, 675-679.
- Kerkhoff, G. (1999). Restorative and compensatory therapy approaches in cerebral blindness - a review. *Restorative Neurology and Neuroscience*, *15*, 255-271.
- Meienberg, O., Zangemeister, W. H., Rosenberg, M., Hoyt, W. F., & Stark, L. (1981). Saccadic eye movement strategies in patients with homonymous hemianopia. *Annals of Neurology*, *9*, 537-544.
- Neetens, A. (1994). Revalidation of homonymous hemianopic patients. In A.C.Kooijman, P. L. Looijestijn, J. A. Welling, & G. J. van der Wildt (Eds.), *Low Vision. Research and New Developments in Rehabilitation* (pp. 296-300). Amsterdam and Oxford: IOS Press.
- Rybash, J. M., Roodin, P. A., & Hoyer, W. J. (1995). *Adult development and aging*. (3rd ed.) Boston MA: McGraw-Hill.
- Schaie, K. W. & Willis, S. L. (1993). Age difference patterns of psychometric intelligence in adulthood: Generalizability within and across ability domains. *Psychology and Aging*, *8*, 44-55.
- Szlyk, J. P., Brigell, M., & Seiple, W. (1993). Effects of age and hemianopic visual field loss on driving. *Optometry and Visual Science*, *70*, 1031-1037.

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- Tant, M. L. M., Brouwer, W. H., Kooijman, A. C., & Cornelissen, F. W. (in press). Grey Scales uncover similar attentional effects in homonymous hemianopia and visual hemi-neglect. *Neuropsychologia*.
- Zangemeister, W. H., Meienberg, O., Stark, L., & Hoyt, W. F. (1982). Eye-head coordination in homonymous hemianopia. *Journal of Neurology*, 226, 243-254.
- Zangemeister, W. H. & Oechsner, U. (1996). Evidence for scanpaths in hemianopic patients shown through string editing methods. In W.H. Zangemeister, H. S. Stiehl, & C. Freksa (Eds.), *Visual Attention and Cognition* (pp. 197-220). Amsterdam: Elsevier Science.
- Zihl, J. (1994). Rehabilitation of visual impairments in patients with brain damage. In A.C.Kooijman, P. L. Looijestijn, J. A. Welling, & G. J. van der Wildt (Eds.), *Low Vision. Research and New Developments in Rehabilitation* (pp. 287-295). Amsterdam and Oxford: IOS Press.
- Zihl, J. (1995). Visual scanning behavior in patients with homonymous hemianopia. *Neuropsychologia*, 33, 287-303.
- Zihl, J. (1999). Oculomotor scanning performance in subjects with homonymous visual field disorders. *Visual Impairment Research*, 1, 23-31.
- Zihl, J. (2000). *Rehabilitation of Visual Disorders After Brain Injury*. Hove, East Sussex: Psychology Press Ltd.

Evaluation of the effectiveness of a hemi-neglect rehabilitation program and generalisation to driving: a case study*

1. Introduction

In the past 30 years various rehabilitation programs and therapeutic interventions have been designed to attempt to improve the recovery of patients with unilateral neglect (UN). Just as there is a multitude of theoretical accounts trying to explain and comprehend the UN syndrome there are multiple ways of trying to treat or compensate for this functional deficit. Research in rehabilitation of functional impairments in brain-damaged patients in general and in UN in particular is a laborious and difficult enterprise. One of the main problems concerns the methodology including comparing patients across studies. Another important issue is the discussion concerning the amount of generalisation of the observed effects. This can be achieved by using testing materials different from training materials, including only patients with chronic and persistent UN and assessing and comparing non-trained functions like degree of anosagnosia pre and post treatment, or success of functioning in activities of daily living (ADL). Therefore it is of the utmost importance to report well documented case-studies with regard to the characteristics of the patient as well as with regard to therapeutic and evaluation methods.

Recently a promising program has been reported by e.g. Pizzamiglio et al. (1992) and Antonucci et al. (1995). These authors claim that their systematic, comprehensive and intensive program is able to produce significant and long lasting results which also generalise to non-trained and everyday life situations. This program consists of 4 main procedures: visual scanning training, reading and copying training, copying of line drawings on a dot matrix and picture description training. The specific characteristics of the entire program can be summarised as follows: there is a great diversity of stimulus material and responses, the level of difficulty can easily be adapted to the patients performance level, and it is quite intensive in time.

As only multiple and independent replications of both group and single-case studies can lead us with confidence to adopt a particular therapeutic method we took this promising program as a basis for a single-case study. Besides evaluation with clinical tests with static stimuli, we also assessed the performance post-training on two different driving simulator tasks: a lane tracking task with variable side-wind conditions and conditions of divided attention, and a test-ride in an advanced driving simulator.

2. Methods

2.1. Case

Kd is a 52-year-old right-handed male who suffered in September 1995 a right sided deep paraventricular heamatoma resulting in damage to the internal capsule sparing the thalamus. At the start of the intervention in 1998, he presented a hemiplegia in his left leg and had a paretic left arm. His primary visual functions (visual acuity and contrast sensitivity) were normal. Perimetric testing revealed a complete left-sided homonymous hemianopia with no macular sparing. Visual evoked potentials with half-field stimulation revealed no activity upon left half-field checkerboard pattern reversals. General neuropsychological testing and

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observation revealed no signs of dementia, aphasia nor apraxia. At start of the program several neglect tests (clinical and experimental) were administered to assess the existence and severity of neglect. On all the administered tests he showed severe neglect (see result section).

2.2. Evaluation methods

The clinical evaluation tests were the Albert's line crossing test ("Albert") (Albert, 1973), The Bells Test ("Bells") (Vanier et al., 1990), an unstructured letter cancellation task ("OZO"), the Mesulam structured Shapes cancellation ("ShCs") (Weintraub & Mesulam, 1988), and an overlapping figures task ("OFT"). These clinical neglect tests were to be assessed several times to follow the progression of the interventions. At no point in time was any feed-back given concerning these assessment measures nor were strategies provided to complete those tasks. The number of omissions on clinical neglect cancellation tasks can be seen in figure 5 (pre scan). These results indicate a severe neglect.

2.3. The Tracking task

The tracking task has two components: a lane tracking task on a 20 inch central screen and a peripheral identification task. In the lane tracking task subjects continuously have to keep course while a variable sidewind (i.e. a distortion signal of three superimposed sine waves) which "pushes" the subject off course. The experimental setup is partly described in Brouwer, Rothengather and van Wolffelaar (1992). The subject is seated in front of a 20-inch video screen on which the road is projected (i.e. what one sees when looking out of the windshield of a car; one does not actually see a car). He or she is told to drive as straight as possible in the middle of the right lane. The car moves at about 50 km/h. Steering was done by means of a steering wheel that was placed in front of the PC screen. The visual angle covered for this task is about 25°. On the left and right of this main screen where the road was projected are two peripheral screens on which traffic signs could be projected. Arrows appeared in these signs and were presented randomly on left and right peripheral screen. The subject was asked to push a button on the steering wheel when an arrow appeared. The visual angle covered by these two additional screens is about 75° (viewing distance is about 75cm). Our subject steered and pressed the button using only his right hand. This tracking task is composed of eight stages. In stage 1 the subject can get familiar with the central task. He or she is encouraged to "play" with the steering wheel for example to see what happens if they drive into the roadside. Stage 2-3 are adaptive blocks of 3 minutes each. Here the sidewind factor is individually adjusted. This is done in a stepwise manner until the subject is able to keep course for 90% of the time. A factor is obtained at the end of stage 3 by averaging the sidewind factors of stage 3. The individual sidewind factor is then maintained throughout the whole task. Stage 4 is an actual testing stage where the subject has to keep course for 2 minutes in the middle of the right lane while "the individual sidewind" is blowing. Stage 5 is again a practice stage where the peripheral task is introduced. The subject has to push a button on the steering wheel when an arrow appears on one of the peripheral screens. He does not have to keep course but is advised to keep his eyes as long as possible on the road. Performance is tested in stage 6. Stages 7-8 are dual-task stages (combination of central and peripheral task) where subjects have to keep course while also pushing the button when an arrow appears on the peripheral screens. Performance is assessed in stage 8. We recorded lateral position (LP), standard deviation of the lateral position (STDLP) for the central task and reaction times (RTs) for the peripheral task.

2.4. The Driving Simulator

The Driving Simulator of the Centre for Environmental and Traffic Psychology (COV) consists of a car installed on a fixed base with a large video projection screen displaying the traffic scenery viewed through the car's windscreen. The car is a modified BMW 518 containing all its original controls. The screen image has horizontal and vertical viewing angles of 150° and 40° respectively. The outside world is displayed in three-dimensional perspective. The route consists of built-up area (50 km/h limit), main road (80 km/h limit) and highway (120 km/h limit). There are a total of 14 intersections with possible traffic coming from left, right and front. There are also parts of road with and without oncoming cars. The total distance of the route is 37 km. While driving, we record among other things lateral position (LP), standard deviation of the lateral position (STDLP), speed (S) and head movements (HM). The head movements are measured by a potential which is connected by a flexible hinge to a very light helmet.

2.5. Training methods

We administered the program serially instead of each component in every session as is done by Pizzamiglio et al. (1992). We first did the visual scanning training, secondly the reading training, then the matrix training and with some overlap finally the figure description.

For a detailed description of the program itself, we again refer to Pizzamiglio et al. (1992). We used the same principles to construct our own materials (Dutch versions). We additionally constructed tests to measure improvements during training.

3. Results and Discussion

We do not report progression during training parts; only before and after each training component (pre and post training respectively).

3.1. Part one: Visual Scanning training

Our patient trained a total of 18 hours in 12 weeks which is comparable to the training hours reported by Pizzamiglio et al. (1992) (20 hours). Figure 1 shows the first and the last test sequence. The training effects can clearly be seen: the overall RT is lower post-training, as is the standard error. However the responses on the leftmost targets still seems to point to some neglect symptomatology. We therefore compared these RTs to those of a left hemianopic patient without any signs of neglect. This patient also shows the elevation of RTs of the leftmost stimuli (Figure 2). We also checked his performance 8 weeks, 9 weeks and 23 weeks after his last session of visual scanning training (see Figure 3). It can be seen that follow-up performance shows the same pattern as post-training performance.

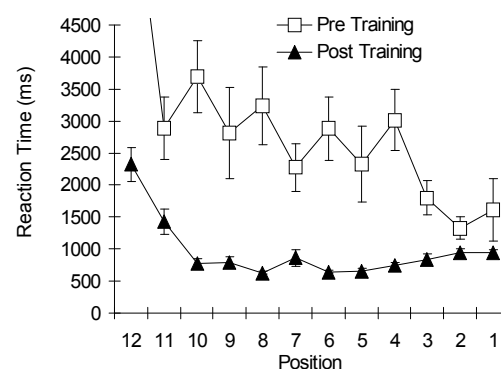


Figure 1. Reaction times by Kd on unpredictable Test sequence before and after training. Error bars are Standard Errors. Position 12 is far left, position 1 is far right. Subject is sitting between position 6 and 7.

NB: The utmost left stimulus was never noticed before training.

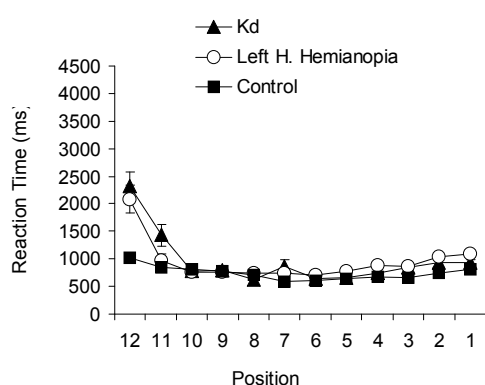


Figure 2. Comparison of Reaction times by Kd on unpredictable Test sequence after training with a Left H. Hemianopia patient and a control subject. Error bars are Standard Errors.

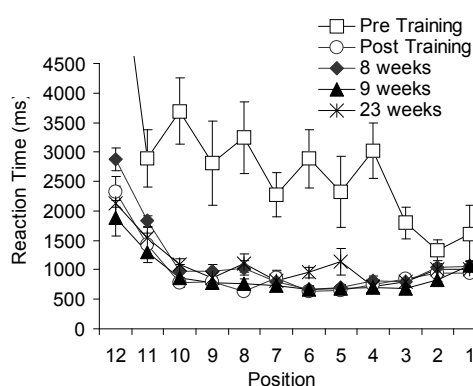


Figure 3. Comparison of Reaction times by Kd on the unpredictable Test sequence before and after training with performance after 8, 9 and 23 weeks without training. Error bars are Standard Errors.

3.2. Part two: Reading training

We trained for 14 hours divided over 7 sessions which is less than reported by Pizzamiglio et al. (1992) who trained for 20 hours. Reading times decreased after training but increased again at follow up. Both types of errors decreased after training and remained stable (see Table 1).

Table 1. Results of Reading training.

Assessment	Reading Time (s)	Word Errors (%)	Line Errors (%)
Pre	285.5	27.5	75.0
Post	196.75	3.3	3.1
6 weeks	280.5	4.4	6.2

3.3. Part three: Matrix training

We trained for 6.5 hours in 10 sessions which again is less than the mean reported by Pizzamiglio et al. (1992) (10 hours). During pre training assessment he completed 47% of the items. This percentage increased to 95% during post training assessment. Additionally, the percentage of errors per item (erroneous line segments per matrix) decreased from 10% to 5%.

3.4. Part four: Picture description

We trained for 2.5 hours over 4 sessions. As we did not have a testing method for this training part, we recorded the number of problems (misidentifications, omissions of important parts etc.) in each category. The results can be seen in table 2.

To our surprise Kd disliked this training the most and found it also quite difficult and stressful. Indeed, while his performance on previous tests was relatively good, he made many errors. Even in the easiest category, he made relatively many errors which again decreased in the medium and hard

Table 2. Misidentifications in picture description (actual number of pictures between brackets).

Category	Errors on first presentation (%)
Easy	36.36 (8)
Medium	20.00 (9)
Hard	27.27 (9)
Extra hard	47.05(16)

categories. This can be interpreted as again a training effect. The extra hard pictures were clearly too difficult to comprehend and describe adequately. The high number of problems encountered suggests that picture description comprises at least some components other than the already trained ones. The picture description task clearly needs more attention and should be improved.

3.5. Assessments of non-trained tasks

To assess any generalisation effect of the trained components to other tasks or components, the assessments should be different from training materials. We therefore assessed with traditional clinical neglect tests at different points in time. The results can be seen in figure 5.

It can clearly be noted that the performance on the non-trained clinical neglect tests already greatly improved after the visual scanning training and did not further substantially improve.

Furthermore on the basis of the combination of tests administered after the visual scanning training, one could argue that clinically one could not diagnose neglect any more on the basis of those tests. This does not mean however that all neglect components had improved. The data seem to suggest that some compensation strategies have been taught, namely scanning the environment. But the persistent problems with the picture description and the results on the OFT suggest that the some deficits remain (under some conditions). This again argues against a complete generalisation of training effects and suggests that the effects are due to compensatory mechanisms instead of functional improvement.

Some results suggest a functional improvement of the neglect syndrome. To further test this hypothesis we should also study more ecologically valid tasks. We chose to assess driving performance. Before any training, we tried to administer the Tracking task. This failed completely. In spite of extensive explanation and instructions our subject could not grasp the concept of simulating driving. He could not understand that the graphics on the screen depicted a road. He constantly wanted to see a car he could navigate around. Even after demonstration of what brings about the turning of the steering wheel, he could not comprehend the simulating situation. However, after the first training component, when all but one of the clinical neglect tests considerably improved (see figure 5), we were successful in administering this task. His sidewind factor was 0.7 which is extremely low if one considers that the starting value is 1 and that with factors below 1 it is generally better not to steer at all to keep a straight course. We compared his lateral position (LP) in stage 4 and 8 (single and dual task respectively). Figure 6 shows the LP during both stages. When the subject is driving in the middle of the right lane the LP is 0, the right border corresponds with LP 200, the middle of the road with -200 , the left border with -600 . The mean LP for stage 4 and 8 respectively was -122.75 and -293.75 . T-test analysis revealed this difference to be significant ($t=2.404$, $p<0.05$). The STDLP in the two conditions was 107.5 and 79.5 respectively ($t=1.04$, n.s.). These values were twice as high as controls. This means that our subject was driving too much to the left of the road. This tendency increased in the dual task

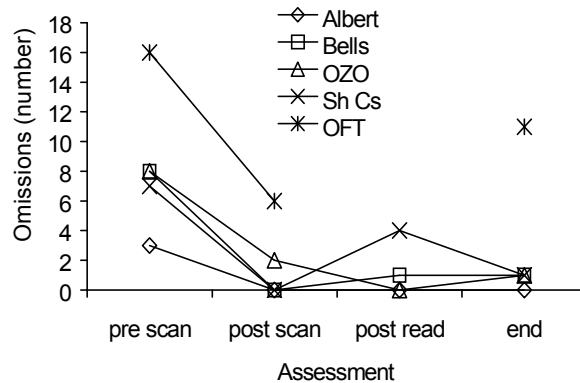


Figure 5. Number of omissions on clinical neglect tests.

situation. He could not handle any sidewind to keep course. In spite of that, he swayed a lot but this did not increase in the dual task situation.

In the peripheral tasks he saw (and reacted to) a total of 20 arrows during the single task and 18 arrows in the dual task. He missed a total of 1 arrow (left screen, dual task). He was apparently scanning both left and right half fields. We further analysed the RTs of stages 6 and 8 (single and dual task situation respectively of peripheral task). We included the stages (6-8) and the side of the screen (left-right) as factors in an ANOVA analysis. Both factors and interaction effect proved to be significant. As can be seen in figure 7, he reacted generally faster in the single task condition ($F(1, 33)=11.36, p<.005$) and to arrows on the right screen ($F(1, 33)=42.49, p<.001$). In the dual task condition the difference increased disproportionately on the left side ($F(1,33)=14.45, p<.005$).

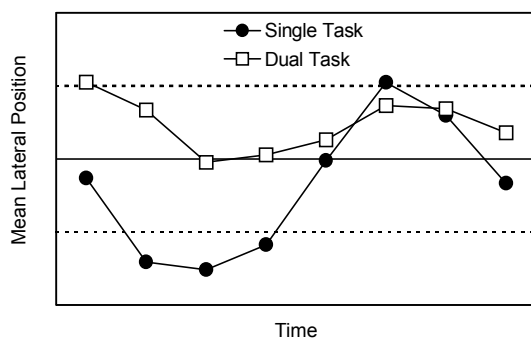


Figure 6. Lateral Position during tracking task

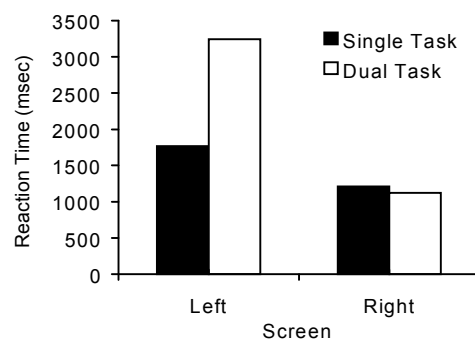


Figure 7. Reaction times on signs on left and right screens

3.6. The Driving Simulator

After completion of the full training program we wanted to use a test still more ecologically valid. We chose again driving. For safety reasons we did not administer a real driving test but used the driving simulator. The experimental test ride takes about 45 minutes (practice included). Again it took a while to fully comprehend the simulated environment. For analysing purposes, we make a distinction between A- and B-sections. The part of roads starting from an intersection to the moment when the next intersection is perceived (marked by a clear slowing of speed) are A-sections. Near-intersection parts are B-sections.

3.7. Head Movements

When considering the head movements we noticed that he was actually looking around, not neglecting the left side. In figure 8, we show the maximum angle of head movement per part of route on B-sections. One can see that most of the time he did look to the left although the amplitudes are generally larger to the right. On parts 9 and 11 he did not look to the left. These were however intersections with right-of-way.

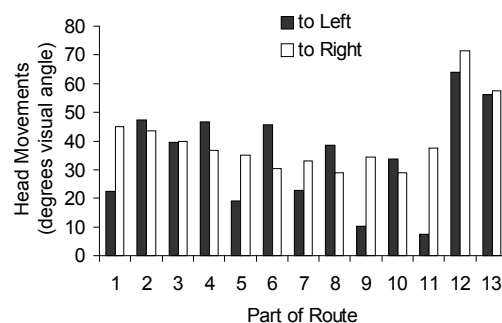


Figure 8. Amplitude of head movements to left and right on B-sections

3.8. Lateral Position

In figures 9 and 10 we plotted the mean LP for sections A and B respectively. Since the STDLP is again quite high, the means could quite disguise extreme LPs. We therefore

included in the same figures minimal and maximal LPs, giving an impression of the most extreme LPs of our subject on the road. Positions 0 and 6 are left and right borders respectively, 1.5 and 4.5 are middle of the left and right lane (dotted), 3 is middle of the road (full line). We estimated the car being 1.80m in width and depicted those as error bars in the figures.

As can be seen, our subject again showed a clear tendency to drive too far to the left. This tendency was to its very extreme in B-sections. This may not be very obvious looking only at the means, but when considering the maximum LPs in combination with the estimated width of the car this reveals very dangerous positions. On nearly all parts of the route, the front-left of the car was at least once on the left side of the road, possibly obstructing oncoming cars. When approaching intersections, he even found himself once in the middle of the left lane. An oncoming car could not possibly have passed.

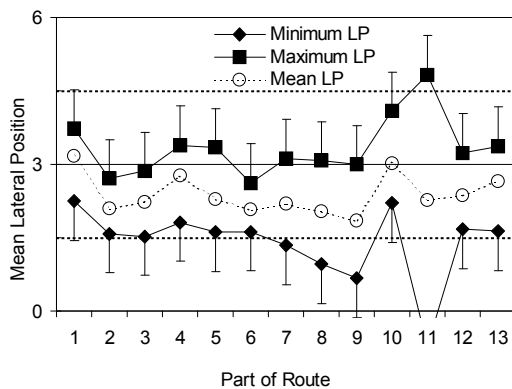


Figure 9. Lateral Position on A-sections

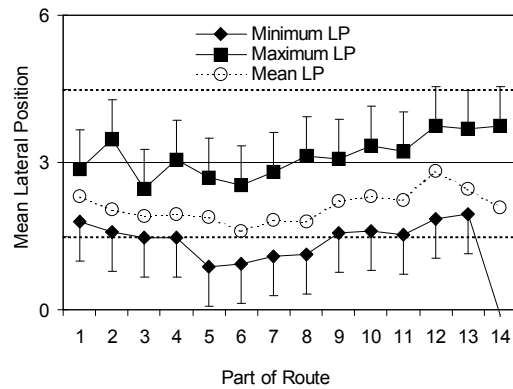


Figure 10. Lateral Position on B-sections

3.9. Speed

He generally drove too slowly and refused to speed up when asked to. Figure 11 shows his average speed on A-sections for each speed limit. The error bars indicate the maximum speed he reached.

4. Conclusions

We successfully replicated the training paradigm by Pizzamiglio and colleagues (1992). At first hand we would also have suggested that we observed generalisation effects because we see improvements on most non-trained tasks. These tasks were however clinical neglect tests. We also asked our patient how he subjectively evaluated the training. His remarks were very positive especially with regard to the first training component. Indeed, we also saw most of the improvements after this type of training. Not all assessment tests improved or were within normal range however. When looking at the Tracking task, he was actually looking around although more effectively to the right side. His scanning component could be judged relative to standard. Although performance decreased in

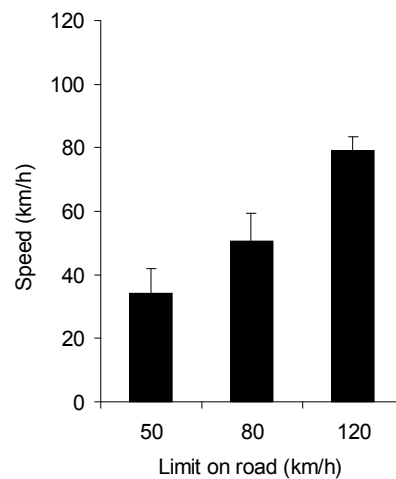


Figure 11. Speed (km/h) on A-sections.

dual-task conditions, his LP and course keeping was and remained below standard. A similar picture emerged from the even closer to real life situation Driving Simulator. Although he was looking around, his LP was dramatically to the left.

These results suggest that training can help to compensate for the scanning deficit in most situations. Since some aspects of real life tasks do not change even after this intensive training, we have no evidence of functional improvement of neglect.

5. References

- Albert, M. L. (1973). A Simple test of visual neglect. Neurology, 23, 658-664.
- Antonucci, G., Guariglia, C., Judica, A., Magnotti, L., Paolucci, L. & Zoccolotti, P. (1995). Effectiveness of neglect rehabilitation in a randomised group study. Journal of Clinical and Experimental Neuropsychology, 17, 383-389.
- Brouwer W. H., Rothengather, T. & van Wolffelaar, P.C. (1992). Older drivers and road informatics. In H. Bouma and J.A.M. Graafmans (Eds.), Gerontechnology. Amsterdam: IOS Press, pp. 317-238.
- Pizzamiglio, L., Antonucci, G., Judica, A., Montenero, P., Razzano, C. & Zoccolotti, P. (1992). Cognitive rehabilitation of the hemineglect disorder in chronic patients with unilateral right brain damage. Journal of Clinical and Experimental Neuropsychology, 14, 901-923.
- Vanier, M., Gauthier, L., Lambert, J., Pepin, E.P., Robillard, A., Dubouloz, C.J., Gagnon, R., & Joannette, Y. (1990). Evaluation of left visuospatial neglect: Norms and discrimination power of two tests. Neuropsychology, 4, 87-96.
- Weintraub, S. & Mesulam, M.M. (1988). Visual hemispatial inattention: stimulus parameters and exploratory strategies. Journal of Neurology, Neurosurgery and Psychiatry, 51, 1481-1488.

Quandranopia can shift to Hemianopia with shift of task-demands *

1. Introduction

Driving is a complex task that requires good perceptual and cognitive abilities. Restrictions of the visual field, confusion between left and right, reduced awareness, inadequate scanning of the environment, and distractibility are important functions for safe driving that are often impaired after brain damage. It is estimated that approximately 90% of the information processed while driving is of a visual nature (Wylie, 1978). Therefore there are established and strict baseline visual requirements for the issuing of a valid driver's license. One of the visual requirements is the extent of the visual field. In the Netherlands the legal standard is: the horizontal visual field, either monocular or binocular, exceeds 140°. Therefore brain damaged subjects with hemianopia are prohibited from driving.

Homonymous hemianopia is the most frequent visual field disorder after postchiasmatic brain damage. Hemianopia indicates that half of the visual field had been affected. The term 'homonymous' means 'the same side'. A left or right homonymous hemianopia indicates that the patient is blind to one half of the entire visual field. About 75% of patients with visual field impairments resulting from acquired posterior brain injury suffer from (a form of) this condition. In about 75% of these cases, field sparing does not exceed 5°. These patients mainly complain of difficulties with reading, detecting stimuli and hence finding objects in the visual hemi-space which corresponds to the affected hemi-field (Zihl, 1995).

The extent and shape of the visual fields can be measured using different procedures and methodologies. In clinical practice these measures are used interchangeably and choice is usually depending on time/effort considerations. For a review on comparison of different confrontational visual field tests we refer to Elliott, North and Flanagan (1997). In this study we used two widely used perimetric tests namely the Goldmann and the Humphrey Field Analyzer.

2. Method: Perimetric tests

2.1. The Goldmann perimetric test

Isopters for white stimuli were plotted by a conventional kinetic technique with a target velocity of approximately 3° per second. In general, for normal subjects, isopters are plotted along each of the 15° meridians of the Goldmann chart. In patients with abnormal fields, however, stimulus presentation is performed in succession, perpendicular to the border of the field defect. Bowl luminosity was 31.5 asb. The stimuli we used were I4 and V4.

2.2. The Humphrey Field Analyzer

The Humphrey Field Analyzer (HFA) is an automated projection perimeter. It has a bowl luminance of 31.5 asb. and a viewing distance of 33 cm. We presented static white stimuli in the 246 Full Field Screening Test with a 3-zone strategy. Stimulus size is III4 equivalent. The intensity is slightly brighter than the subject expected threshold (age corrected).

3. Case report, Results and Discussion

3.1. Case

JH is a 75 year old man . CT scans revealed a dilated ventricular system. It shows a right temporo-parietal infarction with slight cortical atrophy. An ophthalmic investigation revealed

* This manuscript is accepted to appear in: Vision in Vehicles VIII. A.G.Gale, I.D.D. Brown, C.M. Haslegrave, & S.P. Taylor (Eds.), Amsterdam: Elsevier. (Tant, Brouwer, Kooijman & Cornelissen)

no abnormalities except for a left sided field defect. Neuropsychological examination showed no signs of dementia, apraxia, aphasia or neglect.

3.2. Perimetry

The Goldmann visual fields reveal a homonymous lower left quadrantopia (HQ) (figures 1 and 2).

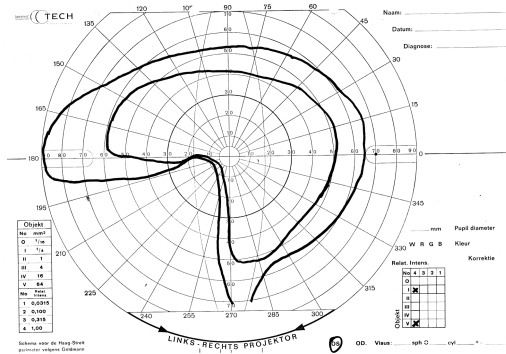


Figure 1. Goldmann visual field, left eye.

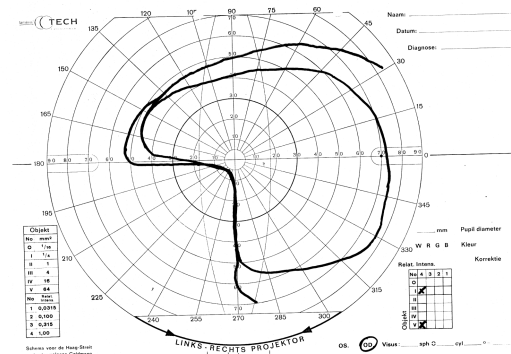


Figure 2. Goldmann visual field, right eye.

On the same day we administered the 246 Full Field Screening Test of the HFA. This perimetric test showed an asymmetric partial homonymous hemianopia (HH). For purposes of comparison we overlapped Goldmann and HFA-plots in figures 3 and 4. This shows the qualitative difference in the appearance of the visual field between both tests. We overlapped the mean of the isopters of the Goldmann which would be III-4 and is thus directly comparable to the isopters used in the HFA.

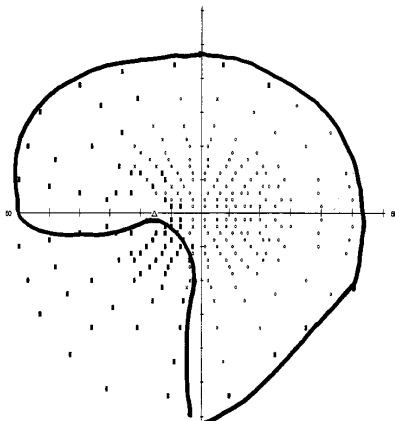


Figure 3. Goldmann over HFA visual field, left eye.

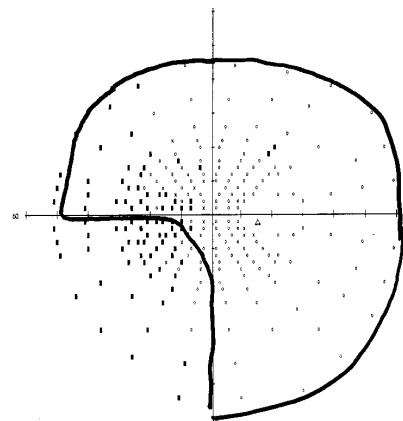


Figure 4. Goldmann over HFA visual field, right eye.

3.3. The Attention task

We tried to replicate this qualitative difference using the same paradigm. For this we used a modification of the Useful Field of View Test (Ball & Owsley, 1991). This test is an attention task and has a central and a peripheral component. For the central component the subject has to identify the mouth of a face in the centre of the screen which can either be laughing or crying. For the peripheral component a circle is presented on 24 possible positions (3 eccentricities along 8 meridians). The field size used is 40° diameter. This test has 4 phases or tasks. Task 1 is an adaptive phase with only the peripheral component. In this phase stimulus

presentation duration is defined where the subject reaches at least 90% correct identifications. For our subject this was 25 ms. This presentation time is maintained throughout the further test. In task 2 both components are present: the subject has to report the position of the mouth and the position of the circle. Task 3 has again only the peripheral component but now the circle is embedded in a field of distracters. Now all possible positions are occupied by stimuli. One of them is the target (circle), the others are squares (distracters). Task 4 is identical to task 2 but now again with the distracters. Thus, the level of difficulty increases with the number of the task. Task 1 is a measure of selective attention because there is only the peripheral task to perform. In task 2 there is selective attention and divided attention since both peripheral and central tasks have to be performed. This is thus a more difficult task to do. Tasks 3 and 4 have the same rationale but now the targets are hidden among distracters, rendering the peripheral (divided attention) task more difficult.

In figure 5 the percentage correct identifications (peripheral tasks) are presented for control subjects. It can be noted that performance degrades from task 2 to 3, but not from 3 to 4. In figure 6 we plot the same percentages but by half-field for our subject. It is apparent that the pattern of results of the controls is mirrored in his right half-field. However in the left half-field we see a quadrantanopic-like performance in task 2 (nearly 50% points seen in this half field) degrading to a hemianopic-like performance in task 4 (approximately 5% points seen). Thus within the same test using the same stimuli and conditions but varying the attentional demands, we shifted a quadrantanopic to a hemianopic performance. We therefore conclude that task-load is a crucial factor determining the extent and shape of the visual field of JH.

This means however that the choice of the perimetric test could influence the diagnosis of the

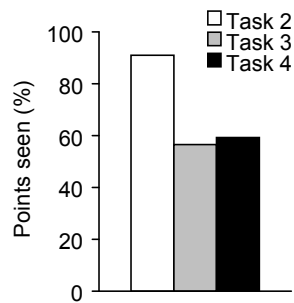


Figure 5. Percentage points seen by control subjects on the Attention Task.

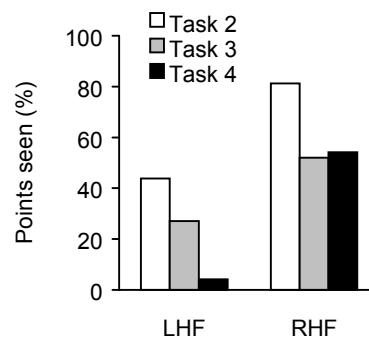


Figure 6. Percentage points seen by JH on the Attention Task. LHF: left half field. RHF: right half field.

visual deficit. The diagnosis, in turn, influences the decision on the drivers permit. Following the Goldmann visual fields, a drivers permit in the Netherlands would be granted because the horizontal axis seems preserved. The conclusion of the ophthalmologist accordingly was “... *but the horizontal visual field is about 140°. There seems to me to be no reason to declare JH unfit to drive*”. But considering the Attention task and looking at the HFA visual fields the horizontal visual field is not preserved at all, making him unfit to drive. Clearly both perimetric tests do not measure the same construct namely the visual field. The extent and shape of this presumed constant entity can be dependent on task-load. It is therefore crucial to select a task-load fitted to the desired goal-task, in this case driving. Since driving can be considered a complex task with high load demands and distracters in the environment, it is closer to the HFA and the fourth task of the Attention Task.

4. References

Ball, K. & Owsley, C. (1991). Identifying correlates of accident involvement for the older driver. Human Factors, 33, 583-595.

Elliot, D. B, North, I. & Flanagan, J. (1997). Confrontation visual field tests. Ophthalmic and Physiological Optics, 17, 17-24.

Wylie, E. J. (1978). Vision and driving. Canadian Journal of Optometry, 40, 70-74.

Zihl, J. (1995). Visual Scanning behavior in patients with Homonymous Hemianopia. Neuropsychologia, 33, 287-303.