

OBJECT-BASED NEGLECT: AN INVESTIGATION OF THE CONTRIBUTIONS OF EYE MOVEMENTS AND PERCEPTUAL COMPLETION

R. Walker¹ and A.W. Young²

(¹Department of Psychology, University of Durham, England; ²MRC Applied Psychology Unit, 15 Chaucer Road, Cambridge, England)

ABSTRACT

Eye movements made by a patient with object-based neglect and no hemianopia, R.R., were recorded while he viewed whole, half, and chimaeric objects. When whole or chimaeric objects were presented centred on his initial fixation point, and when right half objects were presented, R.R. restricted his saccades to the right sides of the images. R.R.'s verbal identifications were consistent with these scan paths, since he correctly reported the identities of whole objects, right half objects, and the right sides of chimaeric objects, but failed to report objects on the left sides of chimaerics. When a left half object was presented to the left of initial fixation, however, R.R. made left saccades to scan the image and correctly named these objects; hence his failure to scan the left sides of chimaeric object cannot simply be attributed to an inability to make contralesional saccades.

We examined the possibility of perceptual completion by testing R.R. with sets of whole and half shapes presented tachistoscopically and asking him to report what he had seen. When R.R. viewed whole shapes he correctly reported seeing a whole shape on every trial. However, R.R. often reported seeing right half objects as whole, whereas he was much less prone to report left half objects as perceptually whole. We discuss the nature of this perceptual completion, and conclude that both scan paths and completion are consequences of object-based neglect, not its causes.

INTRODUCTION

Unilateral neglect is a condition in which brain-injured patients ignore stimuli located contralaterally to the site of the lesion. This problem is usually more severe following right-sided brain injury, where the left side of the world is neglected. Neglect is known to operate in more than one frame of reference, and has been shown to be influenced by spatial and object-based co-ordinates. One of the first demonstrations of object-based neglect was provided by Gainotti, Messerli and Tissot (1972), who asked people to copy a model containing objects located along a horizontal axis (house, fence and trees). They found that some patients with right brain damage would omit the left sides of particular objects from their drawings even though they still drew other objects positioned further into the left side of the page. Object-based neglect has since been illustrated in other studies of patients' drawing performance (Halligan and Marshall, 1994; Hormak, 1995) and in perceptual experiments using nonsense shapes (Bermann and Tipper, 1994; Driver, Baylis, Goodrich et al., 1994; Driver and Halligan, 1991). In some cases, dissociable forms of neglect have been found, and the

same patient may even neglect opposite sides of spatial and object-based representations (Humphreys and Riddoch, 1994, 1995).

Object-based neglect has also been demonstrated with chimaeric stimuli made by joining the left half of one object to the right half of a different object at the vertical midline. Young, Hallowell and Welch (1992) showed that neglect patient B.Q. failed to report the left sides of chimaeric objects and chimaeric faces, even though she could identify these left sides when they were presented without any accompanying right half. Even more compellingly, if the two halves of a chimaeric face were separated by a gap, so that they no longer formed a single perceptual object, B.Q. was then able to identify the left sides. This observation was replicated with 5 further patients by Buxbaum and Coslett (1994).

A contributory factor in demonstrations of object-based neglect may be the eye movements made while viewing the stimuli. An interesting study by Hornak (1995) showed that patients who drew only the right side of an object failed to scan the missing left sides of their own drawings. Hornak (1995) also found that when asked to recognise bilaterally symmetric objects, neglect patients only scanned the right sides, and that if right half objects were presented so that the missing left side would fall initially in the left visual field, neglect patients never made eye movements to scan the region of the missing left half. This held even for neglect patients who did not have left hemianopias.

Object-based neglect can thus be associated with a failure to scan the left sides of seen objects. However, the nature of this link is uncertain because Hornak did not record eye movements made to left half objects presented in the patients' left visual fields. Without this condition, we do not know how easily neglect patients can make leftward saccades if there is no competing right-sided stimulation. This leaves it unclear whether their failure to fixate the left sides of objects is due to a generalised problem in making contralesional (leftward) saccades, or if the patients would only fail to make contralesional saccades when a stimulus is present in their ipsilateral (in this case, right) visual field. In the present study we therefore explored further the relation of eye movements to object-based neglect by recording eye movements made by a neglect patient when he viewed left half, right half, whole and chimaeric objects.

Hornak (1995) also noted that her neglect patients verbally reported right half objects as being whole objects, and failed to notice the missing left sides. She thus considered the possibility that a second factor involved in object-based neglect is perceptual completion (Poppelreuter, 1917; Warrington, 1962). To investigate completion, Hornak (1995) presented left half shapes and right half shapes tachistoscopically, and asked neglect patients to report what they had seen. When these half shapes were aligned with the vertical midline running through the fixation point, so that a left half shape fell in the patient's left visual field and a right half shape fell in the patient's right visual field, all of Hornak's (1995) neglect patients incorrectly claimed that right half shapes (i.e., shapes with the left side missing) were 'whole' on at least some trials. In contrast, none of these neglect patients ever reported left half shapes as being whole. A control group of hemianopic patients without neglect did not make any similar completion responses with the half shapes.

One way of interpreting these completion responses for right half shapes is that neglect patients may in part fail to make appropriate eye movements to the left sides of symmetric objects because they already perceive a whole object by somehow mirror-imaging the scanned right sides. This would leave them unaware of the difference between whole objects and right half objects. On this account, object-based neglect could reflect a combination of unwillingness to scan the left sides of visual stimuli and symmetric completion of right-sided information onto the unscanned left side.

To explore this hypothesis, we investigated eye movements and perceptual completion in a patient with object-based neglect without hemianopia, R.R. In the first experiment, R.R.'s eye movements were recorded when he viewed whole objects, chimaeric objects, and left and right half objects. Our aims were to show whether R.R. could make contralesional saccades when a left half object was presented to the left of fixation, and whether or not he would do this with chimaeric objects. In the second experiment, we examined perceptual completion for R.R. In the discussion section we then outline the implications of our results for the roles of eye movements and completion in object-based neglect. The findings show that both eye movement patterns and apparent perceptual completion are best considered to be consequences of object-based neglect, not its cause, and that the key factor in responses indicating perceptual completion lies in ignoring the contralesional sides of objects, not an active filling in.

CASE HISTORY

R.R., a right-handed man born in 1934, suffered a stroke in 1990. The initial neurological examination revealed a left hemiparesis and left hemianaesthesia. A CT scan showed an extensive attenuation change in the fronto-temporo-parietal region, consistent with an infarct to the right middle cerebral artery. There was also a slight increase of attenuation within the right parietal region, which it was thought could have been due to an earlier haemorrhage. At this time, R.R.'s scores on the Rivermead Behavioural Inattention Test (Wilson, Cockburn and Halligan, 1987) indicated severe left sided neglect (Conventional score = 94, Behavioural score = 18).

After discharge R.R. made a mostly good recovery and could walk with the aid of a stick. Some aspects of left-sided neglect persisted, however, and he was referred to us in 1993. The investigations reported here were carried out in 1993 and 1994.

A general assessment of R.R.'s vision revealed good near visual acuity (N8). His contrast sensitivity was within the normal range for low spatial frequencies and only slightly below normal for middle and high spatial frequencies. R.R.'s visual fields were examined by presenting stimuli briefly to the left and right of a central fixation point on a VDU screen. Two fixation conditions were used; with a continuously displayed fixation point or a fixation point that was extinguished prior to stimulus presentation. This procedure has been used successfully to distinguish between left hemianopia and unilateral neglect (Walker, Findlay, Young et al., 1991). Unlike our previous case, who could only respond to left visual field stimuli when the fixation point was extinguished (Walker et al., 1991), R.R. was able to report left stimuli under both fixation conditions. This demonstrates that he did not have a left hemianopia, and that he was able to attend to the left side of visual space even when there was a competing central stimulus. R.R.'s visual fields were also plotted using an automatic perimeter (Henson CFS 3000). This automatic field plotter obtains a measure of the patient's ability to maintain fixation by presenting stimuli in the region of the blind spot. R.R. reported only two out of a possible fourteen of these stimuli, showing that he was good at maintaining fixation (an essential requirement for accurate eye movement recording).

The resulting field plot confirmed the observation that R.R. did not have a left hemianopia, although he did show evidence of increased thresholds in the outer regions of his lower left quadrant beyond 10 degrees. His upper left visual field and upper and lower right visual fields were intact.

R.R. did not show any signs of speech or verbal comprehension problems. His predicted pre-morbid IQ from the revised NART (Nelson, 1991) was 106, which was consistent with his educational background. He scored 18/20 on the Mini Mental State test (Folstein, Folstein and McHugh, 1975) and he was alert and well oriented with regard to time and place. He stated that his problems of neglect had been more severe immediately after the stroke, but had since improved considerably.

Formal assessment in 1993 showed only a very mild tendency to neglect the left side of spatial displays. For example, when reading a short passage of text 10 line long (102 words), R.R. omitted one word from the left side of one line. Similarly, in a crossing out task with four vertical columns of targets (10 targets positioned randomly within each column) R.R. omitted only 4/40 targets which were all located in the far left column. Note that in both types of task many leftward eye movements would have to be made to sustain these levels of performance.

In contrast to this evidence of only mild spatial neglect, R.R. showed marked neglect of the left sides of individual objects. For example, when asked to copy a scene containing eight objects, R.R. drew the right side of each individual object but omitted several details from the left sides of the objects. His drawings of a clock and a daisy from memory also showed left-sided distortions and omissions. When shown a set of chimaeric faces made from the left and right sides of two different people's faces, R.R. correctly named the face on the right of the chimaeric on 27/31 trials, but he was able to name the face on the left side of the chimaeric on only 12/31 trials.

This type of performance involves what Humphreys and Riddoch (1994, 1995) call within-object neglect, and it is clear that R.R.'s object-based problems were more severe than the mild residual neglect of spatial displays shown in the reading and target cancellation tasks described above. R.R. appeared to lack insight and awareness into this problem. When questioned about his own drawings he was unaware that the left sides of the individual objects were missing and satisfied that his copies were normal. When he failed to report the left sides of chimaeric stimuli, R.R. showed no awareness that the face on the left side was different from that on the right.

In summary, then, at the time of our investigation R.R. had recovered from an initial severe neglect; he still showed object-based neglect, but only mild spatial neglect. The combination of differentially severe object-based neglect and no left hemianopia made R.R. an ideal person to explore eye movements and perceptual completion in object-based neglect.

EXPERIMENT 1

Eye Movements and Object-based Neglect

In Experiment 1, R.R.'s eye movements were recorded while he viewed left half objects, right half objects, whole objects, and chimaeric objects. The objects used were familiar buildings and landmarks; these were chosen so that they formed a reasonably homogeneous set of grey-scale images from which chimaerics could be created. Chimaeric objects were made by joining the left half of one object to the right side of a different object. Our aim was to establish whether R.R.'s object-based neglect could be attributed to an eye movement deficit.

Materials and Method

A set of five photographs of famous buildings and landmarks was used to generate the stimulus set. The buildings and landmarks used were: Ayers Rock, the Colosseum, Stonehenge, the Arc de Triomphe and St. Peter's. The photographs were digitised and presented on an Apple Macintosh VDU at a distance of 57 cm; the whole object images were on average approximately 10 degrees wide. A set of left and right half objects was also made from the original whole images, by dividing each down the vertical midline. Five chimaeric objects were made by joining the left side of the image with the right side of another image. The left and right halves joined to form each chimaeric were selected so that they formed an approximate match for outline shape.

At the start of each trial, a fixation square (sides of 1 degree visual angle) appeared in the centre of the VDU for 1 second. The offset of the fixation square was simultaneous with the onset of the target stimulus. The whole objects and chimaeric objects were presented centred on the fixation point, so that the left half of each appeared initially in R.R.'s left visual field and the right half in his right visual field. Left half objects when presented in isolation were presented in the positions they occupied in corresponding whole objects or chimaerics, i.e. to the left of R.R.'s initial fixation position, and the right half objects were similarly presented to the right of fixation. Each stimulus was presented for 5 seconds; the offset of the stimulus was then followed by a delay of 5 seconds, during which time R.R. was asked to verbally describe what he had seen. The order of stimulus presentation was entirely random.

R.R.'s eye movements were recorded using a Skalar IRIS infrared limbus reflection eye movement recorder (Young and Sheena, 1975). One detector (left eye) monitored vertical eye movements and the other (right eye) monitored horizontal eye movements. The two channel (horizontal and vertical) analogue signal was sampled at 5 ms intervals and digitised using a labdriver interface. A chin rest was used to limit head movements. Sampling of the eye movement record started simultaneously with the stimulus image appearing on the monitor and stopped when the image disappeared. A number of calibration routines were performed to an array of nine stimulus circles (approx. 1 degree in diameter) surrounding a small central fixation point. There were three rows of circles (top, middle and bottom) spaced 6 degrees apart, with three circles in each row (left, centre and right) spaced 6 degrees apart. R.R. was asked to move his eyes in a set sequence from top left to bottom right and to fixate on the centre of each of the calibration points in turn. To ensure that he could follow the desired sequence the experimenter moved a pen slowly from one point to another to enable him to locate each point with his eyes.

The output from the eye movement recorder was sampled and stored to enable it to be translated into degrees of visual angle. The horizontal channel showed that R.R. moved his eyes in the desired sequence and located all of the calibration points, including those located to the left of centre. The calibration record was later used to calculate the number of units (output from recorder) that corresponded to one degree of visual angle (linearity of signal was assumed). The eye movement records from each trial were analysed off-line with a program that enabled the calculation of the amplitude, direction and latency of each saccade. The starting point of each saccade was detected using a velocity criterion of 30 degrees/sec. Each record was examined individually and if contaminated by blinks or failure to maintain pre-trial central fixation it was not analysed; 1 record (St. Peter's in the whole object condition) was lost for this reason. The saccades identified in each record were drawn to scale and plotted as a scan path superimposed onto the original image.

Results

R.R. correctly named all of the whole images, left half images, and right half images. He correctly named all of the right sides of the chimaeric stimuli, but failed to report any of the left sides of the chimaerics. This combination of ability to identify left half objects when presented in isolation, but not when

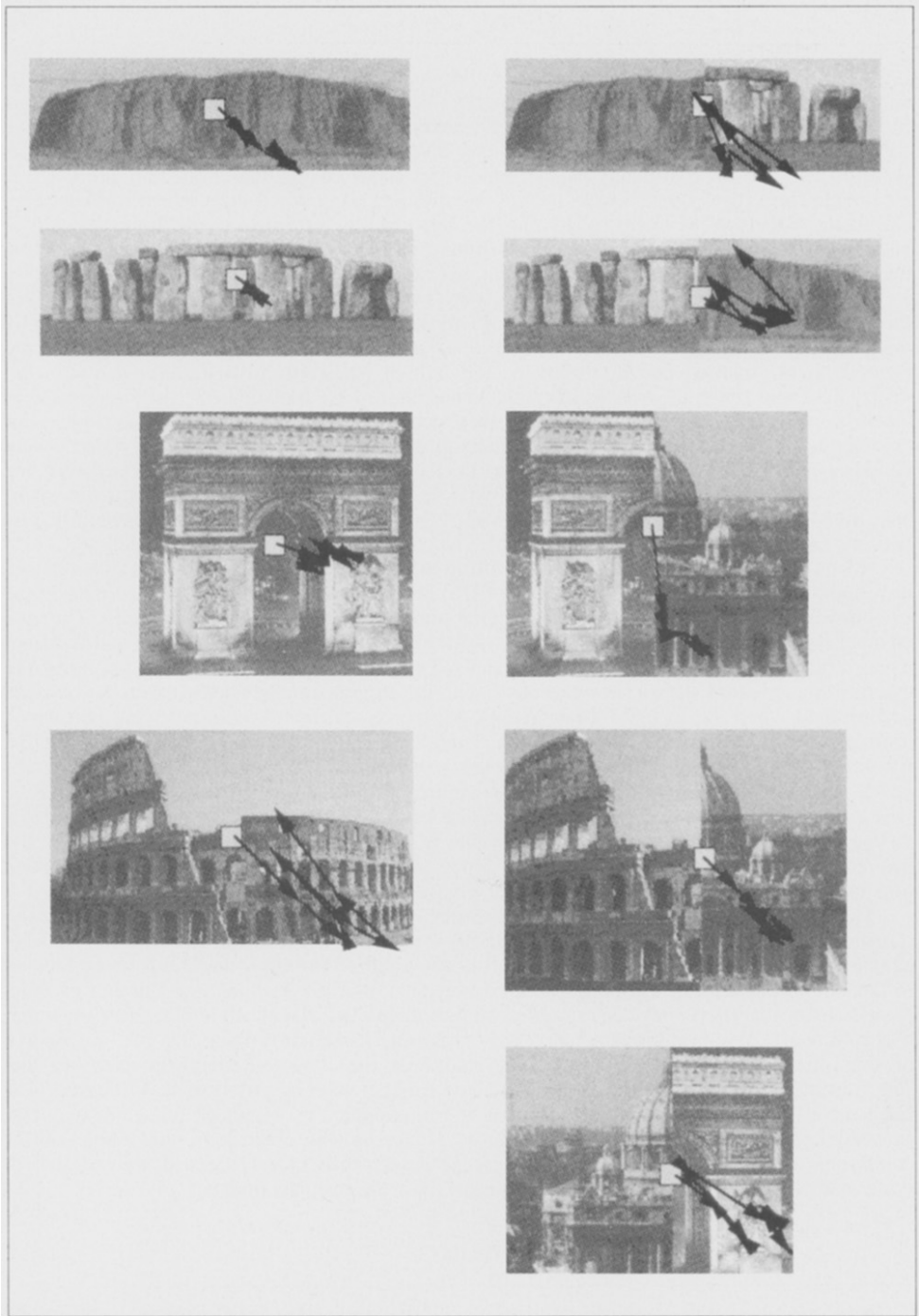


Fig. 1 – R.R.'s eye movements made when viewing whole, left half, right half, and chimaeric stimuli, superimposed onto the originals. The square indicates the position of the initial fixation square. Solid black lines indicate the direction and amplitude of each saccade, and the arrows indicate the location of each fixation.

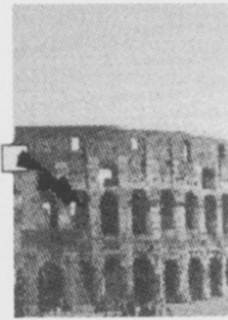
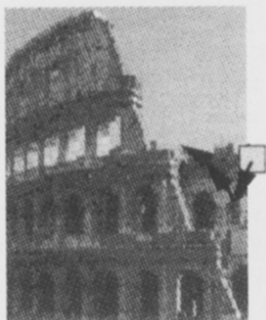


TABLE I

Proportion of total fixation time R.R. spent in each horizontal quadrant for whole objects, chimaeric objects, left half objects, and right half objects

	Outer left	Inner left	Inner right	Outer right
Whole	0%	0%	66%	34%
Chimaeric	0%	0%	69%	31%
Left half	0%	78%	22%	0%
Right half	0%	0%	63%	37%

they formed part of a chimaeric object, is consistent with observations in other reports where eye movements were not recorded (Buxbaum and Coslett, 1994; Young et al., 1992).

R.R.'s eye movement records were superimposed onto the original images and are shown in Figure 1. As noted previously, the eye movement record from one whole building (St. Peter's) was not used as R.R. had not maintained central fixation prior to the onset of the image. When viewing right half images, R.R. always restricted his saccades to the right of the initial fixation point. When viewing whole objects R.R. also restricted his saccades and fixations to the right of the initial fixation point on every trial. Similarly, when viewing chimaeric images R.R.'s initial saccades were always made to the right of initial fixation. Furthermore, R.R. never made any saccades that crossed into the left side of the chimaeric images, and all fixations were restricted to the part on the right side.

Despite this right-sided bias for right half objects, whole objects and chimaerics, R.R. did make leftward saccades to left half objects. On four out of five occasions when a left half image was presented, R.R. made some saccades to the left of initial fixation; on the other occasion the record showed that R.R.'s initial fixation position had been slightly to the left of the fixation point anyway. Hence, on every trial when a left half image was presented to the left of his initial fixation position R.R. was able to make left saccades and fixated on the half image.

Although he was able to make saccades into left half objects, R.R. did not move as far into them as he went rightward with right half objects, wholes or chimaerics. To show this, we divided each whole object into four equal sized columns along the horizontal axis, to create outer left, inner left, inner right and outer right strips. We then calculated the proportions of the total fixation time R.R. spent in each of these horizontal quadrants for whole objects, chimaeric objects, left half objects and right half objects. These are shown in Table I. The proportions for whole objects, chimaerics and right half objects are pretty much the same as each other, but there are two immediately striking features of the data for the left half objects. First, although R.R. fixated left half objects, he confined his fixations to the inner left area. The absence of outer left saccades to left half objects contrasts markedly with the fact that R.R. did make saccades into the opposite (outer right) region with all other types of figure. Second, some of R.R.'s saccades to left half objects fell in the inner right area, and he spent 22% of his time fixating this region of empty space. R.R. never fixated empty space when looking at right half objects.

Discussion

On trials when a *left half object* was presented to the left of fixation, R.R. did scan the image, and these left half objects were correctly reported on every trial. In contrast, when a *chimaeric object* was presented centred on the fixation point, R.R. restricted his saccades to the right of the image midline. On each trial with chimaerics, R.R. reported the object on the right side but failed to report the object on the left side.

The eye movement records show that R.R.'s failure to scan the left sides of the chimaeric objects cannot simply be attributed to an inability to make contralesional saccades, since he made these to left half objects presented in isolation. Thus a failure to make saccades into the left sides of chimaeric objects should be regarded as being a *consequence* of R.R.'s neglect, and not the primary *cause* of his deficit. That said, though, it is clear that the two problems are closely related, since R.R. showed only restricted leftward scanning of the left half objects. It is interesting to speculate that what he seemed to do was almost to treat the left half objects as if they were narrower versions of whole objects, and concentrate his eye movements onto what would then be their right sides (i.e., the inner left region of Table I). Certainly, he seems to have moved his eyes only as far left as was necessary to identify each left half object. This point was also emphasised by Hornak (1995) for her cases, but it still does not account for R.R.'s failure to explore the left sides of chimaerics. R.R. knew that chimaeric stimuli were presented, and that his task was to report both sides. To do this, he would at most only have needed to make eye movements equivalent to those he made to left half objects; yet he was apparently unable to do so with the chimaeric.

EXPERIMENT 2

Completion and Object-based Neglect

Experiment 2 was performed to examine the possibility that R.R. showed a form of visual completion whereby he misperceived right half objects as being whole objects. This form of completion could be a factor that contributes to R.R.'s unawareness of the left sides of chimaeric objects. To explore this, R.R. was shown whole and half shapes and asked to report what he had seen.

Materials and Method

A central fixation square (sides 0.5°) was positioned in the centre of a computer screen; this was made from black lines (1 pt.) on a white background, using a computer drawing package. Horizontal and vertical lines 1 cm long crossed in the centre of this square, forming an accurate centre point for fixation. Ten simple shapes were drawn using a computer package, and used as stimuli; they are shown in Figure 2. Shapes were drawn in black 4 pt. lines on a plain white background, and positioned so that they would fall within a template circle which measured 8° of visual angle in diameter at the viewing distance of 57 cm. Each of these whole shapes was presented centrally to R.R., so that it projected 4° into his left and 4° into his right visual fields. Sets of left and right half shapes were also made by dividing

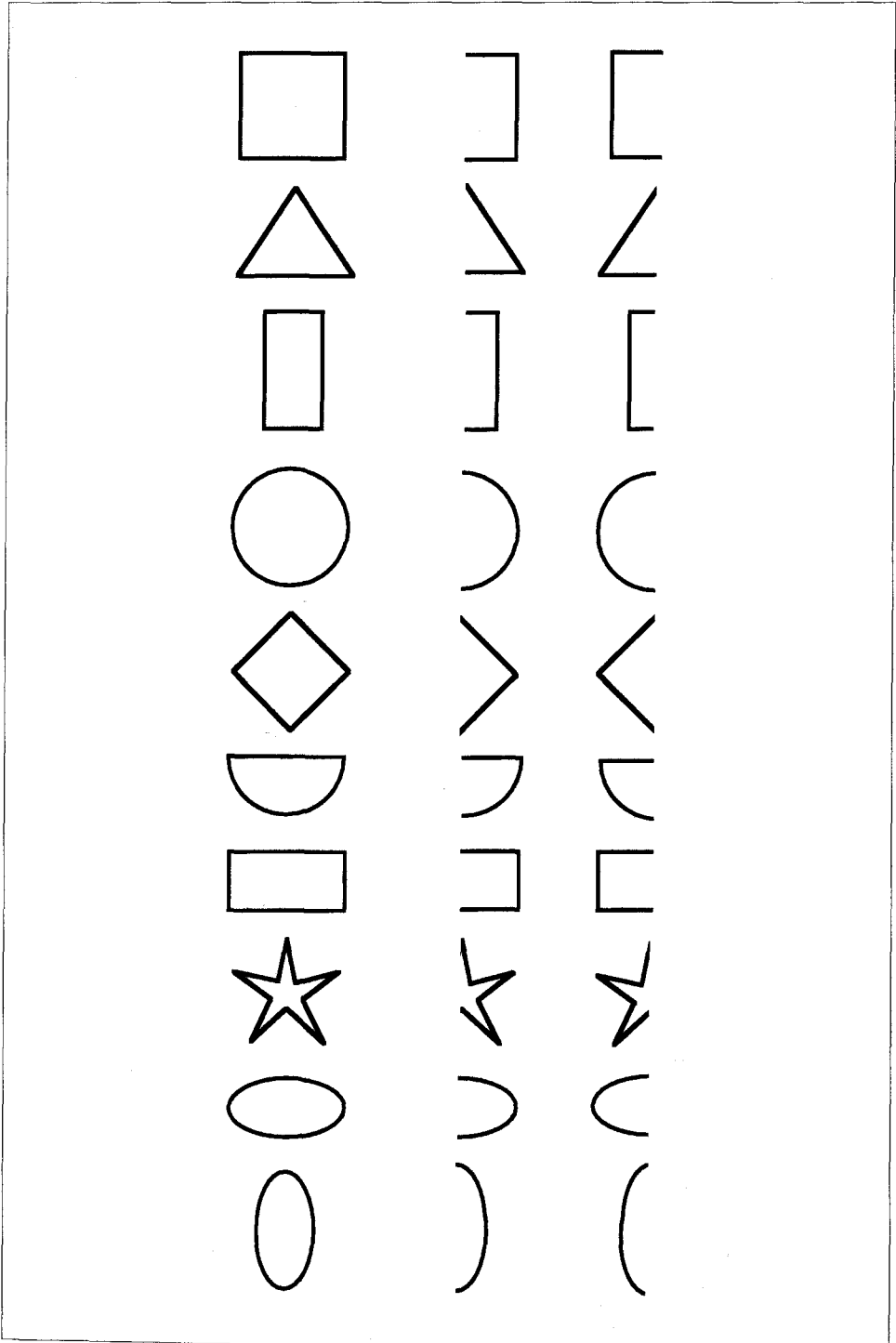


Fig. 2 - Whole shapes, right half shapes, and left half shapes used in Experiment 2.

each of the whole shapes at the vertical midline. This produced a total of 10 whole shapes, 10 left half shapes and 10 right half shapes.

A Macintosh portable computer was used to present the stimuli (Powerbook 165). A tachistoscopic software package (SuperLab® 1.5) was used to control stimulus presentation. For each whole shape, its centre coincided with the centre of the fixation cross. The left and right half shapes were presented to the left and right of fixation respectively, occupying the same position that they would have had they been presented as a whole shape.

The stimulus presentation sequence used for each trial was as follows; a fixation point was presented at the centre of the screen for 2 seconds, followed by a 50 ms presentation of the stimulus shape. The 50 ms stimulus duration was chosen from pilot work to be above R.R.'s recognition threshold for the shapes used, but sufficiently brief to prevent any saccadic eye movements (Young, 1982). The offset of the stimulus shapes was followed by a blank screen, and R.R. was asked to report what he had seen; i.e. which shape, and whether it was a whole or half shape. The experimenter noted R.R.'s response by making a key press which also initiated the start of the next trial. R.R. was tested on five separate blocks of trials during the same testing session. Each block contained one presentation of each of the whole, left half, and right half shapes (total of 30 trials). The presentation order of the whole shapes and half shapes was randomised throughout each block of trials. Thus R.R. received a total of 150 trials, during which he saw each of the whole and half shapes five times each.

The instructions given were as follows: "Please look at the fixation square on the screen. You will then see a shape which will be presented very briefly. You will be asked to name that shape. On some occasions a whole shape will appear, but on other trials only a half shape will appear. Please state which shape you saw and if it was a whole or a half shape".

Results

R.R. had little difficulty in correctly naming the briefly presented shapes. Occasionally he reported a "square" when a rectangle had been presented, and also reported a "circle" when the shape was actually elliptical. When such a mistake was made the experimenter corrected him for future reference and on each occasion R.R. agreed that the shape was actually a rectangle or circle. The percentages of shapes correctly identified and the percentages reported as being whole shapes or half shapes are shown in Table II.

When a whole shape was presented, R.R. reported that he had seen a whole shape on every trial. With left half-shapes he correctly reported that a half shape had been presented on 41 trials, on 9 other trials he mistakenly said that a whole shape had been presented. R.R.'s ability to correctly identify left half-shapes as halves shows that he was able to correctly perceive a half shape and that he was not merely reporting "whole" on every trial. His ability to correctly identify a shape presented for 50 ms in his left visual field also confirms that he was not hemianopic.

TABLE II
Percentages of stimuli correctly identified by R.R., and the percentages of shapes that were reported as being either a whole or half shape

	Percentage of shapes correctly identified	Percentage reported as whole	Percentage reported as half
Whole shapes	96%	100%	0%
Left half shapes	92%	18%	82%
Right half shapes	94%	52%	48%

Despite this, when presented with a right half shape, R.R. correctly identified it as being a half shape on 24 trials, but on the remaining 26 trials (52%) he mistakenly reported right half shapes as being whole. This tendency to report right half shapes as being whole is significantly greater than was shown for the left half shapes ($\chi^2 = 12.6$, *d.f.* = 1, $p < 0.01$). R.R.'s ability to decide if a half shape was a whole or half shape was thus highly asymmetric. With left half shapes in his left visual field his discrimination was good. However, when a right half shape was presented in his right visual field his ability to say if it was a whole or a half was no better than chance. Even so, R.R. was able to distinguish whole shapes from right half shapes; he recognised 50/50 whole shapes as wholes, but only reported 26/50 right half shapes as wholes ($\chi^2 = 31.6$, *d.f.* = 1, $p < 0.01$).

Discussion

R.R. reported right half-shapes as whole shapes more often than he reported left half-shapes as whole shapes. This finding shows that his tendency to report right half shapes as wholes cannot simply be attributed to a response bias. However, R.R. did not report right half shapes as wholes as often as he reported whole shapes as wholes. Clearly, then, he was able to make some limited use of left side information, since the only difference between right half shapes and whole shapes was the presence or absence of the left side.

The present experiment has paradoxically shown that R.R. was better able to report a shape as incomplete when it was presented in his contralesional (left) visual field. The paradox is that the impairment in detecting half shapes occurred when the stimulus was presented in R.R.'s ipsilesional visual field. This performance is in direct contrast to the deficits typically shown by patients with unilateral neglect, who are usually impaired with stimuli presented in their contralesional visual field.

GENERAL DISCUSSION

His differentially severe object-based neglect and his reasonably intact left visual field made R.R. an ideal person to explore the roles of eye movements and perceptual completion in object-based neglect. In Experiment 1, we examined his eye movements when he viewed half, whole and chimaeric objects. When left half objects were presented to the left of fixation, R.R. made left saccades and scanned the image. He had no difficulty in correctly naming these left half objects. However, when a whole object, right half object, or chimaeric object was presented R.R. restricted his saccades and fixations to the right side of each. With chimaeric objects, R.R. failed to report the left sides on each trial. Furthermore, R.R. also appeared to be unaware that the left sides of the chimaerics were in any way different to the object on the right side.

As R.R. could make contralesional saccades when a left half object was presented to the left of fixation, his failure to scan the left sides of chimaerics cannot be directly attributed to an inability to make contralesional saccades.

R.R.'s failure to make eye movements to fixate the left sides of chimaeric stimuli therefore appears to be a consequence of his object-based neglect, not its immediate cause.

This conclusion that defective eye movements are not the primary determinant of object-based neglect is consistent with other findings. For example, Young et al. (1992) showed that patient B.Q. neglected the left sides of chimaeric stimuli even when they were presented tachistoscopically entirely into her right visual field. The brief tachistoscopic presentation excluded the possibility that an eye movement could be initiated, and the positioning of the chimaerics in B.Q.'s right visual field meant that the left sides fell in an area of higher visual acuity than the right sides; yet B.Q. was still better able to report right sides of chimaerics under these conditions.

This is not to say that eye movements are uninteresting or unimportant. On the contrary, they are so tightly linked to our normal exploration of objects and space that they may prove a very useful way of teasing apart impairments that compromise different types of visual representation in neglect. In particular, we note the interesting contrast between R.R.'s pattern of reasonably intact exploration of space (as evidenced in letter cancellation and related tasks) and Karnath's (1994) report of impaired scanning of space in another patient with neglect. This is especially striking because Karnath's patient seemed to fixate individual objects normally whereas we have documented R.R.'s problems in fixating the left side of objects. Hence, it seems that eye movement studies support the distinction of within-object and between-object forms of neglect (Humphreys and Riddoch, 1994).

Turning to the issues surrounding the role of perceptual completion in object-based neglect, the possibility that a form of perceptual completion could be a factor involved in R.R.'s failure to realise that chimaeric stimuli are formed out of two separate objects was examined in Experiment 2. R.R. reported right half-shapes as whole shapes more often than he reported left half-shapes as whole shapes, which can be taken to indicate some form of perceptual completion. However, it was by no means perfect completion, since R.R. did not report right half shapes as wholes as often as he reported whole shapes as wholes. This showed that he was able to make some limited use of left side information, since the only difference between right half shapes and whole shapes was the presence or absence of the left side.

To interpret these findings correctly, our view is that it is necessary to think carefully about what perceptual completion might involve. At first blush, when R.R. reported a right half shape as a whole shape, it is tempting to conclude that he *saw* a whole shape. This would lead to the inference that when R.R. reported only the right half of a chimaeric stimulus, he also *saw* the chimaeric as if it were a whole formed from the right side and its mirror image. There are some anecdotes consistent with this in the literature; most strikingly, Young et al. (1992, p. 61) noted that when B.Q. was asked to show the contour of a chimaeric stimulus, she sometimes traced non-existent left side outlines by extrapolating from the right half of the chimaeric. However, Young et al. (1992) also commented that this was relatively unusual; it was more common for B.Q.'s tracing of the left side of chimaerics to be reasonably accurate, and she could

answer specific questions about features on the left if the experimenter pointed to them. Yet such prompting and interrogation did not lead to B.Q.'s identifying the left sides she had accurately traced or described. So it does not seem that these phenomena *necessarily* involved actually seeing a non-existent left side. Quite the reverse; even when there was evidence from contour tracing or specific questioning to indicate that the left side of a chimaeric was apparently seen veridically by B.Q., its identity could go unreported. Similar observations implying that accurate perception of left sides need not lead to insight into the nature of chimaeric stimuli were reported by Bisiach and Rusconi (1990) and Vallar, Rusconi and Bisiach (1994). Moreover, Halligan and Marshall (1994) noted that if their patient was asked to point to missing left-sided features in his drawings he did eventually acknowledge that he had failed to include them. As they note, if these phenomena reflect perceptual completion, then completion is not hallucination.

A sophisticated discussion of the various meanings of 'completion' has been given by Halligan and Marshall (1994). They noted that there are many different levels at which completion might take place in everyday life, ranging from filling in the blind spot, which is probably done perceptually (Churchland and Ramachandran, 1994), to knowing that space continues to extend behind your head, which is clearly conceptual. For present purposes, there are two main ways in which completion could have been involved in R.R.'s perception of right half objects. The first is the view that completion involved the brain's actively filling in the missing left side, so that the percept was of a whole object. The second possibility is that because R.R. largely neglected the left sides of seen objects, he would often incorrectly report having seen a whole object when a right half was presented simply because right half objects are not different from the right sides of whole objects. Thus apparent completion is really a form of ignoring left sided information; it is another consequence of object-based neglect, not its cause.

A similar debate regarding active filling in and ignoring has been made regarding the blind spot phenomenon in normal observers. At the blind spot, where there are no photoreceptors (because of optic fibres leaving the eye), normal people are usually unaware of any absence of vision. Dennett (1991) proposed that the blind spot region is not perceived simply because the brain ignores that region and represents it as being more of the background region. His suggestion was that the brain ignores the area that lacks a sensory input and forms a representation based on the surrounding area. The blind spot would then be represented as being 'more of the same'. Churchland and Ramachandran (1994), however, quote substantial evidence in favour of the alternative explanation; in their view, the brain does not ignore the blind spot, but instead performs an active filling in process so that the observer is unaware of sensory input from this region.

Although it may be an incorrect account of the blind spot, we think that Dennett's (1991) view that the brain can ignore a region of the visual field, resulting in the observers' impression of a complete representation, is consistent with the performance of R.R. with right half shapes and the other phenomena of object-based neglect we have discussed. The alternative view of completion,

that the neglect patient's brain actively fills in the contralesional side of a partial shape or chimaeric objects, is not demanded by the observed phenomena, and is clearly inconsistent with some of them (accurate tracing of left sides of chimaerics, etc.).

Whilst we may be correct in reasoning that this form of completion is simply a reflection of object-based neglect, this is undoubtedly not the last word on completion after brain injury. A reading of the literature shows that, though they are often conflated, at least two different types of phenomenon have actually been described. First, patients with hemianopias without neglect can report seeing a whole object when part of this whole object is presented into an otherwise blind region of the visual field (Poppelreuter, 1917; Torjussen, 1978). Torjussen (1978) examined this phenomenon using flash induced after images to stabilise the image on the retina. All of his subjects reported seeing whole figures as complete, yet none showed completion for half figures presented in their perimetrically intact half field. These patients also did not report seeing a half figure presented entirely in their hemianopic field, suggesting that residual vision is not the whole explanation of this type of completion. Torjussen (1978) thus demonstrated that people with visual field defects can deny seeing a stimulus projected in the cortically blind hemifield, but that when a whole stimulus was projected into both hemifields they appeared to see with their blind hemifield. He concluded that this form of completion of whole figures is due to inter-hemispheric interaction, whereby the presentation of a stimulus in the intact visual field can facilitate processing a stimulus in an otherwise hemianopic field.

This interaction between sighted and blind parts of the visual field is quite different to the second form of completion, which is what we have investigated here; it is shown by patients who incorrectly report seeing a whole shape when an incomplete shape was presented. Note that Torjussen's (1978) patients did not do this. Instead, the tendency to report incomplete shapes as being whole is closely related to parietal lobe damage, and can occur in the absence of a genuine hemianopia (Hornak, 1995; Poppelreuter, 1917; Warrington, 1962). Warrington (1962) examined completion in 20 hemianopic patients who viewed either whole shapes presented at fixation, or incomplete shapes presented in their intact visual field with the missing portion projecting into the field defect. Eleven of these hemianopic patients showed completion for half shapes, the other nine did not. The eleven patients who showed completion all had evidence of parietal lobe damage, and seven of these were reported as showing signs of visual neglect; only one patient who showed signs of neglect did not show completion. The presence of completion in Warrington's (1962) eleven patients with parietal damage was also found to be strongly correlated with the patients' lack of awareness of their visual field defect. All eleven of the patients who showed completion were unaware of their field defects. None of the patients who were aware of their field defects were found to be completers. Sergent (1988) reported a similar relationship between completion of partial shapes and parietal lobe damage. Four patients with parietal lobe damage completed partial shapes; one hemianopic patient without additional parietal damage did not.

In conclusion, we believe that R.R.'s failure to make contralesional saccades to scan the left sides of whole and chimaeric objects, and his tendency to report

tachistoscopically presented right half objects as whole shapes, were consequences of his object-based neglect and not the cause of it. Of course, this simply serves to deepen the mystery of how object-based neglect arises. But deep mysteries need not be insoluble.

Acknowledgements. This work was supported by MRC Grant G9201154 awarded to J.M. Findlay and A.W. Young.

REFERENCES

- BEHRMANN, M., and TIPPER, S.P. Object-based attentional mechanisms: Evidence from patients with unilateral neglect. In C. Umiltà and M. Moscovitch (Eds.), *Attention and Performance, XV: Conscious and Nonconscious Information Processing*. Cambridge, Massachusetts: MIT Press/Bradford Books, 1994, pp. 351-375.
- BISIACH, E., and RUSCONI, M.L. Break-down of perceptual awareness in unilateral neglect. *Cortex*, 26: 643-649, 1990.
- BUXBAUM, L.J., and COSLETT, H.B. Neglect of chimeric figures: two halves are better than a whole. *Neuropsychologia*, 32: 275-288, 1994.
- CHURCHLAND, P.S., and RAMACHANDRAN, V.S. Filling in: why Dennett is wrong. In A. Revonsuo and M. Kamppinen (Eds.), *Consciousness in Philosophy and Cognitive Neuroscience*. New Jersey: Lawrence Erlbaum, 1994, pp. 65-91.
- DENNETT, D.C. *Consciousness Explained*. Harmondsworth: Penguin, 1991.
- DRIVER, J., BAYLIS, G.C., GOODRICH, S.J., and RAFAL, R.D. Axis-based neglect of visual shapes. *Neuropsychologia*, 32: 1353-1365, 1994.
- DRIVER, J., and HALLIGAN, P.W. Can visual neglect operate in object-centred coordinates? An affirmative single-case study. *Cognitive Neuropsychology*, 8: 475-496, 1991.
- FOLSTEIN, M.F., FOLSTEIN, S.E., and MCHUGH, P.R. "Mini-Mental State": a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12: 198-198, 1975.
- GAINOTTI, G., MESSERLI, R., and TISSOT, R. Qualitative analysis of unilateral spatial neglect in relation to laterality of cerebral lesion. *Journal of Neurology, Neurosurgery and Psychiatry*, 35: 545-550, 1972.
- HALLIGAN, P.W., and MARSHALL, J.C. Completion in visuo-spatial neglect: a case study. *Cortex*, 30: 685-694, 1994.
- HORNAK, J. Perceptual completion in patients with drawing neglect: eye-movement and tachistoscopic investigations. *Neuropsychologia*, 33: 305-325, 1995.
- HUMPHREYS, G.W., and RIDDOCH, M.J. Attention to within-object and between-object spatial representations: multiple sites for visual selection. *Cognitive Neuropsychology*, 11: 207-241, 1994.
- HUMPHREYS, G.W., and RIDDOCH, M.J. Separate coding of space within and between perceptual objects: evidence from unilateral visual neglect. *Cognitive Neuropsychology*, 12: 283-311, 1995.
- KARNATH, H.O. Spatial limitation of eye movements during ocular exploration of simple line drawings in neglect syndrome. *Cortex*, 30: 319-330, 1994.
- NELSON, H.E. *National Adult Reading Test (NART): Test Manual (Revised)*. Windsor: NFER-Nelson, 1991.
- POPPELREUTER, W. *Disturbances of lower and higher visual capacities caused by occipital damage: with special reference to the psychopathological, pedagogical, industrial, and social implications*. Translated by J. Zihl. Clarendon Press, Oxford, 1917, 1990.
- SERGENT, J. An investigation into perceptual completion in blind areas of the visual field. *Brain*, 111: 347-373, 1988.
- TORJUSSEN, T. Visual processing in cortically blind hemifields. *Neuropsychologia*, 16: 15-21, 1978.
- VALLAR, G., RUSCONI, M.L., and BISIACH, E. Awareness of contralesional information in unilateral neglect: effects of verbal cueing, tracing, and vestibular stimulation. In C. Umiltà and M. Moscovitch (Eds.), *Attention and Performance, XV: Conscious and Nonconscious Information Processing*. Cambridge, Massachusetts: MIT Press/Bradford Books, 1994, pp. 377-391.
- WALKER, R., FINDLAY, J.M., YOUNG, A.W., and WELCH, J. Disentangling neglect and hemianopia. *Neuropsychologia*, 29: 1019-1027, 1991.
- WARRINGTON, E.K. The completion of visual forms across hemianopic field defects. *Journal of Neurology, Neurosurgery and Psychiatry*, 25: 208-217, 1962.

- WILSON, B., COCKBURN, J., and HALLIGAN, P. *Behavioural Inattention Test*. Titchfield, Hampshire: Thames Valley Test Co, 1987.
- YOUNG, A.W. Methodological and theoretical bases of visual hemifield studies. In J.G. Beaumont (Ed.), *Divided Visual Field Studies of Cerebral Organisation*. London: Academic Press, 1982, pp. 11-27.
- YOUNG, A.W., HELLAWELL, D.J., and WELCH, J. Neglect and visual recognition. *Brain*, 115: 51-71, 1992.
- YOUNG, L.R., and SHEENA, D. Eye-movement measurement techniques. *American Psychologist*, 30: 315-330, 1975.

Dr. R. Walker, Department of Psychology, University of Durham, Durham DH1 3LE, England, U.K. E-mail: Robin.Walker@cxwms.ac.uk.
Dr. A.W. Young, MCR Applied Psychology Unit, 15 Chaucer Road, Cambridge CB2 2EF, England, U.K. E-mail: andy.young@mrc-apu.cam.ac.uk.