IMPAIRED ORIENTATION DISCRIMINATION AND LOCALISATION FOLLOWING PARIETAL DAMAGE: ON THE INTERPLAY BETWEEN DORSAL AND VENTRAL PROCESSES IN VISUAL PERCEPTION

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We report the case of a patient with left parietal damage (MH) who is selectively impaired at both detecting and localising targets defined in terms of their orientation. Performance was relatively good in other tasks where the target was defined either by a single feature (colour) or an orientation conjunction. The results are consistent with the idea that the dorsal stream supports some aspects of basic visual perception (i.e., the discrimination and localisation of orientation-defined targets). The effect of a parietal deficit may be to stress processing via the intact ventral stream, which groups information for object recognition, making differences in orientation less salient. Consistent with this, MH performed better when localising targets at a larger display size, where elements were less likely to group into a familiar shape and where local texture-based processes can come into play. In addition, MH's ability to localise a target was more impaired than his ability to detect a target, supporting the argument that orientation discrimination precedes (or operates independently of) feature localisation.

INTRODUCTION

Ungerleider and Mishkin (1982) carried out a classic series of lesion studies with primates, in which they showed the following: If a task requires that two visually presented forms be discriminated, the ventral visual pathway is critical; in contrast, if the task requires discrimination between different spatial locations, the integrity of the dorsal visual pathway was necessary. More recently the different roles of the dorsal and ventral visual pathways have been distinguished in terms of whether visual information is processed for perception or for the programming and on-line control of visually guided movement (Goodale, Milner, Jakobson, & Carey, 1991; Milner et al., 1991). The case of DF has been used as a striking illustration of the dissociation of these two visual pathways (see Milner et al., 1991). DF suffered anoxia as a result of fumes leaking from a faulty gas water heater, which caused a severe impairment of visual object recognition (she could recognise few real objects and no line

drawings). Her copying was poor and she was at chance at making perceptual judgements even about the basic dimensions of form (see Milner et al., 1991). Despite this, DF was able to reach appropriately to objects. Her grasp aperture and hand orientation were tuned to the size and orientation of stimuli and the kinematics of her movements were normal. Milner and Goodale (1995) argue that DF's lesion affected the ventral rather than the dorsal visual system, compromising perceptual judgements about even the basic dimensions of form. However, the dorsal visual stream remained intact. Thus, Milner and Goodale concluded that the dorsal stream not only codes stimulus location (cf. Ungerleider & Mishkin, 1982), but also provides visual information for prehensile actions such as reaching and grasping. Orientation and size information can be coded by the dorsal stream and used for action, even if coding the same information in the ventral stream is impaired. On this view, the ventral stream (for object recognition) and the dorsal system (for location coding and action) are separated even from early stages of cortical coding. Consequently, patients such as DF can have a deficit in early shape coding in the ventral system along with intact early shape coding in the dorsal system.

Cases such as DF raise the question of what kinds of form information can be used by the dorsal stream, in order that actions be made to visual stimuli. In addition, we may ask: Is form information coded by the ventral object recognition system in a manner that is qualitatively different from the way it is coded in the dorsal stream?

Additional studies with DF provide some indications that the information used by the dorsal stream is relatively limited. For example, when DF had to code the relations between stimuli, then impairments were apparent even on action tasks. Goodale, Jakobson, Milner, Perrett, Bewon, and Hietanen (1994) reported that, in contrast to when she had to post a letter (coding a single orientation), DF was poor at posting a T-shaped object into a T-shaped aperture. This deficit, when several orientations must be coded, extended beyond orientation information to include the coding of relative locations of other simple visual tokens. Murphy, Carey, and Goodale (1998), for example, found that DF was unable to judge whether arrays containing up to five tokens of different colours had the same configuration. Dijkerman, Milner, and Carey (1998) also demonstrated that DF was unable to orient her hand correctly to put her fingers in three holes in a Plexiglass disk (as in a ten-pin bowling ball), though she could place two fingers correctly when there were just two holes (perhaps coding a single orientation between the holes). Thus, to judge from DF, the dorsal system seems limited at coding spatial relations based on form information.

In contrast to patients such as DF, patients with dorsal (parietal) lesions can be poor even at coding single line orientations.[1] Damage to the left parietal lobe is linked to the disorder of constructional apraxia (De Renzi, 1982), where patients can be impaired at representing line orientations correctly in copying and drawing. In some cases, this can even extend to simple perceptual tasks. We (Riddoch & Humphreys, 1988) reported one patient (LM) with a left parietal lesion who had clear difficulties with left–right oriented stimuli. The problem was found in action tasks (e.g., in copying lines and arm movements, in block construction tasks, etc.) and also in perceptual judgement tasks (when asked to decide whether an oriented line and its mirror reflection were the same). This problem, with oriented lines, might reflect the classic "oblique effect" in perception (Appelle, 1972), with oblique stimuli being coded more coarsely at a neuronal level than stimuli in cardinal horizontal and vertical orientations (Wang, Ding, & Yunokochi, 2003). However, an early locus to the effect seems unlikely given that LM had intact object recognition. Thus, even oblique edge orientations were coded and used implicitly in object processing. Explicit judgements of line orientation, however, may require coding

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[1] Similar effects have been observed in animal studies. Eacott and Gaffan (1991) report impaired orientation discrimination relative to shape discrimination after inferior parietal lobule lesions in the monkey (including the lateral bank of the inferior parietal sulcus).

concurrent variation along horizontal (x) and vertical (y) coordinates within a frame based on the patient's body, a process that seems to be impaired by damage to the dorsal visual stream. The importance of the parietal lobes for orientation coding is also suggested by several recent reports of patients with parietal lobe damage and with impairments in tasks requiring mirror-image discrimination of pictured objects (Davidoff & Warrington, 2001; Priftis, Rusconi, Umiltà, & Zorzi, 2003; Turnbull & McCarthy, 1996; Warrington & Davidoff, 2000). Again, coding of object orientation in relation to a explicit coordinate frame seems crucial for such discriminations. This process seems disrupted by parietal damage. Other patients with lesions to the dorsal visual stream have been shown to be impaired at making both absolute and relative location judgements to visual stimuli. Absolute judgements, about the positions of single stimuli in space in relation to the patient, are often poor—for both action (e.g., pointing) and perceptual judgement tasks (Humphreys & Price, 1994; Perenin & Vighetto, 1988; Ratcliff & Davies-Jones, 1972). In addition, Shalev and Humphreys (2002) have recently shown that judgements about the parts within novel stimuli can be difficult. Their patient, GK, suffered bilateral parietal damage and Bálint's syndrome. He was, for example, unable to judge whether dots fell towards the top or bottom of an oval surrounding shape. Nevertheless, he could perform the task successfully if primed to treat the oval as either an upright or inverted face (eyes top and bottom respectively). Again, visual information (in this case, relative coding of the spatial positions of the parts) was assimilated implicitly, for object recognition, but was not available for an explicit spatial judgement task. Thus, the dorsal system seems to do more than use visual information for action; it also modulates explicit perceptual judgements involving location as well as orientation information.

In the present paper we report data on a patient with posterior parietal damage who shows impaired perceptual judgements as well as actions to both line orientations and their locations. These impaired judgements to line orientations contrast with formally equivalent judgements using colour, which are relatively spared (including localisation).

Thus the type of information leading to the judgement, and not the judgement itself, is critical. We also show that the patient, MH, is detrimentally affected when oriented lines appear to group together. When presented with an orientation-defined target in the context of lines of another orientation, MH would sometimes detect that there was a line with an odd orientation present, but he was extremely impaired at localising this item. This was particularly the case when the lines fell at locations that defined a known shape (e.g., a square or a diamond), and the elements were spaced sufficiently apart to prevent any contribution from local textural discontinuities to contribute to performance (Nothdurft, 1991, 1992). The case consequently raises questions about (1) the implicit coding of line orientation within its spatial context, a process we suggest is conducted within a ventral object-recognition stream, and (2) explicit spatial judgements to the same input, a process supported by the dorsal visual stream. We suggest that, in a patient with a "weakened" dorsal stream, explicit judgements can be disrupted because they are "over-influenced" by the more spared ventral stream. We discuss the implications for understanding orientation and location coding in the brain, for understanding the relations between orientation coding within and outside spatial contexts, and, more generally, for interpreting neuropsychological data. In MH's case, we suggest that outputs from an impaired system are masked by outputs from a more preserved system. We do not witness a normal system minus a particular component but a system changed by altering the balance between two separate processes that normally code line orientations for different purposes.

BACKGROUND INFORMATION

Case history

MH suffered an anoxic incident when aged 42. At the time he was a garage manager, and his previous occupations included having been a bricklayer, a welder, and a chef. Following the incident he was

admitted to hospital, with some right-side muscle weakness and raised sensory thresholds on the right, but in all other respects the neurological examination was unremarkable. His wife reported that while he had no difficulty in walking or in using his arms, he had extreme difficulty in all activities of everyday living (ADL). He was unable to dress, or to use a knife and fork. He could not place the mug on the table without it tipping over. Over time, performance improved but there were still some aspects of ADL that were problematic. He could not fasten a necktie or shoelaces, and had difficulty putting on his socks. He could not coordinate a knife and fork when eating, and after cutting his food would eat using a fork only. Writing was very impaired and he could only produce upper- but not lower-case letters (see Figure 1).[2] Figure 2 illustrates MH's attempts to reproduce figures from the Wechsler Memory Scale (Wechsler, 1987).

The CT-scan report stated that there was increased signal in the lentiform nucleus bilaterally, slightly more pronounced on the left than the right. There was some involvement of the heads of the caudate nuclei bilaterally. There was some increased signal in the subcortical and cortical regions of the hemispheres, particularly in the left posterior parietal region, but also to a lesser extent in the left frontal region. The EEG report indicated an excess of slow wave activity over the right hemisphere. The present experimental tests were conducted over a 3-year period, starting 1 year after the incident. Performance was stable during this time.

Neuropsychological performance

Visual neuropsychological ability was assessed using the Visual Object and Space Perception Battery (VOSP; Warrington & James, 1991) , once 1 year post incident and once 3 years later. The scores are shown in Table 1, along with data from other neuropsychological tests. Essentially, MH

Table 1. *MH's performance on basic neuropsychological tests of object and space perception tested at 1 and 4 years post lesion*

Test	Time post lesion	
	1 year	4 years
VOSP		
Screen		
Shape detection	16/20[a]	19/20
Incomplete letters	19/20	20/20
Object recognition		
Silhouettes (object naming)	17/30	19/30
Object decision	19/20	19/20
Progressive silhouettes	10	9
Space perception		
Dot counting	3/10[a]	4/10[a]
Position discrimination	17/20[a]	19/20
Number location	5/10[a]	2/10[a]
Cube analysis	2/10[a]	3/10[a]
BORB		
Perception		
Circle size (same/different)[b]	15/30*	
Line length (same/different)	21/30*	
Object recognition		
Perceptual categorisation	24/25	
Association match	30/30	
Picture naming	76/76	
BIT		
Star cancellation	47/52[c]	
Letter cancellation	38/40[c]	

VOSP: Visual Object and Space Perception Battery (Warrington & James, 1991); BORB: Birmingham Object Recognition Battery (Riddoch & Humphreys, 1993); BIT: Behavioural Inattention Test (Wilson, Cockburn, & Halligan, 1987).

[a] Impairment relative to the published control data (2 *SD* from the control mean).

[b] MH was unable to perform this test, saying that all the circles appeared to be the same size even on "different" trials.

[c] MH made few omissions on the cancellation tests; where omissions occurred, they tended to be on the left (3/5 in the star cancellation test, 2/2 on the letter cancellation task).

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[2] MH's letters were clumsy and ill formed. He showed particular difficulties with letters with oriented lines; for instance, he was unable to determine the slope of the individual lines making up the letter W (immediately above the letter Z in Figure 1), and he found it easier to produce a + sign than an X. This was particularly striking as, due to his inability to write, he used an X as a signature and had more practice with this letter than with other letters. He also had some difficulties with mirror-image letters (e.g., the misorientation of the letter C in Figure 1).
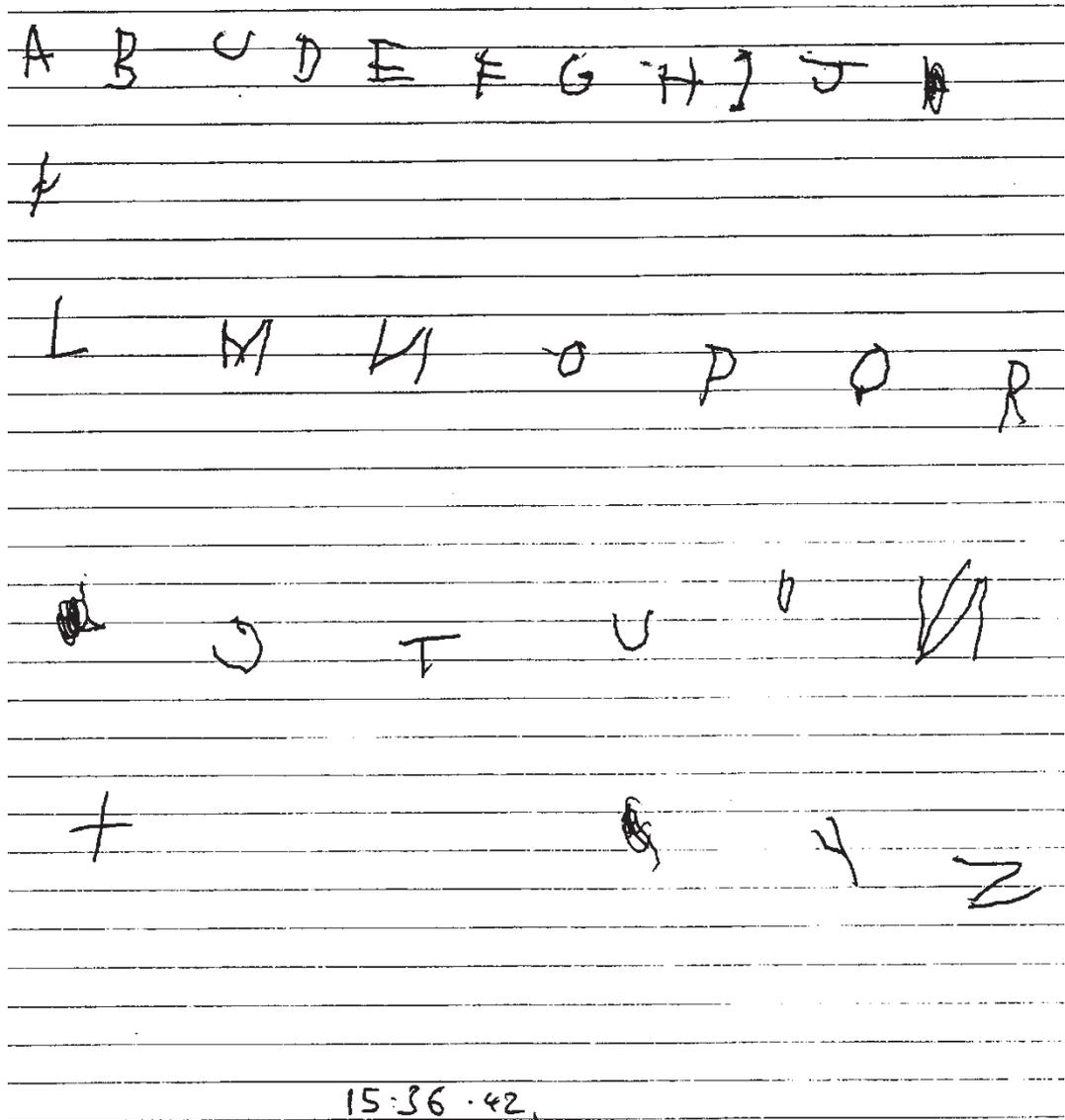
Figure 1. *Illustrating MH's attempts to write letters of the alphabet from memory. The task took 15 minutes. Note the particular difficulty with letters requiring an oriented line component.*

performed the tests of object recognition at control levels, but he was impaired on all tests of space perception. On the BORB (Birmingham Object Recognition Battery; Riddoch & Humphreys, 1993), MH again did well at object recognition tests but had difficulty on tests of perceptual judgement based on basic visual attributes (e.g., circle size, line length). The spatial difficulties apparent in MH were not due to unilateral neglect. He showed no neglect on selected subtests of the BIT (Behavioural Inattention Test; Wilson, Cockburn, & Halligan, 1987; see Table 1).
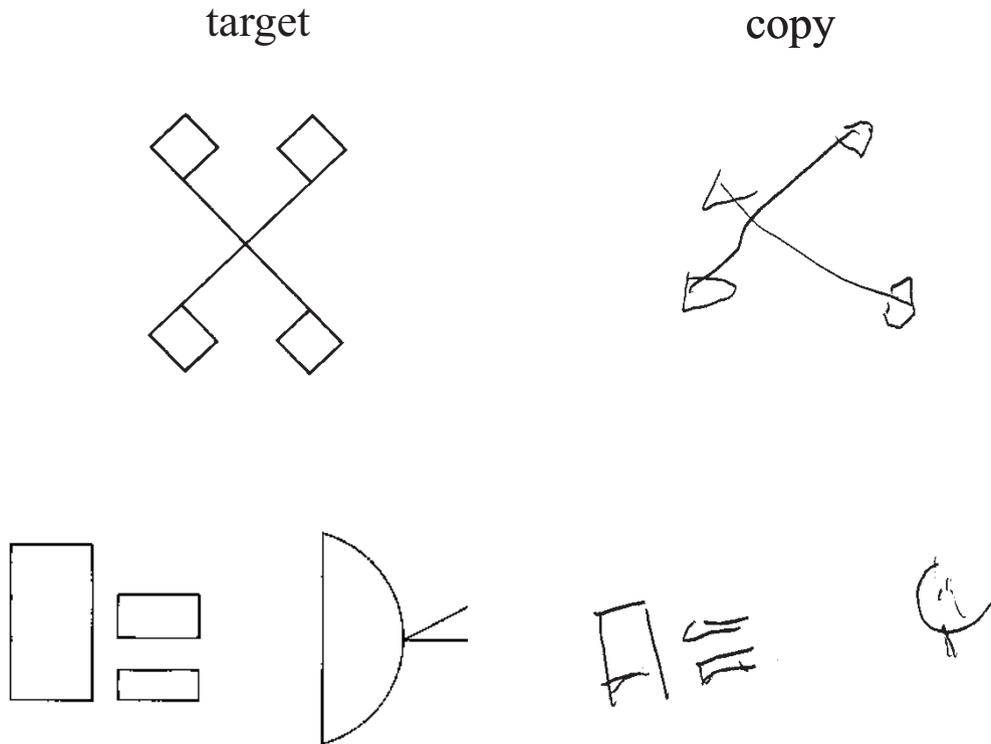
target   copy

Figure 2. *MH's attempts to copy items from the Wechsler Memory Scale.*

MH's sensitivity to mirror-rotated objects was also assessed. Test items were six objects depicted with either a long horizontal axis (elephant, zebra), a long vertical axis (kangaroo, kettle), or a long oblique axis (pliers, axe). In addition, two geometric figures were presented, a right-angle and a 60° angle. A trial consisted of three pictures of the same object, one of the three being the mirror image of the other two. The position of the odd-man-out was randomised across trials. There were a total of 48 trials (each stimulus triad being repeated six times, the stimuli randomised over the session). MH scored 40/48. He made 1 error each with stimuli with a long horizontal or a long vertical axis (22/24 correct), 2 errors with objects with an oblique axis of orientation (10/12 correct), and 4 errors with the geometric figures (8/12 correct). There was no major indication here of an "orientation agnosia" in discriminating mirror images of objects, and indeed if anything his performance

tended to be better with known objects than with geometric figures. It is interesting to note that at least one "orientation agnosic" patient has been reported in whom mirror-image discriminations of lines was preserved relative to objects (Davidoff & Warrington, 2001) and that in another, performance was more impaired for those stimuli she was able to identify than those she was not (Warrington & Davidoff, 2000).

To assess MH's spatial difficulties in more detail he was given sets of same–different match tasks, matching-to-sample, and construction tasks using arrays with either two lines joined at one end to form an angle, or arrays constructed from squares.

Line stimuli
In the same–different matching task MH had to indicate whether two angles placed side-by-side had the same or different angular displacement. For

'different' trials there were three levels of difficulty (with 18 trials at each level): small difference (5°), medium difference (10°), and large difference (15°). There were equal numbers of same and different trials. MH scored 57/108 (52.8%) correct (he had a tendency to answer "same" scoring 48/54 and 9/54 correct on same and different trials respectively). In the matching-to-sample task MH was asked to indicate which of two different angles matched a target angle. He scored 14/24 (58.3%) correct. Three age-matched controls performed these tasks effortlessly.

Squares stimuli

In the matching-to-sample tasks MH was asked to indicate which of two arrays of blocks matched a target stimulus. The target array was placed in a frame and situated below the other two stimuli. The arrays could consist of two or three blocks that were aligned horizontally, vertically, or angled (see Figure 3), although on any trial targets and distractors consisted of the same number of blocks. Target arrays were always angled. Performance was not time limited. With the two-block arrays there were 16 trials each with horizontal and vertical
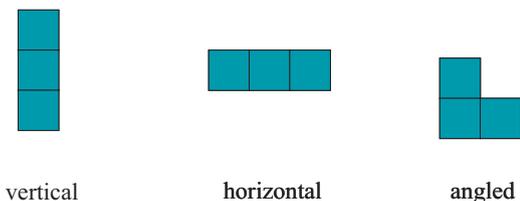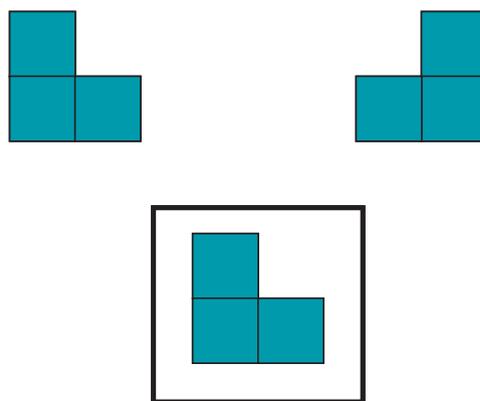
distractors and 16 with an angled distractor. With three-block arrays there were 8 trials each with a horizontal and vertical distractor, and 31 trials with angled distractors (16 trials when the to-be-matched item and distractor item were mirror images of each other, and 15 when they were not, see Figure 4).

While MH's performance was good when the distractor was either horizontal or vertical (47/48 correct), performance deteriorated significantly

Three-block arrays with angled distractors

mirror-image arrays

asymmetric arrays
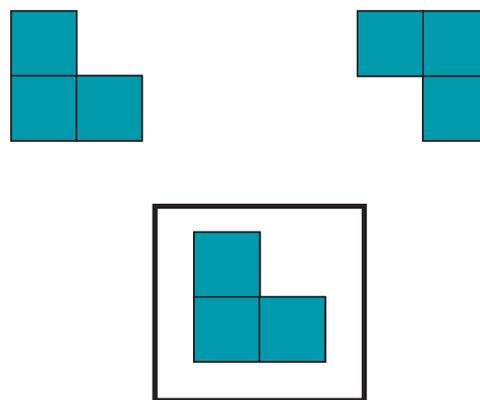

Figure 4. *Match–to–sample test using three–block arrays.*

Two-block arrays

vertical   horizontal   angled

Three-block arrays

vertical   horizontal   angled

Figure 3. *Orientations of two- and three-block arrays.*

with angled distractors (37/47correct), Fisher's Exact p-value = .004. With three-block arrays performance tended to be poorer with the asymmetric arrays (10/15 vs. 14/16 correct). Again, controls were at ceiling.

A similar pattern of performance was shown in construction tasks. When MH was asked to construct an array with bricks that was identical to a target array, he performed well when the target array consisted of a horizontal or vertical line constructed with two or three bricks (19/20 correct). However, when he was asked to construct an angled array (similar to those displayed in Figures 1 and 2) performance deteriorated significantly (17/30 correct), $\chi^2(1)$ = 8.7, p < .003. Thus MH has an impaired ability to code orientation, found in perceptual and construction tasks. In particular, he seemed to have a deficit in the ability to code the "handedness" of visual stimuli (e.g., in making judgements to stimuli with left–right organisation of parts; see also patient LM, Riddoch & Humphreys, 1988).

Given his problems in everyday life (e.g., picking up a mug) we were interested to examine whether MH could correctly orient his hand to match the orientation of a slot (cf. DF, Milner et al., 1991). We therefore examined MH's ability to post a tablet (95 mm × 41 mm × 3 mm) through a slotted disc (dimensions of the slot: 98 mm × 44 mm × 5 mm) using either his left or right hand. MH's wife acted as a control. The slot in the disc was positioned at one of four different orientations: vertical, horizontal, diagonally oriented with the top on the left, or diagonally oriented with the top on the right. Infra-red markers were attached to the hand, allowing movement to be detected by two infra-red sensitive cameras (MacReflex 2.5); kinematic variables were extracted using Wingz software. Movement time was taken as the time taken to pick up the tablet and to post it through the slot (positioned 50 cm in front of MH). There were three trials per condition.

The results are shown in Figure 5. The orientation of the slot had little effect on movement time for the control subject, who also showed no difference in the time taken with left or right hands; however, the position of the slot did affect MH's performance. Overall, he was much slower than the control subject, and this effect was particularly marked for his right hand. In addition, with both left and right hands, movement times were longer when the slot was oriented left or right relative to when it was horizontal or vertical. MH also made frequent errors when performing this task, often initially placing the tablet at the mirror image orientation to the orientation of the slot. He would then use tactile contact with the slot to reorient the tablet so that it eventually went in.

We have demonstrated on a range of clinical tests that MH's performance is particularly impaired when judgements of orientation have to be made, whether these are perceptual tasks (such as the match-to-sample test) or whether an action has to be initiated. In contrast, his object recognition abilities are spared. The particular difficulty shown by MH with orientation perception, and the difficulties shown in correctly orienting the hand in order to post a tablet, led us to perform a detailed series of investigations in order to pinpoint the locus of his difficulties.

EXPERIMENTAL INVESTIGATIONS

MH's perceptual judgements to line orientation, and to the locations of line orientations, were examined more formally using visual search and texture judgement tasks. Performance when targets were defined by orientation was contrasted with performance when targets were defined by a colour difference relative to distractors.

In studies of orientation perception in normal subjects it can be argued that horizontal and vertical orientations serve as "standards," and that oblique lines are coded in terms of their divergence from these standards (see Treisman, 1985; Treisman & Gormican, 1988, for evidence from search asymmetries). Hence we contrasted MH's perception of "standard" (horizontal and vertical) orientations with his perception of oblique orientations, and in particular we used judgements requiring the left–right coding of oblique orientations (e.g., target /, distractors \). We examined performance when single line orientations had to be coded, and when
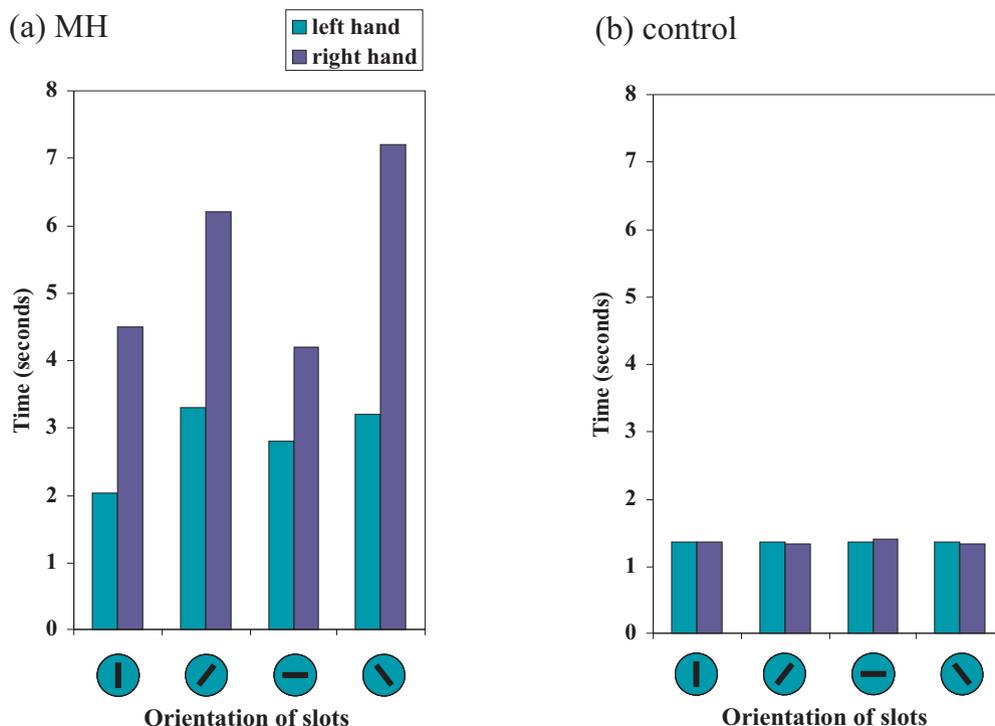
Figure 5. *The time taken (in seconds) for (a) MH and (b) a control to post a tablet through an aperture set at different orientations.*

stimuli were defined by conjunctions of line orientations (T elements—see Goodale et al., 1994). Since actions based on orientation conjunctions were problematic for DF, their coding may depend to some degree on processing within the ventral visual system. We also varied whether MH had to detect a target defined by line orientation or colour, and whether a localisation judgement had to be made to the target. Finally the spatial context surrounding the target was varied, to assess if the context "masked" the location of the target for MH.

Experiment 1: Visual search for targets defined in terms of a single feature (colour or orientation)

Experiment 1a: Detection of colour

Method. In Experiment 1 the target was a red oriented line; the distractors were blue oriented lines. Each line was 9 × 1 mm. Each block consisted of 60 trials, 10 target-present and 10 target-absent

for each display size. The display sizes were 4, 8, and 12. The display area for 12 elements was 17 cm in width, 12 cm in height, for 8 elements it was 13 × 9 cm, and for 4 elements 6 × 6 cm. The different display areas for the different display sizes ensured that the density of the arrays was relatively constant over display size (the lines covered respectively 10.0%, 6.1%, and 5.2% of the display area, for display sizes 4, 8, and 12). The positions of the distractors (and the target, when present) varied randomly on each trial. MH's performance was contrasted with that of eight age-matched controls. MH performed two blocks of trials while the controls performed one. The experiment was run using V-search software (Enns, Ochs, & Rensink, 1990) on a Macintosh Powerbook computer. Responses were made by button press using the X and C buttons pressed by the middle and index fingers of the left hand.

Results and discussion. The mean correct reaction times (RTs) are shown in Figure 6. The mean
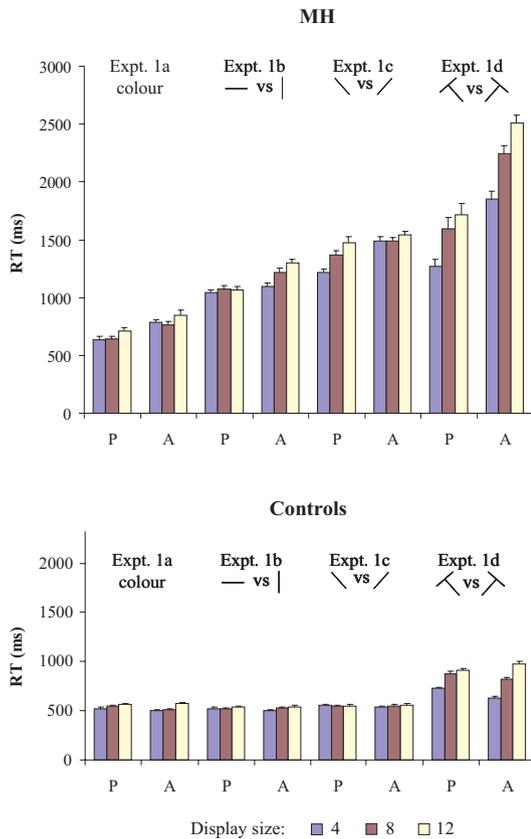
Figure 6. *RT (ms) for MH and the controls on target present and target absent trials in Experiment 1.*

Figure 7. *Percentage correct for MH and the controls in Experiment 1.*

percentage correct errors are shown in Figure 7. The number of errors were small for both MH and the control subjects (the numbers of errors for MH fell within 2 *SD*s of the mean errors for the controls for all display sizes and for both present and absent trials). MH's RTs were inflated in all conditions relative to those of the controls, by an average 194 msec. MH's data were analysed by treating each RT as a separate subject (see De Haan, Young, & Newcombe, 1987). There was a significant main effect of target present/target absent, $F(1, 111) = 29.1$, $p < .0001$, indicating that MH was faster on target present trials. There was also a significant effect of display size, $F(2, 111) = 3.6$, $p < .03$. The interaction was not significant, $F(2, 111) = 0.8$, $p > .05$. For the controls the main effect of target present/target absent was not reliable,
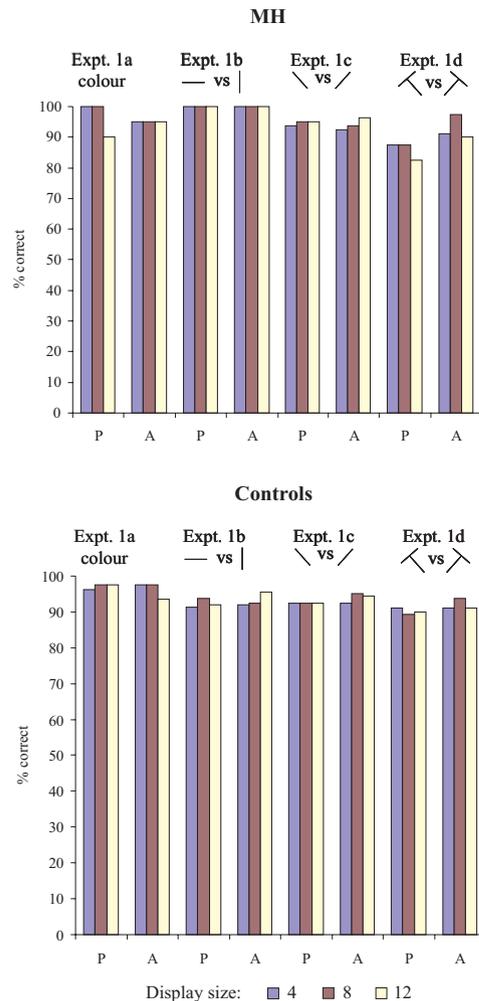
$F(1, 7) = 2.66$, $p > .05$, but there was a significant effect of display size, $F(1, 7) = 42.50$, $p < .0001$. The interaction was not significant, $F(1, 7) = 4.08$, $p > .05$.

The values for the intercepts, slopes, and percentage of variance due to linearity were computed for present and absent trials for both MH and the controls. The values (with standard deviations in brackets) are given in Table 2. The values obtained for MH fall within 2 *SD*s of the control performance in nearly all instances (the exception being the intercept on target absent trials).

Table 2. *Intercepts, slopes, and percentage of variance due to linearity in the colour detection task (*SDs *are given in brackets), Experiment 1a*

	MH		Controls	
	Target present	*Target absent*	*Target present*	*Target absent*
Intercept (ms)	589	738	506 (94)	458 (54)
Slope (ms/item)	9.1	7.6	4.8 (5.1)	9.0 (3.1)
r^2	.8	.5	.3	.6

The results indicate that although MH was slower to respond than controls, particularly on target absent trials, the slopes for both target present and target absent trials fell within 1 *SD* of the control mean. This suggests that the basic processes underlying search for a coloured target were relatively intact. On absent trials, MH may have adopted a relatively conservative response criterion, generating relatively slow RTs (Chun & Wolfe, 1996; Humphreys & Müller, 1993).

Experiment 1b: Detection of an "easy" orientation difference

Method. In Experiment 1b the target consisted of a horizontal line with vertical line distractors. The lines were depicted in black against a white background. In all other respects the procedure was identical to that described for Experiment 1a. MH and the controls undertook four and two blocks of trials respectively.

Results and discussion. As in Experiment 1a, few errors were made in this experiment (in fact, MH made no errors; see Figure 7). The mean correct RTs are presented in Figure 6. The disparity in overall RTs between MH and the controls was greater than in Experiment 1a. While RTs were similar in Experiments 1a and 1b for the controls (537 ms in Experiment 1a vs. 524 ms in Experiment 1b), the same was not true for MH, whose performance was relatively depressed in Experiment 1b (731 ms in Experiment 1a vs. 1132 ms in Experiment 1b; MH's mean RT in Experiment 1b was more than 2 *SD*s from his mean RT in Experiment 1a). For MH, there was a significant effect of target present/target absent, $F(1, 234) = 32.7$, $p < .0001$, indicating that he was faster on target present trials. There was a significant effect of display size, $F(2, 234) = 6.6$, $p < .002$, and the interaction was also reliable, $F(2, 234) = 4.1$, $p < .02$. There was a greater effect of display size on absent than on present trials. For the controls there was a significant effect of display size, $F(1, 7) = 8.8$, $p < .02$, but neither the main effect of target present/absent nor the interaction between present/absent and display size proved reliable (both $p > .05$). The values for the intercepts, slopes, and percentage of variance due to linearity are given in Table 3. The value of the intercept for MH was doubled on both absent and present trials relative to that of the controls. While similar slopes obtained on target present trials, the value on target absent trials was dramatically increased in MH (where his

Table 3. *Intercepts, slopes, and percentage of variance due to linearity in the horizontal line detection task (*SDs *are given in brackets), Experiment 1b*

	MH		Controls	
	Target present	*Target absent*	*Target present*	*Target absent*
Intercept (ms)	1037	1005	514 (100)	489 (62)
Slope (ms/item)	2.8	25	1.3 (1.6)	4.7 (6.0)
r^2	.5	1.0	.2	.3

RTs increased linearly with display size). For the controls, little of the variance on either target present or target absent trials could be attributed to linearity.

The pattern of performance of the control subjects in the colour (Experiment 1a) and easy orientation (Experiment 1b) tasks was very similar. In contrast, MH found the detection of orientation much more difficult than the detection of colour. In our initial investigations, it had seemed that MH had little difficulty distinguishing between horizontal and vertically oriented stimuli (e.g., matching-to-sample, and construction tasks); however, when using a more sensitive indicator of performance (RT as opposed to error rate with unlimited viewing), we have shown that MH is also impaired in the detection of an "easy" orientation discrimination. The implication here is that performance should be even more impaired with a difficult orientation discrimination tasks (e.g., detection of an oriented line among lines of the opposite orientation), as we had demonstrated in the initial clinical investigations. This was tested in Experiment 1c.

Experiment 1c: Detection of a "difficult" orientation difference

Method. In Experiment 1c the target consisted of a right-oriented line against left-oriented distractors (all lines were oriented at 45° with respect to the vertical). The procedure was otherwise identical to that described for Experiment 1a. MH and the controls performed four and two blocks of trials respectively.

Results and discussion. Error rates remained low (see Figure 7). The number of errors made by MH fell within 2 *SD*s of the mean of the controls' errors for each display size, and for both target present and target absent trials. The mean correct RTs are given in Figure 6. The analysis of MH's data revealed a significant effect of target present/target absent, $F(1, 449) = 24.0$, $p < .0001$, indicating that he was faster on target present trials. There was also a significant effect of display size, $F(2, 449) = 8.0$, $p < .0004$, and a Present/Absent × display size interaction, $F(2, 449) = 3.8$, $p < .02$. In this case, present trials were more affected by the display size than absent trials. Descriptive statistics for the search functions are shown in Table 4. No reliable effects were obtained with the control subjects (all $p > .05$).

Performance in terms of absolute RTs did not differ dramatically for the control subjects in Experiment 1c relative to Experiment 1a (mean RTs = 547 ms here vs. 537 ms in Experiment 1a). Also, the slopes of their search functions were less than 5 ms/item, within the benchmark typically taken to indicate spatially parallel search. However, MH's RTs were 1.73 times slower compared with Experiment 1a (1261 ms vs. 731 ms, and more than 2 *SD*s from the mean RT in that study) and they were some 129 ms slower than even Experiment 1b (easy orientation search). MH also showed a large slope on present RTs (32 ms/item). There was a reduced slope on his absent responses. However, MH's RTs on absent trials were very inflated and the fact that the slope was less than that for target present trials may simply indicate that he operated a cut-off criterion in his search for the target (on absent trials, the strategy might be: Search for a set period based, perhaps on the time taken to detect a

Table 4. *Intercepts, slopes, and percentage of variance due to linearity in the oriented line detection task (*SD*s are given in brackets), Experiment 1c*

	MH		Controls	
	Target present	*Target absent*	*Target present*	*Target absent*
Intercept (ms)	1099	1451	533 (104)	525 (66)
Slope (ms/item)	31.6	6.5	0.4 (3.5)	4.7 (5.2)
r^2	1.0	.8	.4	.3

target at the largest display size). With both target present and target absent trials the vast majority of the variance for MH may be attributed to linearity. Thus, relative to the control subjects, MH clearly found the detection of a target defined in terms of orientation a much harder task than the detection of a target defined in terms of colour. This was particularly the case with oriented rather than horizontal and vertical stimuli (in Experiment 1c vs. Experiment 1b).

Experiment 1d: Detection of "difficult" orientation using T stimuli

This experiment was similar to Experiment 1c above, but now oriented Ts were used rather than single line orientations. In order to detect the target, subjects now must compute a particular feature *conjunction*. Previous visual search studies with normal participants indicate that simple form conjunctions may be computed in a spatially parallel manner, giving rise to efficient search when the distractors are homogeneous and group together (Duncan & Humphreys, 1989; Humphreys, Quinlan, & Riddoch, 1989; Humphreys, Riddoch, & Quinlan, 1985). Moreover, search for form conjunction targets can be selectively disrupted after lesions to the ventral visual system (Humphreys, Müller, & Freeman, 1992). If form conjunctions are computed in the ventral visual system, and if responses to such targets are based on outputs from the ventral stream (and so are sensitive to grouping), then MH may even perform relatively well. On the other hand, given that the relations between line orientations must be computed, both within each item and then in comparison across items, we may predict that performance should generally be more difficult.

Method. The method was the same as in Experiments 1a–c except that oriented T elements were used. The target was right oriented (at 45°) and the distractors left oriented (45°). Each line component

of the T was 9 × 1mm in length and width. MH and the controls performed four and two blocks of trials respectively.

Results and discussion. Both MH and the controls found the task relatively difficult when Ts rather than oriented lines were used. The error rates increased (see Figure 7), and RTs were slower (overall: 823 ms for controls and 1864 ms for MH). The number of errors made by MH still fell within 2 SDs of the mean of the controls' errors for each display size, and for both target present and target absent trials. In addition, the relative increase in RTs for MH and the controls was approximately the same, relative to when single lines of the same orientation were used (in Experiment 1c; for controls, RTs were 1.5 times slower here; for MH, RTs were 1.48 times slower).[3] Analysis of MH's RT data indicated a significant effect of target present/target absent, $F(1, 204) = 115.0$, $p < .0001$: MH was faster on target present than target absent trials. There was a significant effect of display size, $F(1, 204) = 26.4$, $p < .0001$, but the interaction was not reliable ($p > .05$). The controls only showed an effect of display size, $F(1, 7) = 41.0$, $p < .0001$; the main effect of target present/absent and the interaction proved unreliable (both $p > .05$). The mean correct RTs are presented in Figure 6. For both MH and the controls, most of the variance was accounted for by a linear trend in the data (see Table 5).

Both MH and the controls found it relatively difficult to search for a right-oriented T amongst left-oriented T distractors. This is not too surprising given that the line orientations making up the targets and distractors had to be conjoined in order to distinguish one shape from the other. Conjunction search is typically more difficult that search for targets defined by differences in a single feature relative to distractors (Treisman & Gelade, 1980). More noteworthy, MH's search was not slowed disproportionately (relative to when single oriented

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[3] When RTs in Experiment 1c were subtracted from those in Experiment 1d, MH's RTs fell within 2 SDs of the control means for all display sizes on target present trials and for set size 4 on target absent trials. His RTs fell outside 2 SDs of the control mean for set sizes 8 and 12 on target absent trials, which may again reflect a conservative response criterion being adopted.

Table 5. *Intercepts, slopes, and percentage of variance due to linearity in the oriented T detection task (*SDs *in brackets), Experiment 1d*

	MH		Controls	
	Target present	*Target absent*	*Target present*	*Target absent*
Intercept (ms)	1082	1545	655 (152)	540 (105)
Slope (ms/item)	55.6	81.9	25 (8.2)	36 (18.8)
r^2	.9	1.0	.8	.9

lines were used as stimuli). Also, although MH's error rates were raised, they still fell within the control range. Thus, while MH clearly found this task more difficult than the controls, it was no more difficult than when he had to search through single oriented lines.

Discussion: Experiment 1

The data from Experiment 1 show contrasting patterns of search performance for MH, according to whether targets are defined by colour or orientation relative to distractors. MH's search for a colour-defined target was relatively efficient, and the slopes of his search functions did not differ from those found with controls. However, he was impaired on orientation search tasks. Some impairment was apparent even in an easy orientation search task (Experiment 1b, horizontal target vs. vertical distractors). Relative to the colour search task, MH's RT increased by 1.55 times whereas controls actually improved on the easy orientation task (the ratio of RTs was 0.98 in Experiment 1a vs. Experiment 1b). When oriented line stimuli were used, MH's performance deteriorated even further. With single oriented lines, control performance differed little from that found with horizontal and vertical lines, and little from colour search. MH's search was 1.73 times slower than with colour search, and a further 129ms slower than with horizontal and vertical line stimuli. We conclude that MH had a selective deficit in detecting targets defined by orientation differences relative to distractors.

In Experiment 1d we used targets defined by a conjunctive relationship between line orientations.

Both MH and the controls found these stimuli more difficult than the stimuli used in earlier experiments; however, there was little evidence for a disproportionate decrease in MH's performance. Dealing with conjunction stimuli did not seem particularly difficult for MH. This contrasts with the performance of patients with ventral lesions, who can find form conjunctions disproportionately difficult (Humphreys et al., 1992). The results are consistent with form conjunctions being coded within the ventral visual system, and with this coding being relatively preserved in MH.

During testing MH remarked on several occasions that, though he had "the feeling" that an orientation-defined target was present, he was frequently unsure of where it was in the display. This was examined more formally in Experiment 2, where MH was required to localise a target defined by a colour or orientation difference relative to distractors.

Experiment 2: Localisation of targets defined by colour or orientation

Experiment 2a: Colour-defined targets

Method. The method for Experiment 2 was the same as for Experiment 1, except that now MH was asked to localise the target on the VDU. He was asked to do this as quickly and accurately as possible. On absent trials he was asked simply to say "no target." RTs were recorded by a stopwatch,[4] which was started when stimuli were presented and stopped when MH touched the screen. MH began

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[4] Though this may introduce some error into the recordings, MH's RTs were so long in the critical conditions that any recording errors are unlikely to be an important factor.

each trial with his finger placed on a standard position on the table directly in front of the computer. In Experiment 2a MH was asked to point to a red oriented line target, when it was present. The distractors were blue oriented lines. There was a total of 120 trials (presented in two blocks), 20 target present and 20 target absent for each display size. The display sizes were 4, 8, and 12 and the positions of the distractors (and the target, when present) varied randomly on each trial. Controls were not tested here and our interest concerns the relative differences between MH's performance with the different stimuli. Control data are reported in Experiment 3, where RTs were recorded by computer on similar localisation tasks.

Results and discussion. Only RTs on present trials were recorded: Mean RTs and percentage errors are shown in Figure 8. MH's RTs were relatively slow here compared with Experiment 1a, when the same stimuli were used but targets had simply to be detected (943 ms vs. 731 ms in Experiment 1). Since RTs here included the time to move to the target, the increase in latency is not surprising. There was also some evidence of an increased slope (see the descriptive statistics in Table 6 relative to Table 2), although the effect of display size was not reliable here, $F(2, 119) = 2.30$, $p > .05$. These data, on the localisation of a colour-defined target, serve as a baseline for the subsequent tasks involving localisation of an orientation defined target.

Experiment 2b: Easy orientation target

Method. The method matched that in Experiment 1b, except that in Experiment 2b MH was asked to point to a horizontal line target when it was present amongst vertical distractors. The stimuli were black, on a white background. There was a total of 240 trials (presented in two blocks), with a total of 40 target present and 40 target absent trials for each display size.

Results and discussion. The mean correct RTs and percentage errors are shown in Figure 8. MH's RTs were some 432 ms slower here than in Experiment 2a (an increase of 1.45 in ratio terms). Thus there
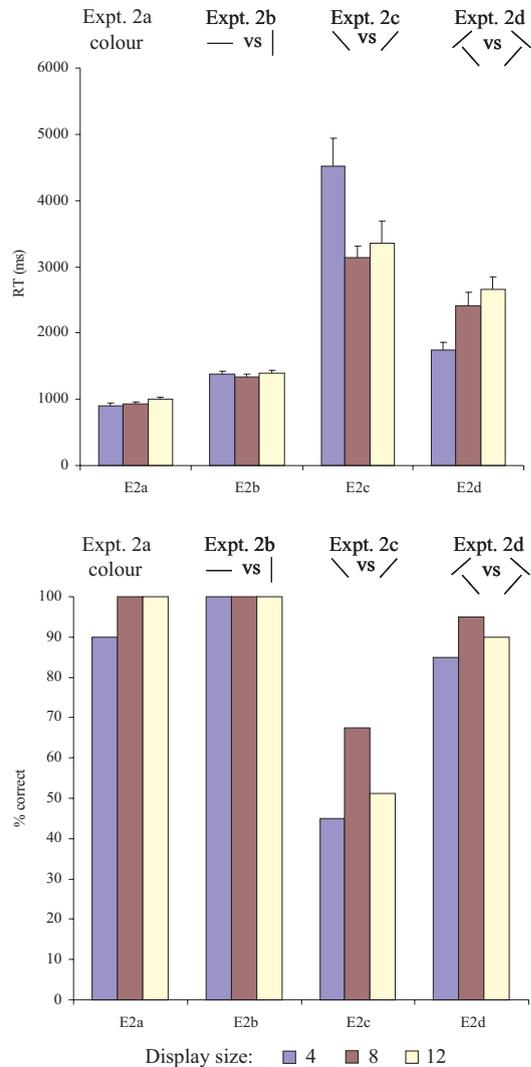

Figure 8. *RT (ms) for MH on target present trials in Experiment 2.*

Table 6. *Intercepts, slopes, and percentage of variance due to linearity, for Experiments 2a–d*

	Experiment			
	2a	*2b*	*2c*	*2d*
Intercept (ms)	844	1357	4840	1365
Slope (ms/item)	12.5	1.0	−146.0	113.9
r^2	1.0	.02	.6	.9

was a relative increase in difficulty in this task compared with when MH had to localise a colour-defined target. As in Experiment 2a, the effect of display size was not reliable ($F < 1.0$). MH made no errors (see Table 6).

Experiment 2c: Difficult orientation target

Method. The method was the same as in Experiment 1c except that MH had to point to an oriented line target (when present). The target was right-oriented at $45°$, and the distractors left-oriented at $45°$. There were 480 trials (four blocks of 120 trials).

Results and discussion. The mean correct RTs and percentage errors are shown in Figure 8. MH clearly had difficulty on this task, and his overall RTs were a full 2.7 s longer than in the colour localisation task. He also made vastly more errors (44.6% here compared with 3.3% in Experiment 2a). There was also an interesting negative slope on his RTs, with performance being faster at the larger display sizes than at display size 4: the main effect of display size, $F(2, 35) = 11.44$, $p < .01$, with a significant, negative linear component, $F(1, 33) = 14.39$, $p < .001$.

This last result suggests that the contextual relationship between the stimuli might have disrupted MH's localisation of targets at display size 4, since it is difficult to account for the improvement in performance at the larger target display sizes in terms of factors such as limited processing resources. Errors were also increased at set size 4, so the result was not due to a speed–accuracy trade-off. When errors occurred, MH typically pointed to a distractor adjacent to the target.

In Experiment 2d, we examined whether MH continued to show this pattern of performance when presented with oriented T stimuli.

Experiment 2d: Oriented Ts

Method. The method was exactly the same as in Experiment 2c except that MH was asked to point to a right-oriented T target (when present) which fell amongst left-oriented T distractors (all stimuli were oriented $45°$). The stimuli were the same as in

Experiment 1d. There were 60 trials, performed in a single block.

Results and discussion. The mean correct RTs and errors are given in Figure 8. MH's overall RTs were 2275 ms which, whilst still slow, were nevertheless faster than in Experiment 2c (single oriented lines) by some 1400 ms. In addition, errors were drastically reduced (10% overall). The improvement in both RTs and errors was reliable, $F(1, 170) = 36.7$, $p < .0001$ for RTs, $\chi^2(1) = 9.51$, $p < .01$ for errors. In Experiment 2d there remained a reliable overall effect of display size, $F(2, 51) = 8.5$, $p > .001$, but unlike Experiment 2c, this was due to slow RTs at the larger rather than the smaller display sizes ($p < .05$ for comparisons between display sizes 8 and 12 and display size 4).

The improvement with oriented T stimuli, compared with single oriented lines, is intriguing, given that search to detect an oriented T was relatively difficult for both MH and the control subjects (Experiment 1d). This points to a dissociation between the factors leading to target detection and those underlying localisation based on orientation information. MH had relatively poor detection of targets defined by orientation differences relative to distractors (Experiment 1). Over and above this, though, he showed poor localisation of targets, particularly at set size 4 with simple oriented lines. We propose that this reflects a form of context effect in which the relations between all the items present "masks" the detection and (especially) the localisation of the target. When there are four elements present, the stimuli fall in locations that always define a simple identifiable shape, whereas this is not the case with random positioning of items at larger display sizes (see Mandler & Shebo, 1982, for a discussion of this in the context of subitisation effects in normal observers). When the target was positioned so that it was a part of an identifiable shape, any "weak" signal for an orientation disparity may have been less salient than the shape information. Consequently, if attention became focused on the overall shape, target detection and target localisation may have become difficult.

It is also important to note here that the inter-element spacings (the density of the display) were

held roughly constant over the display sizes. Hence, the improvement at the larger display sizes was unlikely to reflect a contribution from another factor, such as the presence of local orientation discontinuities when there are more elements present (as would have occurred if the overall display area was held constant, Nothdurft, 1991, 1992).

Discussion: Experiment 2

MH was able to localise a colour-defined target but he was strikingly poor at localising targets defined by an orientation difference relative to distractors. Relative to the colour-target condition, performance with oriented targets was overall impaired, but this difference was particularly marked with single oriented line stimuli shown amongst a small set of mirror-oriented distractors (Experiment 2c). Furthermore, MH was worse at relatively small display sizes compared with when there were more elements in the field (although the inter-element spacing was roughly constant, and large, across the display sizes). We attribute this to MH showing poor detection and localisation when the target is coded as a part of a more global (and identifiable) shape. With relatively few elements present, the stimuli typically describe a familiar shape, a tendency that decreases with display size (Mandler & Shebo, 1982). The familar shape may be more salient to MH than an orientation disparity based on mirror image reflections (when the orientation signal is weak). As a consequence, MH may attend to the overall shape and not to the individual target element, making target detection and localisation difficult.

Experiment 3: Forced-choice localisation of orientation-defined targets

In Experiment 3, we incorporated a more formal assessment of MH's ability to localise orientation-defined targets. To do this, we presented him with multi-item displays composed of single oriented lines in which a target was always present. The displays were presented briefly (3000 ms) and were followed by a probe display in which a "?" symbol fell either at the location of the target, or at the location of an adjacent distractor. MH (and controls) had to decide whether or not the probe fell at the location of the target. In Experiment 3a we used symmetrical arrays and varied the spacing between elements. Any effects due to masking from the context provided by the other elements may be changed as these variables are manipulated. Grouping effects may be stronger with reduced inter-element spacing (see Pomerantz & Schaitzberg, 1975). In Experiment 3b we used asymmetrical displays, which may also reduce grouping effects.

*Experiment 3a: Symmetrical displays*

Method. Stimuli were presented on an Apple Macintosh Powerbook, having been drawn in MacDraw and transferred to VScope software (Enns et al., 1990). Two display sizes were used, one with four elements (set size 4) and one with eight elements (set size 8). The items for display size 4 also appeared across two display areas ("close" being 9 cm^2 and "spaced" being 16 cm^2), whilst display size 8 had a display area 25 cm^2 but the critical items fell at the same locations for the spaced display size 4 and for display size 8. Thus, here, the elements covered 40, 25, and 23% of the total display areas for the close 4, 8, and spaced 4 displays, respectively. The minimal separations between the centres of each item were 3 cm (close 4), 2.06 cm (8), and 4 cm (spaced 4) respectively. The displays were bilaterally symmetrical around fixation. Set size 8 displays were created by adding four elements to set size 4 displays so that the additional elements were adjacent to the original elements. There were two types of display: a target display and a probe display. Probe displays contained black dots and a "?" symbol and immediately followed target displays (any probe display consisted of the same number of elements as the preceding target array). The elements in target arrays consisted of oriented lines (the lines in the individual stimuli were 13 × 1 mm, and were oriented from bottom left to top right; each array had a single target line that was oriented orthogonally to the other elements). Lines were replaced by

dots in the same locations in probe displays. On valid probe trials a question mark was located in the spatial position of the target element in the preceding target array. On invalid trials the question mark replaced one of the other elements. All locations were probed equally often on invalid trials. Examples of the target and probe displays are shown in Figure 9.

The location of the target was manipulated across trials and all positions were equally sampled.

With set size 4 the target appeared at each location eight times for each of the two sizes of display. With set size 8 only target locations that were congruent with the locations sampled on four-item trials contained targets and each of these four locations was sampled 16 times. This created a total of 128 trials, 64 at each display size, half with a valid probe and half with an invalid probe. The order of the conditions was fully randomised, with the trials presented in blocks of 64.

(a) Target display
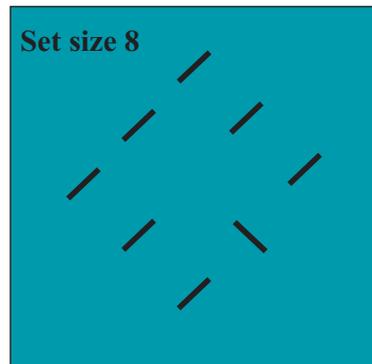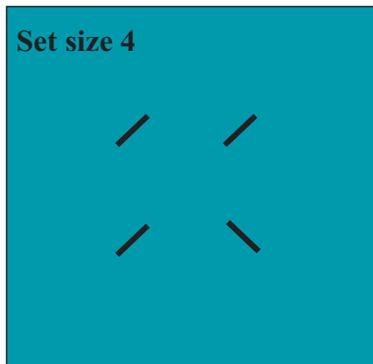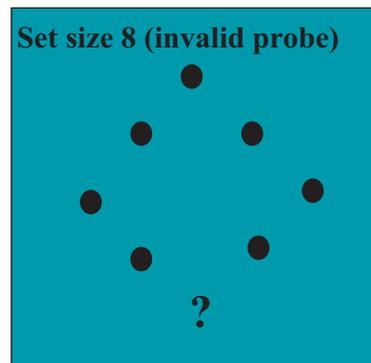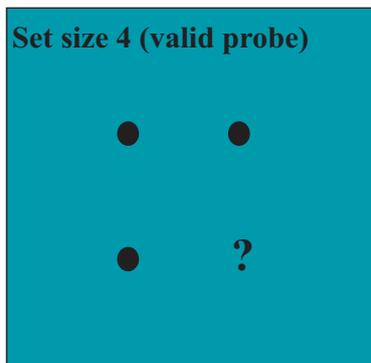

(b) Probe display

Figure 9. *Examples of the displays used in Experiment 3a.*

Trials were initiated by a central fixation cross (duration 150 ms) followed by a target array (duration 3000 ms) and then the subsequent probe array, which appeared for a maximum duration of 7500 ms (the offset of this display was triggered by the subject's key press response). Participants were asked to respond as quickly and accurately as possible using either the M or the N key on the keyboard (to signal when they thought the target was in the location of the "?", and when they thought the "?" was not in the target's location, respectively). Subjects were familiarised in a series of 32 practice trials and they received feedback after each response (+ for a correct and − for an incorrect response). There was a response deadline of 7500 ms.

Along with MH, an age- and education-matched control (JH) and 10 undergraduate students (ages 18–28) were tested.

Results and discussion. The mean correct RTs and percentage errors are presented in Figure 10. For the control subjects and for JH error rates were low (an average of 5.7 and 8 errors respectively). In contrast, MH failed to perform above chance at the smaller display sizes, summing across valid and invalid probes, both $\chi^2 < 1.0$ relative to chance. MH's performance was somewhat more accurate for display size 8, $\chi^2(1) = 33.1$ and 28.7 for display size 8 relative to spaced and close items at display size 4, both $p < .001$.

Given MH's low accuracy at display size 4, it is difficult to analyse his RTs, though we note that he was overall slower than the controls, particularly at display size 4. There was no evidence for a speed–accuracy trade-off.

JH's RTs were analysed separately in an independent factors ANOVA, treating each data point as a separate subject. There was no main effect of display size, $F(2, 115) = 1.6$, $p > .05$, but there was a main effect of probe validity, $F(1, 115) = 34.7$, $p < .0001$. The interaction between display size and validity of probe was not reliable, $F(2, 115) = 0.5$, $p > .05$.

The mean scores for each younger control subject were entered into a repeated measures ANOVA. The main effect of display size was not
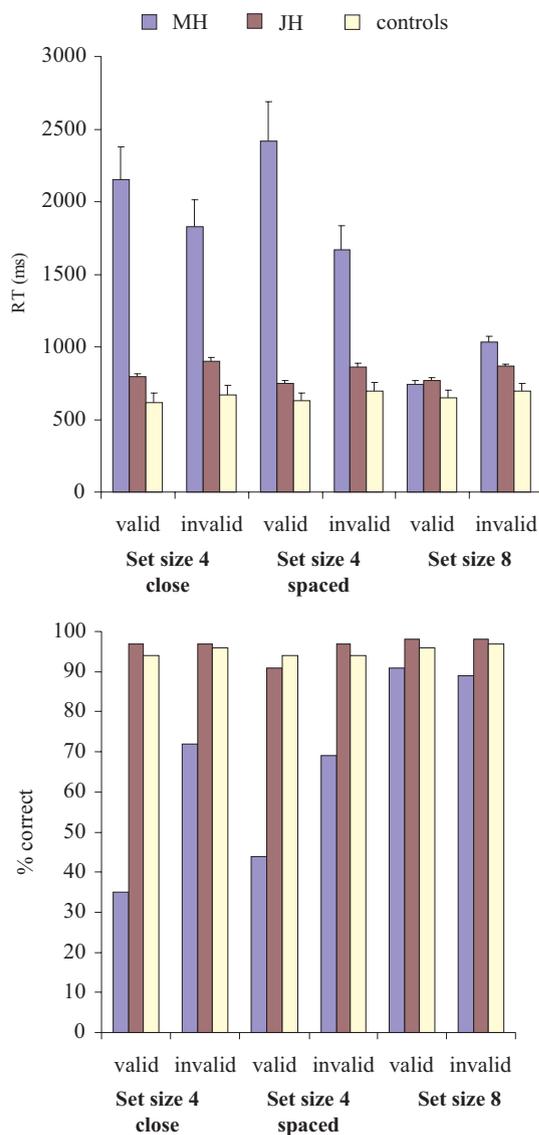

Figure 10. *RTs and percentage correct performance for MH, JH, and the controls in Experiment 3a.*

significant, $F(2, 18) = 1.2$, $p > .05$, nor was the interaction, $F(2, 18) = 0.08$, $p > .05$, but there was a main effect of probe validity, $F(1, 18) = 7.2$, $p < .025$. Thus, for the controls, there was no evidence that display size 4 was particularly difficult.

The data here confirm those we observed in Experiment 2c. MH was strikingly poor at making

localisation judgements to a 45°-oriented target presented amongst mirror-image distractors. The deficit was greater for display size 4, and this held with both close and spaced configurations.

Across the different displays here, the overall density of the display and the minimal inter-element distance varied orthogonally. The close 4 display had a higher overall density than the display with 8 elements, but the minimal inter-element distance was smaller for the 8-element display. The data suggest that MH was better able to detect and localise the target when the minimal inter-element distance was small (display size 8). This in turn indicates that there may be two factors at play. One is the strength of an orientation disparity signal, contingent on local inter-element spacing. The other is whether the elements fell at locations that define an identifiable shape. Target detection and localisation is good when there is a strong orientaion disparity signal. However, when this signal is relatively weak, and the elements define an identifiable shape, then he tends to attend to the shape. Target detection and localisation suffer most under this circumstance.

However, one problem in comparing across display sizes 4 and 8 here is that, on invalid trials at display size 8, probes appeared at four locations where targets were never presented. If MH learned this, his performance at display size 8 could have improved because responses on some invalid trials would not necessitate target localisation. There are several reasons to think that this factor was not critical. For example, there was little difference between MH's performance on valid and invalid trials. Also, for the control participants, probe validity did not interact with any other factor, so there did not appear to be differential effects on invalid trials at display size 8. Nevertheless, in Experiment 3b this potential problem was remedied by only presenting probes at locations where targets could appear, across all display sizes. In Experiment 3a we used symmetrical displays, and in Experiment 3b we used asymmetrical displays. With asymmetrical displays there may be a reduced tendency to code the whole display as a single object, in which case MH's performance should improve.

Experiment 3b: Asymmetrical displays

Method. The stimuli for this experiment were created by manipulating the original stimuli from Experiment 1. The positions of the original stimuli changed by moving individual elements to create random and asymmetric displays (we attempted to maintain the total area of both set size 4 and set size 8 displays) matching those used for the spaced 4 and display size 8 conditions in Experiment 3a. For both display sizes, four different arrays were produced.

With set size 4, each location was sampled four times for each array, both for valid and invalid trials (making a total of 32 trials at each location, 128 trials altogether).

With set size 8 arrays, target elements only ever occupied one of the four central locations, matched to the positions of the targets at display size 4. Each of these locations was again sampled four times for each array, for both valid and invalid trials, again creating 128 trials in total.

The trials for set sizes 4 and 8 were randomised and presented in two blocks of 128 trials each. The durations of the different displays were the same as in Experiment 3a. The sizes of the stimuli were also the same as in Experiment 3a. Examples of the stimuli are shown in Figure 11.

Results and discussion. The mean correct results and percentage errors for the different display sizes are presented in Figure 12. In contrast to Experiment 3a, MH performed at above chance at display size 4, $\chi^2(1) = 47.5$ vs. chance, $p < .0001$. He also performed better at this display size than in Experiment 3a, $\chi^2(1) = 4.0$, $p < .04$. Localisation accuracy of stimuli at display size 8 was above chance, $\chi^2(1) = 91.1$, $p < .0001$, and did not differ from that found in Experiment 3a, $\chi^2(1) = 1.7$, $p > .05$. However, it remained better than his discrimination at display size 4 $\chi^2 = 9.5$, $p < .002$. MH's response latencies showed a significant effect of display size, $F(1, 194) = 166.0$, $p < .0001$, and an effect of valid/invalid probe, $F(1,194) = 8.58$, $p < .004$; there was no significant interaction between display size and probe validity ($p > .05$). Overall, his RT's were 208 ms faster than in Experiment 3a.

(a) Target display
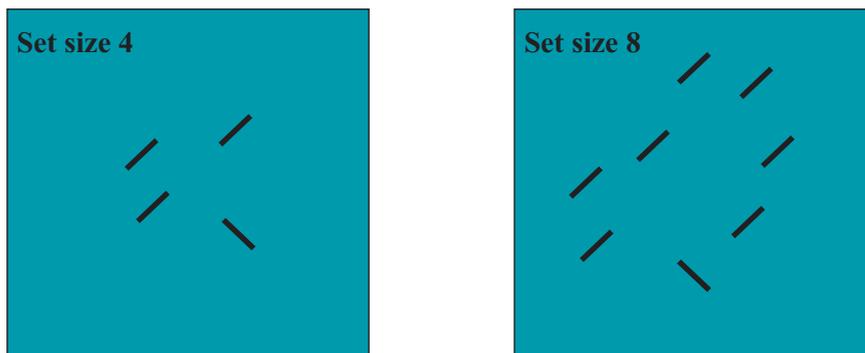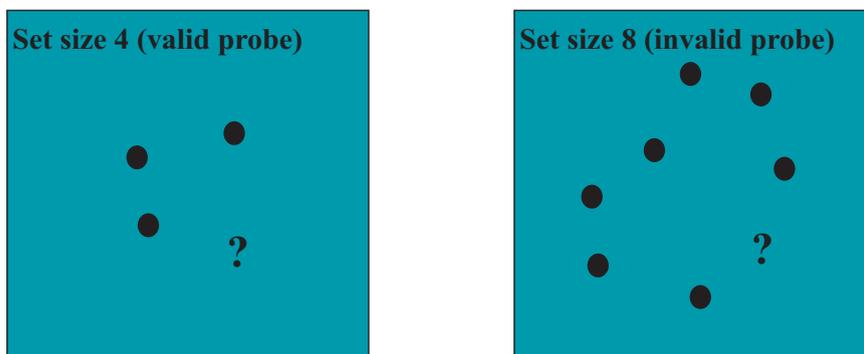

(b) Probe display

Figure 11. *Examples of the displays used in Experiment 3b.*

For JH there was no effect of display size, $F(1, 242) = 0.084$, $p > .05$, but there was a significant effect of validity of the probe, $F(1, 242) = 10.15$, $p < .0016$. The interaction was unreliable, $F(1, 242) = 2.9$, $p < .09$. Similarly, the younger controls also showed no effect of display size, $F(1, 9) = 4.6$, $p > .05$, a reliable effect of validity, $F(1, 9) = 15.24$, $p < .0036$, but no reliable interaction, $F(1, 9) = 0.36$, $p > .05$.

Further analyses were performed contrasting MH's RTs in Experiments 3a and 3b (see Figure 13). The factors entered into the analysis were Experiment (Experiment 3a vs. Experiment 3b), Display Size (4 vs. 8), and Validity (valid vs. invalid probe) Significant main effects were obtained for experiment and display size, indicating better performance in Experiment 3b, $F(1, 339) = 9.3$, $p < .003$, $F(1, 339) = 279.3$, $p < .0001$ for experiment and display size respectively) but the main effect of validity was not reliable ($p > .05$). Two of the 2-way interactions were significant: Experiment × Validity, $F(1, 339) = 12.5$, $p < .0005$;
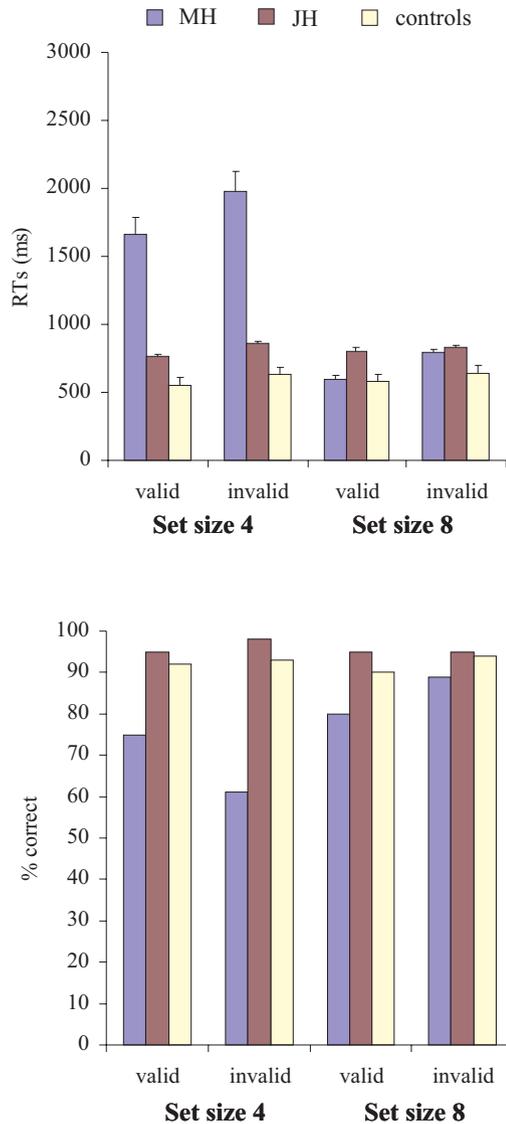
Figure 12. *RTs and percentage correct performance for MH, JH, and the controls in Experiment 3b.*

Figure 13. *Comparison of MH's performance in Experiment 3a (E3a) and Experiment 3b (E3b) in terms of RTs and accuracy.*

and Display × Validity, $F(1, 242) = 11.4$, $p < .0008$, but the interaction between experiment and display size failed to reach significance, ($p > .05$). The 3-way interaction was also found to be reliable, Experiment × Display Size × Validity, $F(1, 339) = 17.88$, $p < .0001$. MH improved at the small display size in Experiment 3b, particularly on valid trials.
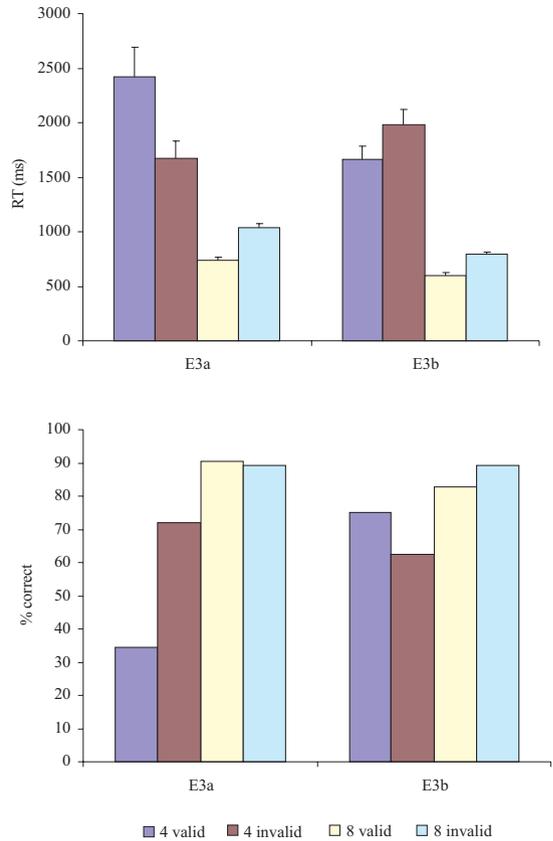
The results show that MH found it easier to localise the target in an asymmetric display (Experiment 3b), relative to when it appeared in a symmetric display (Experiment 3a). Indeed, it was only with asymmetric displays that MH performed above chance at the smaller display size. This result provides direct evidence that MH was particularly disrupted by cues that led him to code the elements as a single object, including overall positional symmetry. The controls too found it easier to localise the target in an asymmetric display, but the effect was much less dramatic (an overall RT gain of 67 ms for the young controls, and no effect for JH). We conclude that MH was abnormally sensitive to the contextual relations between target and nontarget elements when the task required

selective attention and localisation of an oriented target.

GENERAL DISCUSSION

We have reported a series of studies examining detection and localisation of orientation and colour-defined targets in a patient with left parietal brain damage, MH. MH was relatively good at both detecting and localising a colour-defined target. However, in comparison with the controls, he was impaired at all tasks with targets defined by their orientation. This impairment was apparent even with a simple orientation discrimination task (target = horizontal line, distractors = vertical lines), but it became more pronounced as the discrimination increased in difficulty (target = /, distractors = \ ) and when localisation was required (Experiments 2 and 3). Interestingly, performance was not impaired disproportionally relative to controls when orientation conjunctions were used (target = right, 45°-oriented T , distractors left, 45°-oriented Ts), and indeed MH's localisation of orientation conjunctions was better than his of single-line oriented targets (Experiment 2).

These results are consistent with the proposal that the dorsal visual stream is not only involved in "vision for action," but also that it supports some aspects of basic visual perception—in particular the discrimination and localisation of orientation-defined targets. The deficit for MH was most pronounced with 45°-oriented stimuli, where targets and distractors were mirror images of each other. We may think of this in various ways. One possibility is that the parietal lobe is important for coding the "handedness" of visual stimuli, so that their left–right orientation is made explicit (Riddoch & Humphreys, 1988). Another possibility is that, following his parietal lesion, MH is oversensitive to information coded by his ventral visual system, which responds in a rotation-invariant manner to stimuli (Cooper & Humphreys, 2000; Turnbull, Beschin, & Della Sala, 1997; Turnbull, Laws, & McCarthy, 1995). As we discuss below, there was evidence for strong effects on MH of contextual relations between the stimuli, consistent with him being over-affected by a ventral pattern-recognition system. However, his relatively better performance with oriented Ts, compared with oriented single lines, does not fit with this proposal. For example, a rotation-invariant ventral system should have just as much difficulty discriminating rotated Ts as rotated lines. The relative improvement with oriented Ts may instead be attributed to their discrimination being supported by conjunctive coding and grouping within the ventral visual system, which segments the target and distractor into separate groups (Humphreys & Müller, 1993; Humphreys et al., 1992). In contrast to this, single lines of different orientations can group into a single object, which makes it difficult to discriminate the target. Whichever account is maintained, MH did have some problems even with horizontal and vertical orientation discriminations (Experiment 1a), so the difficulty was not confined to left–right reflected stimuli. Neurophysiological evidence indicates that, in the monkey, cells in the anterior intraparietal sulcus are sensitive to orientation information (e.g., Sakata, Taira, Kusunoki, Murata, Tanaka, & Tsutsui, 1999), though it is not clear whether these cells support orientation discrimination as opposed to the visual guidance of hand actions. FMRI data also indicate that the parietal cortex is activated in orientation discrimination tasks, with the anterior intraparietal sulcus particularly activated when orientation discrimination is contrasted with imagery for orientation information (Faillenot, Sunaert, Van Hecke, & Orban, 2001; Shikata et al., 2003). Indeed, Shikata et al. demonstrate that the caudal part of the intraparietal sulcus was activated more strongly in an orientation discrimination task than when surface orientation was used to guide reaching. In Experiments 1 and 3 here MH was not asked to act to the stimulus but to show a discrimination response based on an orientation disparity. The clear deficit in his case indicates that orientation discrimination is supported by the parietal lobe. Note also that MH showed good performance with colour-defined targets. There was not a general problem in feature discrimination, but a more specific deficit within one feature domain.

The interplay between dorsal and ventral streams

There are two pieces of evidence indicating that MH was overly sensitive to pattern coding in the ventral visual stream. One is that his localisation performance was strikingly poor at display size 4 compared with when larger display sizes were used. Oriented lines at display size 4 are likely to configure into a familiar shape (a square or rectangle). The ventral pattern recognition system should respond most strongly to familiar shapes. In the search displays used in Experiments 1 and 2, with randomly placed elements, stimuli at display size 8 may not be coded as a familiar figure. In Experiment 3, the stimuli at both display sizes 4 and 8 fell in locations corresponding to parts of a familiar figure (e.g., a diamond for display size 8). However, the minimal inter-element distance was smaller at display size 8. It is possible that, with a small inter-element distance, targets are detected from local orientation disparities (Nothdurft, 1991, 1992), operating in a texture discrimination system. In work with normal observers, Wolfe (1992) has demonstrated that texture-based segmentation can be distinguished from orientation discrimination in visual search. There are also neurophysiological data indicating that texture discrimination can be based on cells in early visual areas (V1, Knierim & Van Essen, 1992). Thus MH may have other information available to support his discrimination at the larger display sizes in Experiment 3.

The second piece of evidence on the effects of ventral coding came in Experiment 3, where we found that MH was better at localising stimuli in asymmetrical displays than in symmetrical displays (in Experiment 3b compared with Experiment 3a). Again this fits with the idea that MH is disrupted when stimuli can be responded to as a single pattern. These data, where the grouped whole seems to "mask" part-information, match results from normal participants reported by Pomerantz and colleagues (Pomerantz & Garner, 1973; Pomerantz, Sager, & Stoever, 1977; Pomerantz & Schaitzberg, 1975), where again factors such as symmetry made it difficult to detect a "part" target in a "whole" grouped array. In MH, however, the "masking" effect is abnormally strong, and leads to him sometimes not being able to localise targets even with unlimited presentations (Experiment 2). It should also be noted that a form of cognitive rather than perceptual masking seems to operate. In Experiments 1 and 2 in particular, we used low-density displays where it is highly unlikely that perceptual masking took place. Instead of perceptual masking, we suggest that MH tended to attend to familiar shape information when it was present. When attention was allocated to the whole rather than the part, detection and localisation of a local target part was disrupted.

In cognitive neuropsychology, the effects of brain damage are frequently interpreted in terms of the loss/impoverishment of a particular processing module. In MH's case, however, we suggest that performance is not simply impaired by impoverished coding of line orientation but also by output from a separate (ventral) system. We propose that orientation information is coded by both dorsal and ventral visual systems in parallel, but for different purposes. The ventral system is concerned with organising orientations implicitly into shapes for pattern recognition. The dorsal system is concerned with explicit coding of orientation. Normally we may gain access to each type of information, depending upon task demands. However, damage to the dorsal system can mean that orientation information is not simply lost, but coded in a different way (more strongly weighted to the ventral stream). The system is not simply reduced, but operates in a qualitatively different manner. This possibility, of neural damage producing a qualitative change and not just a reduction in performance, needs to be taken into account when reviewing neuropsychological patients.

Feature detection and localisation

MH was typically able to detect orientation-defined targets, albeit slowly. In contrast, he was markedly inaccurate at localising the stimuli, even when unlimited presentations were used (Experiment 1). Localisation was more impaired than discrimination. In studies of feature detection in normal participants there has been some debate

over the relations between detection and localisation performance. Some authors have argued that features can be detected prior to localisation (Treisman & Gelade, 1980), whilst others have argued that coarse discrimination can be achieved prior to feature discrimination (Atkinson & Braddick, 1989; Donk & Meinecke, 2001) or that discrimination and localisation occur together (Green, 1992; Johnston & Pashler, 1990). MH's data are relevant to this debate, since his localisation was worse than his discrimination performance. This is consistent with orientation discrimination preceding (or at least operating independently of) feature localisation. Note, though, that MH did have coarse location information available. For example, when pointing he typically made near-neighbour errors. This was not due to inaccuracy in making the motor response, since he was certainly able to point to colour-defined targets (Experiment 2a). Thus feature discrimination can be dissociated from (relatively) fine-grain localisation. Feature disparities can be computed, but their explicit, fine-grained localisation is disrupted following damage to the parietal lobe. Nevertheless, given that MH had spared object recognition, we assume that feature locations are coded implicitly within the ventral object recognition system.

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