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**Deposited in DRO:**

23 June 2008

**Version of attached file:**

Accepted Version

**Peer-review status of attached file:**

Peer-reviewed

**Citation for published item:**

Smith, D. T. and Lane, A. R. and Schenk, T. (2008) 'Arm position does not attenuate visual loss in patients with homonymous field deficits.', *Neuropsychologia*, 46 (9). pp. 2320-2325.

**Further information on publisher's website:**

<https://doi.org/10.1016/j.neuropsychologia.2008.03.010>

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**Arm position does not attenuate visual loss in patients with homonymous field deficits**

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Short Title: Posture does not attenuate hemianopia

## **Abstract**

One of the most common and debilitating consequences of stroke is the loss of vision in the contralesional visual field. Clinicians typically regard this loss as irreversible, and attempts at visual restoration have delivered only small and unreliable improvements. However, Schendel & Robertson (2004) reported that the visual abilities of a hemianopic patient (WM) were significantly improved when the left arm was extended into the blind field. They suggest that visual stimuli near the arm recruited bimodal visual-tactile neurons, and this activity was sufficient to bring the stimulus into awareness. This result has enormous potential therapeutic value, but given that it is a single case study there are a number of reasons to be cautious about interpreting the data. Here we investigate the effects of manipulating arm position on visual loss in a sample of 5 patients with homonymous field deficits and no visual sparing. None of our patients showed any evidence of improved implicit or explicit visual ability in the blind field as a consequence of moving the arm. We suggest that WMs improvement was the consequence of a spatial bias towards the space containing his extended arm rather than the recruitment of bimodal neurons, and conclude that manipulating arm position is of little therapeutic value to patients with dense hemianopia

**Keywords:** Hemianopia, Rehabilitation, Attention, Bimodal Neurons, Stroke, Posture

## Introduction

Visual loss in part of the visual field is a common consequence of stroke (Kerkhoff, 1999). This visual loss is most frequently observed in one half of the visual field of both of their eyes, and is known as homonymous hemianopia. Hemianopia is associated with significant chronic disability, and although attempts to restore vision to the blind fields have been reported since 1979 (Zihl & von Cramon, 1979), they have often produced disappointing results (Lane, Smith, & Schenk, 2008). More recent attempts to restore vision have used a computerized training which utilises repeated presentation of stimuli along the border between the blind and seeing field (visual restoration training; *VRT*). Early studies using *VRT* appeared promising, and it was claimed that the training produced an average reduction in the extent of the blind field of 5% (Kasten, Wust, Behrens-Baumann, & Sabel, 1998).

However, it is important to note in this context that the visual field of a human observer is defined as the space within which visual stimuli can be detected *while fixation is maintained* at a central location. Strict fixation control is therefore essential to ensure reliable visual field measurements. Unfortunately, the early studies that demonstrated *VRT* driven reductions in the extent of the blind field failed to adequately monitor fixation, so the claims of significant reductions in the blind field were based on unreliable visual field measurements. Studies which used strict means to monitor fixations found no significant benefits of *VRT* (Reinhard et al., 2005).

Recently, (Schendel & Robertson, 2004) suggested another possible way of reducing the visual loss experienced in patients with hemianopia. They reported the case of a patient with left-sided hemianopia whose ability to detect stimuli in his blind field

improved significantly when he had his arm extended into the blind field. The authors explained this finding by pointing to the existence of bimodal, visuo-tactile neurons in dorsal regions of the visual cortex of monkeys (M. S. A. Graziano, C. G. Gross, C. S. R. Taylor, & T. Moore, 2004). They suggest that similar neurons may also exist in humans and that the manipulation of the arm position stimulates those bimodal neurons. This stimulation provides a sufficient boost to the visual signal from the blind field to bring it above the threshold for conscious detection. Schendel and Robertson (2004) conclude that their findings provide evidence for the existence of such bimodal neurons in the human cortex and importantly might provide a new avenue for restoring vision to the blind field of hemianopic patients.

There are, however, a number of features of this study which suggest that caution should be exercised in interpreting these results. Firstly, these findings were obtained in only one patient. Importantly this patient was not a very typical hemianopic patient. His baseline performance clearly shows spared visual ability in various locations of his so-called blind field. The study also suffered from a number of methodological flaws. Fixation during the visual field mapping was not properly monitored. Instead a central task was used to force subjects to keep fixation on a central location. This task is problematic for two reasons. Firstly, it introduces an additional attentional load to the detection task which could impair performance (Cartwright-Finch & Lavie, 2007). Secondly, the central task can only act as a fixation control if it employs very small visual features that can only be recognized in foveal vision. No details regarding the size of the stimuli in the central task were provided, therefore it is unclear whether the central task effectively prevented eye-movements into the blind field. As we have seen above the

problem of insufficient monitoring of fixation has already led to the dismissal of earlier claims of partial restoration of visual loss in patients with hemianopia, and therefore it is a real worry that the same problem plagues the findings by Schendel & Robertson.

However, insufficient fixation control is not the only problem. It is clear from previous studies which have investigated preserved visual abilities in hemianopia that it is necessary to take into account the possibility that patients may just guess or that they might use different decision criteria for different task conditions (Campion, Latto, & Smith, 1983). Schendel & Robertson (2004) tried to correct for guessing by measuring the false-alarm rate in catch trials (i.e., trials where no visual target was presented). They then used a simple formula to correct the obtained hit-rate on the basis of the measured false alarm rate. Their formula calculated the guess-corrected hit-rate by multiplying their original hit-rate with the correct-rejection rate (i.e.,  $1 - \text{false alarm rate}$ ) obtained in the catch trials. This approach has two problems: it does not control for criterion-shifts between task conditions (Campion et al., 1983) and it does not fully discount the effects of guessing. To illustrate this problem, let's assume that there are two conditions A and B. Let's further assume that the patient sees nothing in both conditions. However in condition A he expects that there are stimuli in 50% of all trials (guess rate 50%) and in condition B he expects stimuli in 20% of all trials. The uncorrected hit-rate will be 50% and 20% respectively, the corrected hit-rates according to the above formula ( $\text{hit-rate} \times (1 - \text{false alarm})$ ) will be 25% in condition A and 16% in condition B. If the correction process would work properly the corrected hit-rate should be identical, in fact should be 0% since no genuine detection took place in both conditions. Instead with the correction process used in the Schendel & Robertson paper there remains a substantial difference in

the corrected hit rate of the two tasks despite the fact that genuine detection was absent in both conditions.

The aim of our study was to test the effect of arm position on the detection of visual stimuli in the blind field of hemianopic patients while avoiding the problems identified in the Schendel and Robertson study. Firstly, we tested not just a single case but a group of 5 patients. Importantly all 5 patients had a dense hemianopia with no evidence of spared vision in their blind field. The visual fields of all patients were mapped using a manual Tuebinger Perimeter which allowed us to monitor the patients' fixation during the perimetric assessment. Moreover, we avoided the problems of insufficient fixation control during the experiments by using video-based eye-tracking. The best way to control for guessing and to avoid the confounding influence of criterion shifts is to use a criterion free method of assessing the detection rate (Gescheider, 1997). This can be done by using a two-alternative forced choice method (2AFC). In 2AFC observers always have to make a decision regardless of their conscious experience. This avoids problems of criterion-shifts and guessing but it cannot discriminate between implicit (unconscious) versus explicit (conscious) detection. To find out whether the arm-position may have (as claimed by Schendel & Robertson) an effect on conscious experience, we also employed a conventional detection paradigm where patients are simply asked to indicate whether they saw the visual probe or not.

## **Methods**

### *Participants*

Five patients with homonymous visual field deficits participated in the study. Participants were selected from a group of patients who had previously completed an experimental visual exploration training, and were chosen for their ability to maintain fixation during perimetry. Visual fields were established using Tuebinger Perimetry. Table 1 details the gender, age, lesion site and length of illness of each of the patients. Figure 1 illustrates lesion locations in the three patients for whom brain images were available. None of the patients had co-morbid spatial deficits, as assessed by the star cancellation task (Halligan, Cockburn, & Wilson, 1991). Patients FP and VH presented with mild hemiparesis of the contralesional arm when first diagnosed, however their clinical notes indicated that these conditions had resolved by the time of testing. All participants gave informed consent to participate according to the Declaration of Helsinki (International Committee of Medical Journal Editors, 1991). The study was approved by the local NHS Research Ethics Committee and the Departmental Ethics Committee at Durham University.

\*\*\*TABLE 1\*\*\*

\*\*\*FIGURE 1\*\*\*

### *Apparatus*

Stimuli were generated using a VSG 2/5 graphics card (CRS, Rochester, England) and displayed on Sony Trinitron monitor with a 100 Hz refresh rate. Eye movements were recorded using a Cambridge Research Systems Video Eyetracker Toolbox (2.1)

sampling at 50 Hz. Participant responses were recorded by the experimenter using a standard keyboard.

### *Stimuli*

The display consisted of a black screen with a fixation point at the centre (a  $0.7^\circ \times 0.7^\circ$  white cross) and a horizontal white reference line running across the width of the screen which was located  $7.5^\circ$  below the fixation point. The probe target consisted of a  $0.3^\circ \times 0.3^\circ$  white spot. Probe targets could appear at one of 12 locations ( $4.5^\circ$ ,  $9^\circ$  or  $13.5^\circ$  to the left or right of fixation and  $2.2^\circ$  above or below the reference line, see Figure 2). Thus, half the probes were presented to the blind field and half were presented to the sighted field

\*\*\*FIGURE 2\*\*\*

### *Procedure*

Trials began with the presentation of a black screen with a white cross at the centre and a horizontal white line running across the lower portion of the screen. After 1500ms a probe appeared for 150ms then disappeared. After the offset of the probe the fixation point turned red, at which point the patient was instructed to report whether or not they had seen the probe (Experiment 1) or indicate whether the probe was above or below the reference line (Experiment 2). The response was recorded by the investigator. The fixation point then went white, signalling the start of a new trial. Targets were randomly presented at one of the 12 potential locations.

Participants were instructed to maintain fixation on the central cross throughout trials, and not to search for the probe target. Compliance was measured using a video-based eye-tracker. The order in which blocks were presented was counterbalanced across the participants. For four of the five participants the screen was located 57cm away, such that the screen could be brushed with the fingertips. For one participant (patient RE) this distance was more than 20cm beyond the end of the outstretched arm, so the display was moved forward by 20cm. For this patient the probes appeared at eccentricities of 6.9°, 13.6° and 20° from the midline and had a diameter of 0.46°.

CL completed one block of 96 trials with his arm in his lap and one block of 96 trials with his arm extended. LM completed one block of 120 trials with his arm in his lap and one block of 120 trials with his arm extended. RE, FP and VH completed 2 blocks of 120 trials with the arm in the lap and 2 blocks of 120 trials with the arm extended. For RE, FP and VH the arm-in-lap blocks and arm-extended blocks were interleaved and the order of the blocks was counterbalanced across the participants.

In the *arm-extended* condition the contralesional arm was stretched out such that the fingertips were level with the monitor screen and the hand was just inside the edge of the monitor.

*Experiment 1* used a standard detection paradigm. Subjects were instructed to report whether they had seen the probe stimulus or not. This experiment explored subjects' capacity for conscious vision in the blind field.

*Experiment 2* used a two-alternative forced choice paradigm (2AFC). This paradigm tested subjects' implicit ability to respond to visual information in their blind field. Performance in this paradigm will be independent of the decision criterion of the observer and does not require visual awareness. The setup was identical to Experiment 1, with the exception that participants were instructed to report whether the probe appeared above or below the horizontal reference line. If they did not know they were required to guess. CL completed one block of 96 trials with his arm in his lap and one block of 96 trials with his arm extended. LM, RE, FP and VH completed 2 blocks of 60 trials with the arm in the lap and 2 blocks of 60 trials with the arm extended. For these participants arm-in-lap blocks and arm-extended blocks were interleaved and the order of the blocks was counterbalanced across the participants.

## **Results**

### ***Experiment 1***

#### *Fixation Control*

Fixation data was analysed off-line. Any trial which contained an eye-movement with a magnitude of  $> 2^\circ$  that occurred within 1650 ms of the trial onset (i.e. before the probe stimulus had been presented) was excluded. Technical issues prevented the collection of fixation data from patient RE, and he was not included in the fixation analysis. This procedure resulted in the exclusion of 75 trials out of a total of 1632 trials (4.6%). Specifically we rejected 51 trials from CL (21 from the blind field, 30 from the

sighted field), 16 trials from LM (6 blind, 10 sighted), 6 trials from FP (1 blind, 5 sighted) and 2 trials from VH (1 blind 1 sighted). Although we were not able to monitor RE's fixation during the task, previous visual field assessment with Tuebinger perimetry had established that this patient was able to maintain good fixation when required.

### *Detection Accuracy*

Scores were collapsed across the vertical position. The mean accuracy scores were subjected to a 3 (*Probe Eccentricity*: 4.5°, 9° or 13.5°) x 2 (*Probe Location*; Seeing Field vs. Blind Field) x 2 (*Arm Position*: arm-in-lap vs. arm-extended) repeated measures ANOVA. The analysis revealed a significant main effect of probe location ( $F_{(1,4)} = 1903$ ,  $P < 0.01$ ) such that detection accuracy was better in the seeing field than the blind field. There was no main effect of Arm Position ( $F_{(1,4)} = 0.455$ ,  $P = 0.537$ ), and no interaction between Arm Position and Probe Location ( $F_{(1,4)} = 0.333$ ,  $P = 0.595$ )

Although there was no group effect of Arm Position, it is possible that the arm manipulation produced significant improvements within individuals which were masked by the group analysis. To assess this possibility we collapsed trials within each hemifield and compared detection in the arm-in-lap condition to accuracy in the arm-extended condition for trials where the probe appeared in the blind field for each individual patient. Fishers Exact Test was used when there were fewer than 40 observations in three or more cells, otherwise we used Chi-Square. There was no significant effect of moving the arm into the blind field on detection accuracy for any of our participants (Table 2).

\*\*\*TABLE 2\*\*\*

The results of Experiment 1 demonstrate that patients' ability to detect visual stimuli appearing in the blind field was not significantly improved when the targets appeared in close proximity to the outstretched arm. This negative result was observed at both a group level and individually within all five patients. This finding appears to be directly contrary to that by Schendel and Robertson (2004), who reported that manipulating arm position significantly improved stimulus detection in the blind field, and related this result to activity of bimodal visual/tactile neurons. However, although the arm-position manipulation was not sufficient to elicit improvements in explicit target detection, it is possible that presenting stimuli close to the extended arm was sufficient to mediate implicit, unconscious visual processing. Experiment 2 explores this possibility using a two alternative forced choice localisation task.

## ***Experiment 2***

### *Fixation Control*

Fixation data were analysed as described for Experiment 1, resulting in the rejection of 163 out of 912 trials (17.9%). Specifically we rejected 79 trials from CL (44 from the blind field, 35 from the sighted field), 42 trials from LM (23 blind, 19 sighted), 18 trials from FP (10 blind, 8 sighted) and 14 trials from VH (6 blind, 8 sighted). Again, technical issues prevented the collection of fixation data from patient RE so he was excluded from the fixation analysis.

### *Localisation Accuracy*

Mean localisation accuracy scores were subjected to a 3 (*Probe Eccentricity*: 4.5°, 9° or 13.5°) x 2 (*Probe Location*; Seeing field vs Blind Field) x 2 (*Arm Position*: Arm in lap vs Arm extended) repeated measures ANOVA. The analysis revealed a significant main effect of probe location ( $F_{(1,4)} = 155, P < 0.01$ ) such that localisation accuracy was better in the seeing field than in the blind field. Intriguingly, there was also a significant Probe Location by Probe Eccentricity interaction ( $F_{(2,8)} = 5.49, P < 0.05$ ). Inspection of Figure 3 suggests that this interaction was driven by facilitated localisation rates for targets in the blind field which appeared closest to fixation. There was no main effect of Arm Position ( $F_{(1,4)} = 1.025, P < 0.369$ ), and no interaction between Arm Position and Probe Location ( $F_{(1,4)} = 1.026, P < 0.368$ ).

### \*\*\*FIGURE 3\*\*\*

As with Experiment 1, it is possible that manipulation of arm position elicited *individual* improvements in performance which were masked by the group analysis. To test this possibility, localisation accuracy was compared in the arm extended and arm-in-lap conditions for each individual participant. Fishers Exact Test was used when there were fewer than 40 observations in three or more cells, otherwise we used Chi-Square. None of the patients exhibited significantly better localisation accuracy in the arm-extended condition (Table 3). Furthermore, one participant (VH) showed a non-significant trend toward improved localisation in the blind field in the arm-in-lap

condition ( $P=0.089$ ) which was accompanied by a drop in performance in the sighted field.

In summary, we observed no improvement in implicit target localisation in the arm-extended condition. Critically, although localisation of targets in the blind field was more accurate when targets appeared close to fixation, this was not mediated by the position of the arm. As with the explicit detection task these negative findings were obtained both for the group data and for individual patients. These data are not consistent with the suggestion that presenting visual stimuli close to the hand can mediate implicit visual perception in the blind field of hemianopic patients.

## **Discussion**

Not a single patient showed improved ability to detect visual stimuli in their blind field when their arm was extended into the blind field. This was true both for the explicit detection task (patients verbally report whether they had seen the target or not) and the 2AFC task (patients had to indicate whether the stimuli was above or below a reference line). This result is clearly in contrast to the findings by Schendel & Robertson (2004).

It might be speculated that we did not find benefits of the arm-manipulation as the relevant areas containing bimodal neurons have been damaged in our sample of patients. However, this explanation is highly unlikely. On the basis of the findings in monkeys it would be expected that those areas are found in the human parietal and frontal lobes (M. S. A. Graziano, C. G. Gross, C.S.R. Taylor, & T. Moore, 2004) but in three cases (FP, CL and LM) the patients lesions appear to be restricted to the medial occipital lobe.

However, it should be noted that there is neuroimaging for only one of these patients (FP). In the two other cases (CL & LM) we have relied on the clinical notes for lesion localisation.

It is worth noting that some patients (LM and RE) in Experiment 2 improved slightly, but not significantly when the arm was in the blind field. It might thus be suspected that our failure to obtain significant effects for the arm-manipulation might be related to a lack of statistical power. However, we would like to stress that on average the improvement was only 3% and in Experiment 1 the improvement was less than 0.2%. Both numbers are substantially lower than the improvements reported by Schendel & Robertson. Thus we would argue that it is not differences in statistical power but differences in methodology that explain the discrepancy between our results and those of Schendel & Robertson. Of course we cannot exclude the possibility that arm-manipulation might lead to improved unconscious visual processing in the blind field of individual patients. However, even if such improved unconscious visual processing were to be confirmed such a finding would be quite different from the claimed improvement of conscious vision and thus its relevance for neurorehabilitation would be unclear.

On the basis of our findings we would suggest that extending the arm into the blind field does not attenuate visual loss in a patient's blind field. This prompts the question of how to explain the improved performance observed in the arm-extended condition of the Schendel & Robertson study. In our view attention provides the best explanation. We assume that extending the arm into the blind field will lead to a shift of attention into the blind field, and thereby enhance the processing of near-threshold sensory information in this hemifield. This would mean that the arm-manipulation does

not restore vision but enhances the ability to detect preserved, but degraded visual information in the blind field. This account is consistent with earlier findings and can also explain the differences between our findings and those by Schendel & Robertson. It is clear that attending to a location will enhance the detectability of visual stimuli presented in or near the attended area (Smith & Schenk, in press (2008)). It is also well-established that by positioning the arm into one half of the visual field (in particular if this is combined with movements of the fingers) spatial attention is shifted into this part of the visual field (Reed, Grubb, & Steele, 2006). In fact this technique is routinely used in the treatment of patients with unilateral neglect (Robertson, McMillan, MacLeod, Edgeworth, & Brock, 2002). Taken together it is therefore not surprising that a patient with partial visual field loss may also benefit from an extension of his arm into the impaired visual field.

This explanation assumes that vision is not completely destroyed in the patient's blind field but only degraded. There is in fact clear evidence from the visual field assessment of Schendel & Robertson's patient WM that he had islands of degraded but preserved vision in his so-called blind field. However, we think even those visual field measurements may have underestimated the true extent of the patient's spared vision. Since Schendel & Robertson used a central task to control fixation they effectively turned the visual field assessment into a dual-task experiment. It is known both from the literature on healthy subjects and patients with unilateral neglect that under such dual-task conditions the detectability of peripheral stimuli can be substantially reduced (Cartwright-Finch & Lavie, 2007; N Lavie, 2005; N. Lavie & Robertson, 2001; Russell, Malhotra, & Husain, 2004; Santangelo & Belardinelli, 2007). This would suggest WM's

true ability to detect stimuli in his “blind” field may be substantially greater than what has been recorded in this dual-task form of perimetry. If we accept this analysis we could conclude that the arm-extension manipulation led to an attentional shift into the blind field and counteracted the attentional pull towards the centre induced by the central task. The improvement observed in the arm-extended condition would then simply reflect the true state of preserved vision in the affected field as compared to the suppressed state induced by the central task in the standard condition.

This account can also explain why we did not find any effects of arm-extension on detection in the blind field of our patients. Our patients did not have any evidence of preserved vision in their blind field. This would explain why they could not benefit from the attentional boost provided by the arm-manipulation.

Schendel & Robertson also observed a slight improvement in detection accuracy when the display was 180cm away and WM was asked to hold a tennis racket which extended his reach toward the monitor. They attribute this improvement to the expansion of the receptive fields of bimodal visuotactile neurons centred on the arm. However, we believe that this explanation is unlikely because WM simply held the racket and did not actively use it to make reaches. Previous studies investigating the expansion of receptive fields during tool use have found that passive holding of a tool is not sufficient to elicit the expansion of receptive fields in either monkeys or humans (Maravita & Iriki, 2004). A more plausible explanation is that holding the tool produced a spatial bias towards the blind field, and it was this bias which produced improved detection accuracy.

As we have already stated in the introduction there may have been other factors explaining the improved detection performance in the Schendel & Robertson study. The

arm-extension condition may have raised WM's awareness for his blind hemifield and led him to expect more stimuli in this hemifield. Consequently he may have made more eye-movements into this direction or just changed his decision criterion or guessing strategy. These confounding factors cannot be excluded in the Schendel & Robertson study. These strategies were unavailable in our case (at least not in the case of Experiment 2) which could also explain why we did not find the effects described by Schendel & Robertson.

In our view the findings of Schendel & Robertson are best explained in terms of attentional modulation. It is unclear whether bimodal neurons are needed to explain such limb-movement induced shifts of attention, and therefore the existence of such attentional effects in humans is insufficient to prove the existence of bimodal neurons in the human cortex. More importantly, while such an attentional benefit may lead to improved detectability of preserved but degraded vision, there is currently no evidence that it will attenuate complete visual loss in a patient with hemianopia. We would therefore conclude on the basis of our findings that extending a patient's arm into their blind field does not attenuate visual loss, and is not a promising way for treating patients with homonymous visual field deficits.

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## Tables

**Table 1:** Details of the gender, age, visual field defect location, lesion site and aetiology, and duration of the visual field defect for each of the 5 patients.

Patient	Gender	Age (years)	Visual field defect	Lesion (site and aetiology)	Time since onset (months)
CL	M	62	Left hemianopia	Right occipital ischemic infarct	32.0
LM	M	78	Left hemianopia	Right occipital ischemic infarct	3.5
RE	M	73	Left lower quadrantanopia	Right occipital and parietal ischemic infarct	16.0
FP	M	74	Left hemianopia	Right occipital ischemic infarct	5.0
VH	F	71	Right hemianopia	Left thalamic and intraventricular haemorrhage	4.5

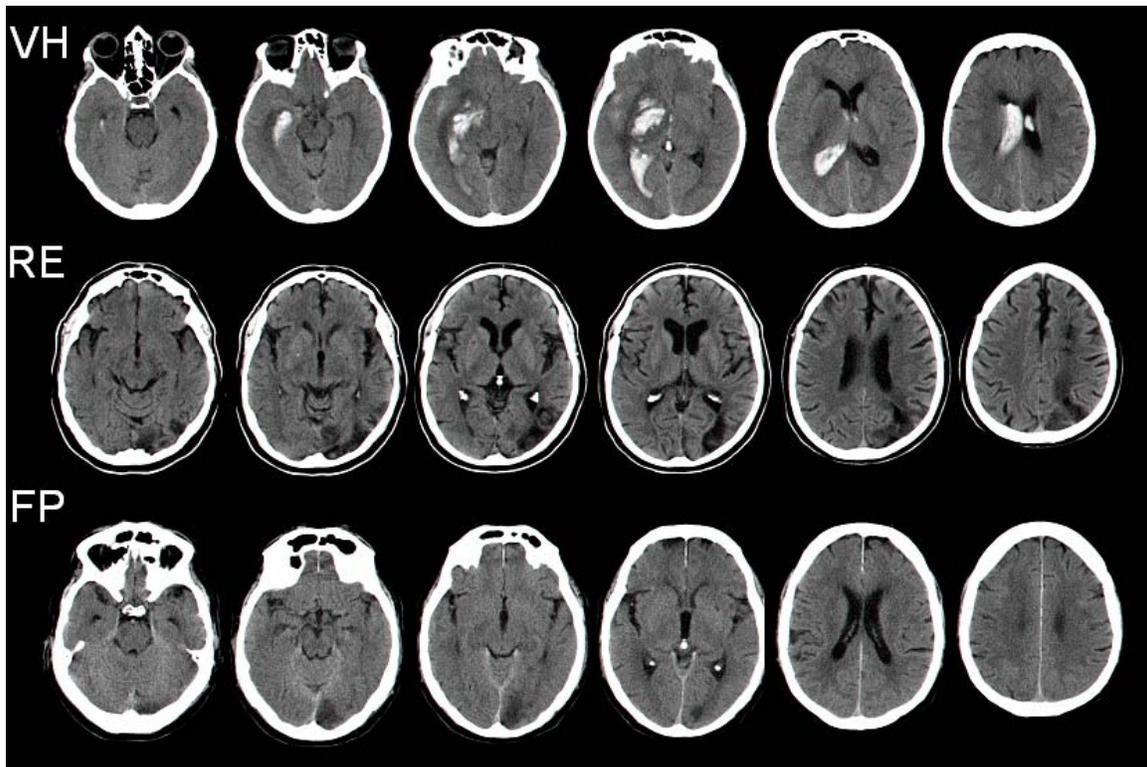
**Table 2:** Analysis of probe detection (Experiment 1). The figures in brackets are the number of trials included in the analysis after the data had been filtered to remove eye-movements. None of the patients exhibited significantly improved probe detection in the arm-extended condition relative to the arm-in-lap condition

Patient	Number of Correct Detections, Target in Blind Field		Chi-Square	Fishers Exact test
	Arm-in-lap	Arm-extended		
CL	0 (36)	1 (39)		$P = 0.49$
LM	0 (57)	0 (57)	-	-
RE	0 (120)	0 (120)	-	-
FP	3 (119)	2 (120)	$\chi^2 = 0.222,$ $P = 0.16$	
VH	0 (119)	1 (119)	$\chi^2 = 0.996.$ $P = 0.32$	

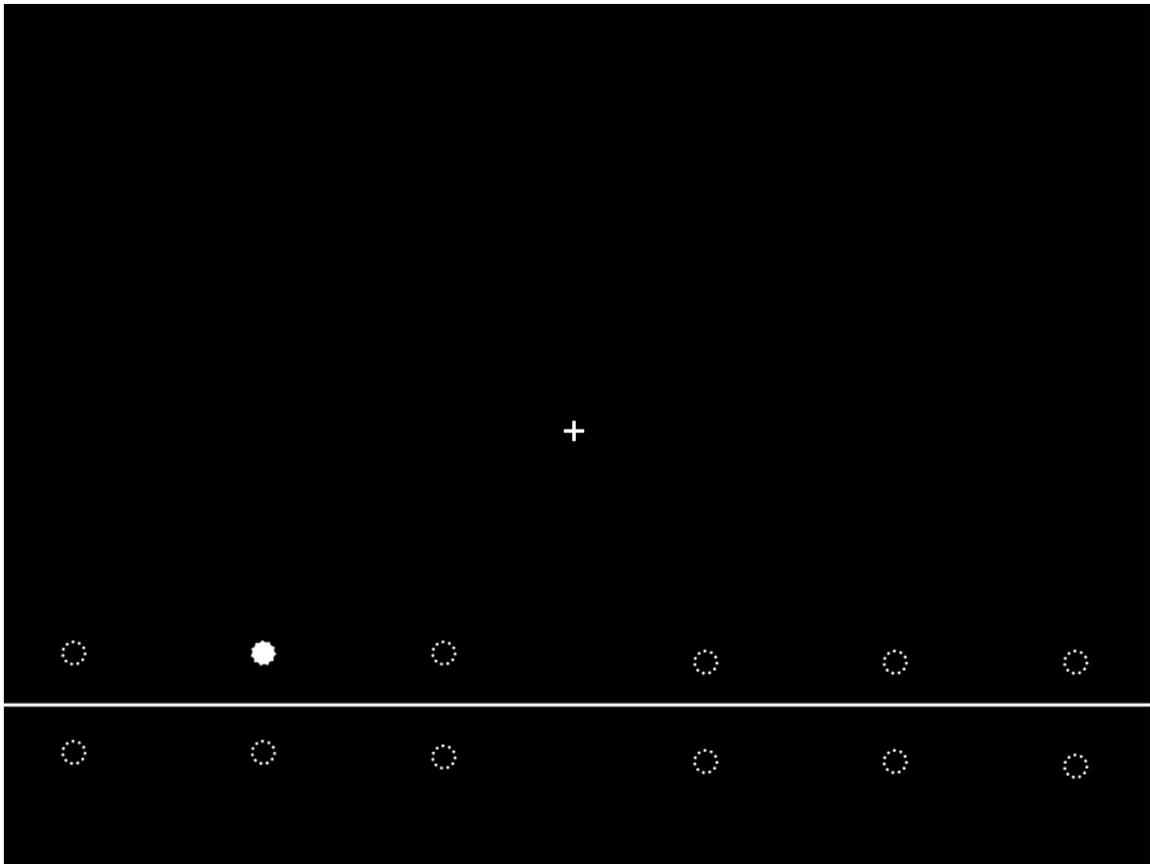
**Table 3:** Analysis of probe localisation (Experiment 2). The figures in brackets are the number of trials included in the analysis after the data had been filtered to remove trials during which eye-movements had occurred. None of the patients exhibited significantly improved probe localisation in the arm-extended condition relative to the arm-in-lap condition.

Patient	Number of Correct Localisations, Target in Blind Field		Chi-Square	Fishers Exact Test
	Arm-in-lap	Arm-extended		
CL	16 (26)	12 (26)	-	$P = 0.40$
LM	23 (50)	29 (47)	-	$P = 0.42$
RE	24 (60)	33 (60)	$\chi^2 = 1.81, P = 0.23$	-
FP	31 (52)	29 (58)	-	$P = 0.85$
VH	35 (58)	27 (56)	-	$P = 0.09$

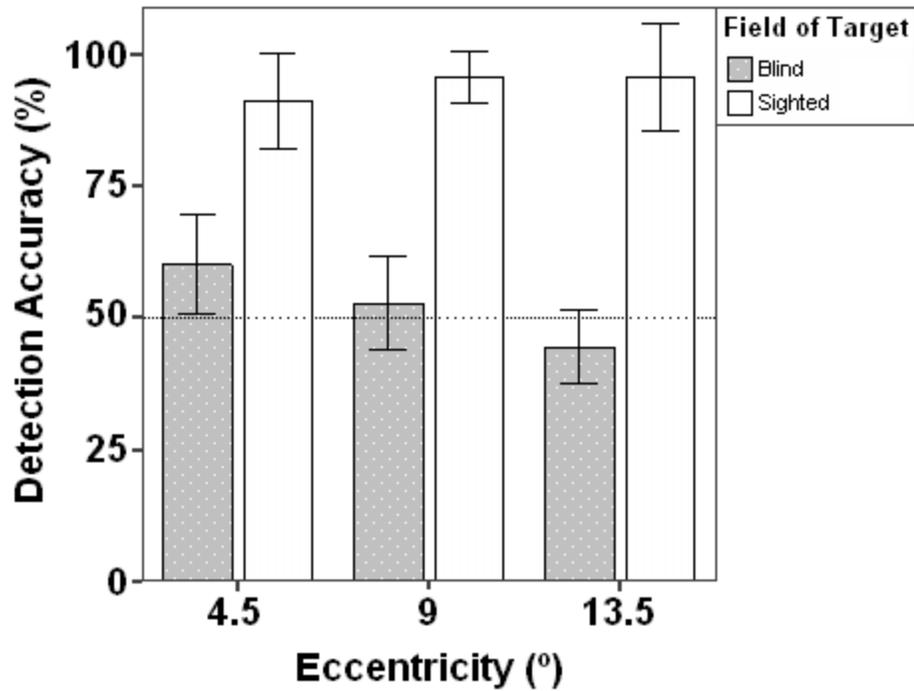
**Figure Captions**



**Figure 1:** Lesion locations for patients VH, RE and FP



**Figure 2:** Cartoon showing the experimental setup (not to scale). The white reference line was always present. Dotted circles illustrate the potential location of probe stimuli. These outlines were not visible during the experiment.



**Figure 3:** Probability of correct probe localisation at each horizontal eccentricity. Localisation was always better in the sighted field, and significantly better than chance when probes appeared at 4.5° (or 6.9° in the case of patient RE) in the blind field. Error bars show 95% confidence intervals and the reference line shows chance level of performance.