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Blindsight and shape perception: deficit of visual consciousness or of visual function?

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Summary

Two people with homonymous right hemianopias were tested on a number of measures of non-conscious and conscious perception of shape in the blind field. Experiment 1 examined preparatory manual adjustments in grasping objects. Both subjects performed well above chance not only in three-dimensional location but also in preforming the hand to the shape, size and orientation of objects. In Experiment 2 single upper-case letters were briefly exposed in the blind field, and subjects made forced choices among 6 alternatives in the sighted field. Performance improved over blocks of trials and was above chance, but not dramatically. In Experiment 3 single upper-case words were briefly presented in the blind field, and subjects chose which of two words exposed after in the intact field was semantically closer. In Experiment 4 subjects had to give the meaning of single ambiguous words (e.g. BANK) presented both visually in the intact field and auditorily. Each ambiguous word was preceded by a single upper-case word briefly presented in the blind field, biasing each meaning on different blocks of trials (e.g. MONEY and RIVER). In Experiment 3, although results were in the appropriate direction, they were not consistently well above chance. By contrast, in Experiment 4 both subjects were consistently semantically biased to a high degree by words in the blind field. Experiments 2, 3 and 4 taken together suggest that indirect techniques (priming) are more sensitive to showing effects of non-conscious perception than direct ones (forced-choice). More importantly the experiments indicate that not only orientation but curvature, structural descriptions of component strokes and spatial ordering of letters are registered non-consciously in the blind field. Experiment 5 examined after-images in the blind and sighted fields, showing veridical conscious perception of shape in the blind field provided it was accompanied by a shape in the sighted field which together formed a good Gestalt. Experiment 6 showed conscious perception of illusory contours spanning the hemifields induced by Kanizsa figures. The experiments suggest that aspects of shape are much better perceived in blindsight than previously thought, that this is independent of their use in motor control, that the main deficit in blindsight is one of consciousness, and that the loss of conscious vision in the blind field is far from total. The effects and their relationship to those in other neuropsychological deficits suggest an intimate link between perceptual consciousness, attention and object perception.

Keywords: blindsight, consciousness, shape perception

Introduction

Blindsight is the name given to tacit residual visual capacities in a scotoma, such as discrimination and localization of visual stimuli that neurologial patients deny seeing (Sanders *et al*., 1974). It is often taken by psychologists and philosophers as a deficit of consciousness (Natsoulas, 1982; Dennett, 1991). It has also been traditionally studied as a deficit of visual function, especially with regard to the two-visual-systems hypothesis (Schneider, 1967; Pöppel *et al*., 1973), and data do show several functional deficits, e.g. in form and colour perception (for reviews see Weiskrantz, 1986, 1990). This raises several issues. (i) Is blindsight both a deficit of visual consciousness and (separately) of visual function(s), or basically a deficit of just one kind? (ii) Are any such deficits of function linked in an important way, causally or constitutively, to a putative deficit of consciousness? (iii) To what extent are reported empirical demonstrations of functional deficit in fact tied to ways of measuring that function? Of course, if a person cannot do something when it is measured in one way but can show the capacity in question when measured in another way, while normal people show the capacity, however it is measured, then that person does have a functional deficit—of putting the capacity to a certain use.

These were the questions which prompted the present research. The function in question is shape perception, in its several aspects (specifically shape perception in static vision;

for parameters of and evidence for the static/transient distinction in blindsight see Weiskrantz *et al.*, 1995). Shape or form is taken to mean various things. For example, Weiskrantz (1986) has shown that in his hemianopic field the subject D.B. can discriminate orientation well above chance and appears to use it to discriminate some forms such as X and O, but that he is poorer at discriminating other alphanumeric characters, very poor at discriminating curvature in the sides of triangles and almost incapable of discriminating rectangles of different ratios of long to short side when orientation cannot be unambiguously used. Some aspects of shape extraction and representation thus appear more preserved than others when measured by forced-choice discrimination. Yet it is possible that there are more appropriate or sensitive ways of measuring aspects of shape perception, and Weiskrantz (1990) has reviewed some of them. However, most of the techniques used so far in blindsight research amount to 'direct measures'. Direct measures are those in which subjects attempt to address themselves to that which is at issue, while indirect measures are those in which what is at issue is measured by its influence (e.g. priming) on some other nominally main task. In research on non-conscious perception, indirect measures are often found to be much more sensitive than direct measures (Milner and Rugg, 1992). The techniques used in the present studies include preparatory adjustments of the hand and wrist in grasping objects, orthographic and semantic forced-choice and priming, and induction of afterimages and illusory contours.

Before proceeding to these studies it will be helpful to return to the relationship between consciousness and perceptual function, since it relates to the interpretive underpinnings of the first study, which used motor adjustments to throw light on the perceptual information which guides them. Some authors link consciousness and function in particular ways. Goodale and Milner (1992) and Bridgeman (1992) dichotomize perception into that which is for the purpose of and coded for action and that which is conscious, and they constitutively link identification and recognition with consciousness. This may turn out to be valid, but appears to be a conflation of two distinctions that is not only unwarranted but is at odds with other data and approaches in psychology. In studies of visual masking (Marcel, 1983*a*; Cheesman and Merikle, 1985) stimulus representations of which subjects are unaware influence or prime the processing of other stimuli, suggesting non-conscious identification, but the presence of such non-conscious representations is not manifested as the basis for action or as involved in actions related to them. Few authors concerned with non-conscious perception propose that the only non-conscious representations are those involved in action, since it is supposed, perhaps wrongly, that conscious perception of the world is underlain by, and preceded by, a corresponding non-conscious perceptual representation, even if it differs in some respects from its experiential counterpart. It is one thing to show that unreportable stimuli can be effective in guiding motor control, i.e. as a measure of their perceptual processing; it is quite another thing to claim that this control of action is their only non-conscious representation, or to claim that identification and recognition are inseparable from consciousness. However, what is important is to consider a possible distinction between two kinds of non-conscious perceptual representation, one that underlies conscious perception and one that underlies or guides bodily action. It may well be that the former entails identification or recognition while the latter does not, that the former can be conscious while the latter cannot, or that the former is representational or intentional while the latter is not. This possibility is at least contained in the hypothesis proposed by Jeannerod (1994) which contrasts 'pragmatic' representation for action with 'semantic' representation for object recognition, both of which can be conceptualized as non-conscious. Also Milner (1995) has recently modified his position in this direction. Indeed it was Jeannerod's earlier work (1981) that inspired the first study.

Subjects

T.P., a right-handed female chief radiographer, suffered a left cerebral haemorrhage in March 1979 at the age of 50 years. A left temporoparietal haematoma was removed 4 days after her initial trauma. Two weeks later an angioma was removed from the left occipitotemporal region and the residual intracerebral haematoma was evacuated, removing most of the superficial area of occipital cortex, including that in the calcarine fissure. A CT scan carried out in 1980 was reported to show the above. Unfortunately the films are no longer available (due to Addenbrooke's Hospital policy of limited preservation). Initially T.P. had a dense right hemiplegia and a complete right homonymous hemianopia. The hemiplegia cleared quickly and completely, leaving no motor impairment; the hemianopia remained unchanged. She did have some reading and spelling problems (Hatfield and Patterson, 1983) which is how attention was originally drawn to her. She said that, although when she 'looked' she did not see anything in the right-hand part of her vision, she thought that she had visual images on the right and was anxious to know if that meant her vision might return, although she preferred not to think about it. Goldmann perimetry re-conducted in 1981 confirmed the homonymous hemianopia with the largest and brightest stimuli and revealed ~1° of macular sparing. However, when T.P. was experimentally tested with bright (>108.3 cd/m^2) targets that were very large (5°), she did show some detection at the bottom of the lower right quadrant when the central edge of the target was within 5° of the vertical midline. When she was asked to point to white circular stimuli against a black wall, after first demurring, her performance was remarkably good, markedly more so when she relaxed. This is what motivated further testing of her visual capacities. When she asked, she was told how well she had done, and it was this that induced her to participate in the experimentation. Towards the end of the testing reported here, she acknowledged that her normal vision would not return and preferred not to be tested any more. Although formal perimetry was not carried out again, nothing in T.P.'s comments or in her performance indicated that the extent of her blind field or vision within it changed significantly during the period of research.

G.Y. has been studied by several workers (Barbur *et al*., 1980; Blythe *et al*., 1987; Weiskrantz, 1990) and details are provided by Barbur *et al*. (1980). A road accident when he was 8 years old left him with an almost complete dense right homonymous hemianopia, except for an area of ~3° around the fovea (i.e. macular sparing) which has remained virtually unchanged, but with no other neuropsychological deficits. An MRI scan was published by Barbur *et al*. (1993). G.Y. knows about his visual capacities from what he has been told, and has become quite used to giving commentaries on his experience. For normally exposed static stimuli he insists that he does not 'see' them and has become used to guessing. However, if a target is flashed in the blind hemifield he reports for low illumination targets that they appear as 'a dark shadow', and for brighter targets that they appear as a localized flash. Testing for this project was begun when he was 24 years old. Both subjects gave their informed consent to participate in this study, which was approved by the MRC Applied Psychology Unit Ethics Committee, Cambridge.

Reaching and grasping as indices of visual shape perception

Experiment 1

The main evidence that blindsight patients retain coding of egocentric location of stimuli has not come from reports or forced-choice discrimination, but from their ability to point manually and fixate light sources falling in the blind field (see Weiskrantz, 1990). By the same token, one can use motor indices of shape perception. Jeannerod has, for some time (1981, 1994), successfully used preparatory adjustments of hand, wrist and arm in reaching and grasping of objects as reflections of perceived spatial aspects of visually presented objects in both normal and pathological subjects, the original inspiration for the present work being his 1981 paper. Since the present experiments were conducted, Goodale *et al*. (1991) have likewise used manual adjustments as an index of the visual perception of orientation that a neurological patient could not report. To examine shape perception it is necessary to use objects whose perceivable shape invokes differential manual postures in grasping them. As an initial foray it was decided to use cylinders and spheres of different sizes. The preparatory hand posture for graspable cylinders of different diameters tends to be fingertips in a line opposed to thumb with the wrist oriented parallel to the cylinder's long axis. Thinner cylinders tend to evoke the use of just the first two fingers aligned against the thumb, and cylinders <1 cm in diameter often evoke just the forefinger and thumb. The different diameters of graspable spheres evoke different preparatory grasping postures; table-tennis balls are grasped by the thumb and the first two fingers in triangular formation, while croquet balls are grasped by all fingers forming an arc which completes a circle with the thumb. In addition, the maximum aperture of the grasp prior to closure is usually suited to the size of the object. One can also take advantage of these adjustments to investigate a dimension of location that has not been studied in blindsight—proximity. Objects of different sizes project the same-sized retinal image at appropriately different distances. Therefore, while different sized spheres at the same distance should produce different preparatory manual postures, identical retinal projections at different distances raise the question of the relationship between deceleration of the forearm, as an index of perceived distance of target, and size and shape of the preparatory grasp, as an index of perceived size and shape of target object.

Method

The general design of the procedure was to record the preparatory adjustments of arm, hand and wrist in attempts to grasp objects located at different points both in two-dimensional space and in depth. Two kinds of object were used: spheres and cylinders. Each was of two sizes. In the main experiment their retinal angular projections were approximately equal at the two different distances used. The objects were made from UPVC (unplasticized polyvinyl chloride), the spheres were produced using a ball-turning bit on a lathe, and were painted matt white.

The subjects sat at a table on a chair which was adjustable so that the table was at waist height. An adjustable chin rest and, from the second session, a bite bar were used to hold the head steady in a comfortable position. The hand ipsilateral to the side of objects in a block of trials rested between trials on a pad on the edge of the table. When hand pressure on the pad was released, a relay recorded a pulse which enabled timing of the interval from opening of the eyes to onset of movement and from onset to termination of movement (see Procedure below). The subjects were trained to fixate a bright white spot at eye level 65 inches away in the midline. This spot was at the bottom of the lens guard of a zoom lens on a video camera (Prostab, IMCAP 11 Monochrome), which recorded fixation and eye movement. The table and surrounding background diorama were a uniform dark grey, as were curtains at the sides which occluded a technician, the objects to be used and recording apparatus. Since this study was carried out prior to acquisition of a Watsmart recording system, two other video cameras (ITC, CTC-5000) were positioned one above and one to the side of the space of arm movements, with their lenses calibrated to give equally scaled images of the space including the subject and target objects (see Fig. 1). The images from these two cameras were combined both by superimposition and by screen division via a video mixer (ITC Special Effects Amplifier, Model MEA 5100). This gave a three-dimensional picture of movements, wrist orientation, finger shape and maximal grasp aperture. Temporal calibration with eye fixation records

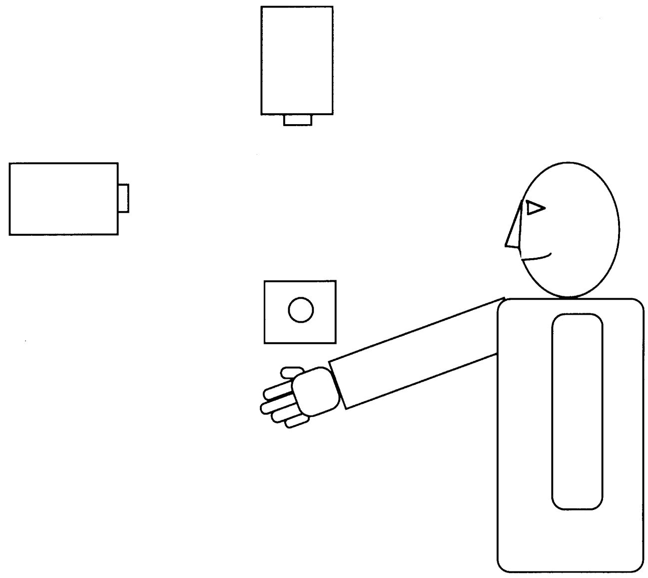


Fig. 1 Positions of videocameras in Experiment 1. The camera opposite the subject records fixation and eye movements. The cameras above and to the side record arm movements and hand shape.

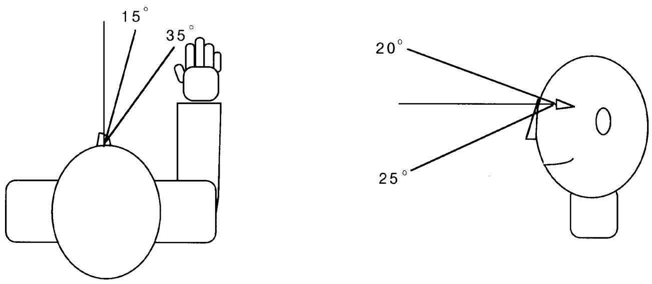


Fig. 2 Radial locations of objects in Experiment 1.

was achieved by vocalization of trial numbers on the audio tracks (see Procedure below).

White objects were positioned on each trial at one of eight positions (four in two-dimensional space and two in depth) in the blind field, and for control data at the equivalent locations in the sighted field (tested in separate blocks). These positions were at 14 and 22.5 inches distant from the eyes (marginally less from the shoulder), at 15° and 35° horizontally from the midline and 20° above and 25° below the horizontal plane (see Fig. 2). The objects were located by sheaths at their rear being fitted onto pre-adjusted stalks on retort stands positioned one per trial according to tape marks on the table. The retort stands and tape marks were painted the same dark grey as the table and diorama.

An initial experiment was conducted with spheres of 1.5 and 3.9 inches diameter and cylinders of 1.3 inches diameter × 6.0 inches in length and 3.75 inches diameter × 6.2 inches in length, where the cylinders were presented either horizontally or vertically. In this experiment ambient overhead lighting was low, and directional lighting was solely from an anglepoise lamp with a 60-W bulb positioned at the same distance from the objects as the subject, 18 inches distant and at 45° from the neck, on the same side as the stimuli. While good results were obtained from this, preparatory manual adjustments for size and arm deceleration for distance were somewhat less accurate than for other dimensions (see Results). First, the effect of the restricted lighting was to reduce depth information. Therefore the overhead lighting was increased in the main experiment. Secondly, by better controlling the dimensions of the objects, two other aims can be achieved. (i) If the visual angle projected by the small cylinder and sphere at the nearer locations equals that projected by their counterparts at the distant locations, one can assess the roles of distance information in size scaling or their independence. (ii) The projected area of at least one pair of cylinder and sphere at a given distance can be made equal, eliminating discrimination on the basis of gross differences in reflected light. One cannot do this for both large and small pairs without violating the first objective of equal visual angle for each of the types of object at different distances. Therefore in the main experiment, area was equalized for the large pair only. Of course, while all stimuli were front illuminated, the additional overhead lighting now provided slight shading cues distinguishing sphere from cylinder, though one would not necessarily expect blindsight subjects to be sensitive to them. The dimensions used in the second, main, experiment are shown in Table 1.

Procedure

Between trials the subjects closed their eyes; this was monitored on the eye-level video, both on-line and in later analysis. They also wore padded earphones throughout, to reduce auditory cues as to placing of objects, and through which they heard instructions. For blocks of trials on the right they used their right hand and the left hand was used for those on the left. Between trials they placed the hand on a pad on the edge of the table just to their left or right, which recorded the moment at which pressure was removed by initiation of the reaching movement. On each trial when an object was in place, the experimenter said 'Ready? Trial number *x*'. Subjects were instructed to open their eyes when they heard the trial number and fixate the spot on the lens guard in front of them. They were told that, in any particular block of trials, the objects would be on one side only and which side it was. They were asked to try to reach and grasp the object as normally as they were able, but to try to start the movement as soon as they could after opening their eyes. They were encouraged not to try to base their actions on what they thought the location and type of object might be. They were not told the proportional distribution of locations and object types. Any trial on which the gaze was off-centre or moved away from fixation, or on which the movement initiation was >1.5 s after fixation was established, was discounted and re-added at the end of a block of trials. After initial training, the subjects were very accurate in immediate fixation, which was straight ahead, and there were very few

Table 1 *Main Experiment 1: dimensions and subtended visual angles of objects at different distances*

	Dimensions (inches)	Projected area (square inches)	Visual angle(s) at 14 inches	Visual angle(s) at 22.5 inches
Large sphere	3.9 diameter	11.94	16.96°	10.4°
Small sphere	2.4 diameter	8.55	10.4°	6.13°
Large cylinder	3.0 diameter × 4.0 length	12	13° × 17.3°	8° × 10.6°
Small cylinder	1.85 diameter × 2.5 length	4.625	8° × 10.6°	4.9° × 6.5°

movement delays. The location, shape and orientation of objects were varied on a pseudo-random schedule with two constraints: (i) the prearranged number of trials per block of each combination of stimulus values, and (ii) no more than two values repeated on successive trials. Twenty-four practice trials were given, on which the subjects were encouraged to start slowly and then attain a comfortable speed as near normal as they felt able. In the initial experiment these were repeated for T.P. since she was less confident than G.Y. They were then given two blocks of 48 trials in their blind field with two blocks of 48 trials in their good field intervening. For the two values on each dimension of vertical, horizontal and depth location, and size there were equal numbers of trials, as there were for horizontal and vertical orientation of the cylinders. There were 16 trials with the spheres and 32 with the cylinders in each block. The investigator instructed the subjects and watched a monitor showing the subject's eyes. A time line on this monitor recorded initial movement of the subject's hand. Any obvious delay from fixation was perceptible but was checked later. A technician removed and placed objects between trials. The same procedure was employed in the initial and main experiments.

Analysis

The two video cameras together yielded a three-dimensional record of the hand and arm movements. Dividing the raster of the video film into its two half-frame components yielded 50 half-frames per second. For most trials, a frame-by-frame (25/s) analysis was adequate. Three people performed independent analyses (the investigator, an MRC research assistant and a paid member of the Applied Psychology Unit Subject Panel). These analyses consisted of separate scoring of each dimension with a strict criterion of unambiguously exactly correct, and then concordance across analysts. For all dimensions except distance the relevant data were those just prior to the grasp closure. The measures for size, orientation, shape and distance follow Jeannerod's (1981) measures adapted to video film. For vertical and horizontal location the hand had to be at the correct location in trajectory for grasp, not merely either side of the midpoint between them. For distance, the measure was the first deceleration of the wrist, such that if, for a far object, the wrist decelerated before the 14 inch position and then continued, or the opposite for near objects, it was counted incorrect. (This was the most laborious analysis.) For size, the measure was the maximal aperture between thumb and forefinger or second finger related to the respective object. For orientation of the cylinder, the measure was orientation of the wrist/thumb–finger aperture. For shape, the measure was shape of fingers opponent to thumb. For cylinders, the fingers formed an approximate straight line, though for the small cylinder the little finger, and less often the ring finger, sometimes bent in beyond the end of the cylinder. For the large sphere, the fingers formed an arc of a circle completed by the thumb. For the small sphere, most frequently for G.Y., the little and ring fingers bent in and the thumb, forefinger and second finger formed a triangle. On most trials these hand-shapes were easily distinguishable.

Results and discussion of Experiment 1

Both T.P. and G.Y. were initially reluctant to attempt to reach and grasp, G.Y. less so for he had already participated in research over a number of years and knew he had capacities that were not evident to him. Since T.P. was less confident, in the initial experiment the 24 practice trials were repeated, and another 10 were added for G.Y. An extra reason for this was that each of them early in practice reached for a distant location when an object was actually at a near location on the same trajectory, and contacted the object before their grasp was ready. Since the retort stands were not fixed to the table they were simply knocked and caught, and it did not hurt. Nevertheless it was a surprise, and both subjects resorted to cautious movements for several trials. Their ensuing performance restored their confidence.

It is important to note that during practice in the blind field for the initial experiment, both subjects on several trials initially fixated to the right and either corrected or did not, and on a few other trials initially fixated correctly and then moved their eyes to the right. After discussion of this both subjects were able to fixate accurately without correction (possibly due to macular sparing). In both experiments hardly any trials had to be discarded for these reasons (in the main experiment, six for T.P. and four for G.Y.).

Throughout testing, and in their comments afterwards, both T.P. and G.Y. insisted that they were guessing. They said that they had been apprehensive to start with, but had

Table 2 *Preparatory reaching and grasping performance in the blind field*

Stimulus Dimension	Stimulus Value	Trials (*n*)	Initial experiment		Main experiment			
			Percentage correct		Percentage correct		Percentage wrong*	
			T.P.	G.Y.	T.P.	G.Y.	T.P.	G.Y.
Vertical	Hi	48	69	69	77	81	4	4
	Lo	48	83	77	88	83	2	0
Horizontal	Central	48	96	71	94	85	0	2
	Peripheral	48	92	85	90	77	2	6
Distance	Near	48	73	60	83	79	4	6
	Far	48	81	69	81	75	8	10
Shape	Sphere	32	81	72	84	75	2	4
	Cylinder	64	88	81	86	83	2	0
Orientation	Horizontal	32	88	84	84	84	0	0
	Vertical	32	75	75	81	88	2	0
Size	Large	48	75	67	73	71	4	2
	Small	48	65	56	69	73	13	8

*Percentage wrong is the percentage of trials in the main experiment when performance on that dimension was appropriate to the wrong alternative, or 'value', not merely an imprecise attempt at the appropriate response.

relaxed and had not thought about what they were doing 'after a while', especially in the second (main) experiment.

Table 2 shows the results for T.P. and G.Y. for objects in the blind field, separately for the initial and main experiments. The results for the sighted field are not shown; they were >90% correct for all dimensions except size and distance of peripheral stimuli, where they ranged between 84 and 92% correct. For the main experiment only, Table 2 also shows the percentage of trials on which subjects' actions were appropriate for the wrong, alternative value on each dimension. Since the criterion for correctness was strict, it is only from this measure that one can assess bias or lack of perceptual information.

Although the principal focus is on the main experiment, it is worth comparing the two experiments with regard to (i) shape and orientation of the objects, since in the main experiment ratio of long-to-short axes of cylinders was reduced and the large cylinder and sphere projected the same area; and (ii) size and distance of the objects, since in the main experiment lighting provided better distance cues but visual angle was equalized for near small objects and far large objects. Concerning shape and orientation, performance was slightly better in the main experiment. Concerning object size, while T.P. showed no difference, G.Y. was more accurate. It is worth pointing out that as a cautious strategy it is better to use a wider grasp as a default, and the 'wrong value' scores for the main experiment do confirm this, though to a small extent. Taking both size and distance together, T.P. performed marginally better, and G.Y. clearly better, in the main experiment, suggesting that lighting cues to distance did aid performance.

Henceforth only the results from the main experiment will be considered. If one assumes that the subjects learnt the values on all stimulus dimensions during practice, which is to assume much, then chance performance would be 50% on each dimension except shape, where it is 33% for the sphere and 66% for the cylinder. This is very conservative, since the criterion for correctness on each dimension was much stricter than a dichotomy. Taking each dimension singly, subjects performed well above chance on all dimensions. On a binomial distribution all performances were significantly above chance ($P < 0.001$). T.P.'s grasp size on smaller objects and G.Y.'s on larger objects were less significantly above chance ($P < 0.01$). In fact, the percentages of trials on which their actions were suited to the wrong value/alternative (as shown in the 'Percentage wrong' column in Table 2), as opposed to failing to reach criterial accuracy, indicate that except for distance and size they were very rarely *categorically* wrong. The relative direction of errors on distance and size would seem to reflect the proportion of those trials on which a cautious strategy was used, e.g. 'decelerate in case the object is near and keep the grasp wide to allow for either object'. However, the video films show that on the vast majority of trials, especially in the second block, the reach and grasp was fluent and indistinguishable from that in the sighted field. Mean movement duration (from removal of the hand from the rest-pad to the grasp closure) for the far objects in the blind field was 1182 ms. for G.Y. and 1237 for T.P., and in the sighted field was 993 for G.Y. and 1042 for T.P. (These measures are not exact since, although movement initiation was electronically recorded, grasp closure was derived from the video film. However, frame-by-frame analysis yielded high agreement between the three analysts' marking of grasp closure, and complete concordance was necessary for a dimension to be recorded as correct on any trial.)

One can go further and examine the percentage of trials on which all dimensions of location were correct (chance = 12.5%) and on which all object dimensions of shape, size and orientation were correct (chance, for sphere = 16.5%, for cylinder including orientation = 16.5%). Completely correct performance for location was 74% for T.P. and 76% for G.Y. Completely correct performance for shape and size of spheres was 63% for T.P. and 71% for G.Y.; for shape, size and orientation of cylinders it was 60% for T.P. and 72% for G.Y. These are highly significant statistically, but well below perfect.

It is clear that both for three-dimensional location and for shape, size and orientation, perceptual information guiding actions was remarkably accurate. Almost all previous research on location in blindsight has examined only two-dimensional location. The present work shows that if measured by action, depth is also computed. Perenin and Rossetti (1996) have used a similar technique to the present one, and have also found good distance performance in reaching.

One thing that should be noted is that for both subjects on ~25% of trials, one or two dimensions of location were correct while the other(s) were not, and that on between 26% and 37% of trials one or two dimensions of object characteristics were correct while the other(s) were not. This may reflect either of two things. It may be that on such trials the dimensions that were correct were so by chance. Alternatively, it may be that non-consciously different features are analysed separately such that they can independently vary in success of analysis. While this is plausible for size, shape and orientation of objects, it is implausible for location, at least for vertical and horizontal dimensions.

The question arises as to how shape information was mediated. Weiskrantz (1986) reviewed all the work on form discrimination in the subject D.B., which used forced-choice discrimination. The many and careful studies led Weiskrantz to conclude that D.B. relied on orientation information to discriminate shape. Thus ‘O’ could be discriminated from ‘X’ as a default since ‘O’ lacked orientation, but a triangle and ‘X’ could not be discriminated and nor could triangles with straight and curved sides. Since Weiskrantz’s conclusions were only about research using forced-choice discrimination, they are neutral with respect to the present research using grasping. In the present study it is unlikely that spheres were discriminated from cylinders on the basis of the presence or absence of orientation information, since the total time from eye-opening to grasp was rarely >2 s; and since it was no longer in either subject for spheres than for cylinders, it is unlikely that the hand was shaped for spheres as a default for lack of orientation information. If this reasoning is valid, then the present performance is due either to differences between what is preserved in T.P. and G.Y. on the one hand and in D.B. on the other, or to the procedure used, or both. If such a difference lies in the procedure, then, as remarked in the Introduction, it is either because perception-action coordination is a more sensitive reflection of certain perceptual information or because certain perceptual information is separately coded for action and cannot influence, or be used for, forced-choice discrimination. From this experiment one cannot decide whether what was guiding motor control was the non-conscious counterpart of a conscious percept, or a representation dedicated to action and either unavailable to consciousness or underlying a different aspect of experience, e.g. bodily movement. The rest of the studies reported here use different techniques to address these issues.

An additional note is worth recording. Some time after this experiment was finished, G.Y. returned to participate in other research. We took advantage of this to explore a question raised by Daniel Dennett (personal communication). Both T.P. and G.Y. had denied seeing or knowing the shape of the objects they successfully grasped. Dennett asked ‘If a blindsight subject’s hand can be appropriately pre-formed to grasp differently shaped objects, could not that subject use or learn to use their manual posture before contact with the object, to indirectly perceive or infer the shape of the object?’. The ideal way of examining this would be by use of Jeannerod’s (1981) apparatus, whereby a virtual image of an object is seen, via a mirror, at a location different from its real one, thus pre-empting feedback from actual haptic contact with the object. Not having such apparatus, we simply performed the experiment as before but attempted to remove the object before G.Y. closed his grasp on it. On several trials he was too fast for us, almost producing a tug-of-war, and he obligingly slowed down. We took to saying ‘stop’ before he closed his grasp, as the object was removed. Out of 40 trials when his manual grasping posture was appropriate but he did not close on the object, he was only able to report his manual posture (in terms of object shape) on six trials, claiming that he found it difficult. Whether he would eventually learn with practice we do not know. However, it appears, and is consistent with work in motor control (Castiello *et al*., 1991), that motor adjustments that are not an explicit part of conscious intention are not readily accessible to consciousness, which is an interesting limitation on the contribution of reafference, kinesthesis and proprioception to bodily awareness.

Structural descriptions of strokes and letters

It would appear that, like D.B., T.P. and G.Y. have preserved orientation information. Many instances of the variety of what we call shape or form consist of particular combinations of orientations. Within classes of objects or forms what distinguishes the members are the structural descriptions of component orientations. Thus a ‘T’ and an ‘L’ are both composed of a vertical and a horizontal stroke. They are distinguished by the way and the location in which the strokes are conjoined. Indeed for all upper-case letters of the Roman alphabet, except for ‘N’ and ‘Z’, and ‘M’ and ‘W’, structural descriptions of the stroke shapes and combinations are unique independently of their orientation relative to the viewer's upright. D.B. discriminated 'T' from '4', and 'A', 'C', 'D', 'R' and 'S' better than would be expected by chance in his blind field but not as well as in his sighted field at greater retinal eccentricities (Weiskrantz, 1986).

It was decided to test the abilities of T.P. and G.Y. in discriminating upper-case letters. Structural descriptions of strokes composing letters differ from single strokes in ways that might be thought either to help or to hinder discrimination. On the one hand the additional information in a structural description or the combination of several strokes in a letter might overload the subject or degrade otherwise good discrimination. On the other hand, adding contextual information of strokes could help in either of two ways. Adding two surrounding parallel vertical strokes to a horizontal stroke and to an oblique stroke turns them into H and N, which have categorical descriptions as opposed to merely orientations. Further, it is often harder for people to respond on the basis of more analytic descriptions; we seem to have greater intentional access to high-level than low-level descriptions, even though the former consist of the latter (Marcel, 1983*b*). In perhaps the same vein, we have greater facility in perceiving words than individual letters, even though words consist of ordered permutations of letters. In the following studies, since both T.P. and G.Y. performed above chance with individual letters (see first experiment below), it was decided to 'push them to the limit' with visually presented words, requiring them to base responses on lexical rather than visual characteristics.

In these studies another factor was examined which has particular pertinence to measurement of non-conscious perception. It is usually found that indirect measures provide greater sensitivity to non-conscious information than direct measures. Indirect measurement examines the influence of the relevant information on a separate but related task, rather than asking the subject to report or base an intentional response on the information in question. This technique, often in the form of 'priming' has had great success with studies of perception in normal subjects and of neurological patients with a variety of apparent deficits (for several examples, see Milner and Rugg, 1992). Indeed Marzi *et al*. (1986) have found that, in some hemianopic subjects, faster detection responses were made to a flash in the sighted field when accompanied by an undetected flash in the blind field, thus showing non-conscious blindsight by an indirect measure.

In all the following three experiments, stimuli were presented in an Electronic Developments '3-field' tachistoscope. Fixation and eye movements were monitored as follows. In the lower field, an infra-red LED (light-emitting diode) was placed 3 inches from the eyes on each side of the viewing aperture; they illuminated the subjects' eyes adequately without being seen. A mini-videocamera (2.5 × 0.75 inches; Panasonic WV-CD1E) was mounted inside at the top of this field focused on the eyes, with its image relayed to a TV monitor and recorded on tape. In the tachistoscope the viewing distance is 20 inches.

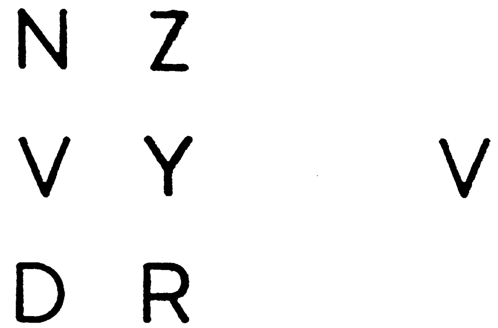


Fig. 3 Example of the stencil letters used in Experiment 2. A single letter is presented to the blind field, and a choice of six letters presented to the sighted field.

Experiment 2. Individual letters

Stimuli

The stimulus letters were taken from a stencil for which the MRC Applied Psychology Unit had empirically derived a confusion matrix (Poulton, 1968; Hull and Brown, 1975). Examples are shown in Fig. 3. Letters subtended 1.6° visual angle in height and up to 1.5° in width. Eighteen letters were chosen as stimuli such that they could be used in the following manner. After a black letter on a white field was shown, a choice of six letters (the choice letters) were presented in three rows of two. One row contained the target and a letter of a similar stroke composition (orientation of straight lines, curves) and structural description (relationships of strokes), one row contained two letters with stroke types and orientations similar to the target but dissimilar structural descriptions, and the other row contained two letters, both of whose stroke types, orientations and structures were different from those of the target. Figure 3 illustrates this for the target letter V. The complete set of stimuli and choices are shown in Appendix 1. The position of row containing the target and that of the target in its row were randomized over trials. Each single target letter was positioned with its centre 7° from the centre of the field, once in each hemifield.

Procedure

The experimenter monitored the subject's gaze throughout on a TV fed by the video camera as described above. The adaptation field with a central black fixation cross was kept illuminated between trials and was used for fixation and as a post-exposure field. Each trial was started when the subject said 'ready' and his/her gaze was fixated on the central cross. An auditory click was followed after 1 s by a 20-ms exposure of a single upper-case letter centred 7° either to the left or right of fixation, followed by a return of the fixation field for 1 s. The pre- and post-exposure fixation field was less bright (34.3 cd/m^2) than the target field (51.45 cd/m^2; measured using a SEI spot photometer) to avoid peripheral energy masking. Under such circumstances in normally sighted fields a 20-ms exposure is easily adequate, especially with visual persistence, for subjects to see and recognize a

Table 3 *Experiment 3: blind-field stimuli: forced-choice letter identification*

Run	Performance (number correct out of 18)[†]			
	T.P.		G.Y.	
	Letter	Row	Letter	Row
1	4	7	6	8
2	4	9*	7*	10*
3	7*	9*	9**	10*
4	8**	12**	9**	11*
Chance level	3	6	3	6

[†]Three rows of two letters per trial. *$P < 0.05$; **$P < 0.01$ (significance relative to chance level).

word consciously. The six choice letters were then exposed in the subject's sighted field for as long as needed, but the subjects were encouraged not to delay choosing. A block of trials consisted of 18 target exposures to the blind field and 18 to the sighted field in a pre-randomized order. The first block of 36 trials was used to familiarize the subjects with the procedure, in which on blind-field trials they had to use a different method of choice (i.e. guessing) than on sighted-field trials. The use of randomized sighted- and blind-field presentations was both to obtain a measure of performance in the sighted field and to dissuade subjects from moving their gaze from fixation. Any trials on which their eyes were not correctly fixated were discounted and replaced at the end of a block of trials. Stimulus and choice cards were pre-arranged in card-feeders before a block of trials. The subjects' responses were recorded by a second investigator who was ignorant of the stimuli (Dr Marie-France Beauvois). Four blocks of trials were given over the course of a day with no knowledge of results.

Results

Two of T.P.'s trials had to be discarded and replaced on each of the first two runs. For G.Y., one trial had to be discarded and replaced on the second run, also two on the third and one on the fourth run.

Table 3 shows the results for blind-field stimuli only. In the sighted field, G.Y. scored 100% and T.P. made two errors on each of the first two blocks of trials. The correct row would have been chosen six times by chance, and the correct letter three times. Blind-field performance, in choosing the correct row (with the target letter and one with similar strokes and structural description) was always better than chance for both subjects in any particular run, but it only became significantly so with later blocks of trials. Choice of letter also improved, becoming more significantly above chance with later blocks for both subjects (see Table 3). The fact that performance on choice of letter and row improved monotonically across blocks of trials for both subjects, though not statistically significantly, suggests that some information as to stroke type and structure of strokes is extracted, but that it is difficult for these subjects to put it to effective use in this procedure. The target letters correctly chosen were not consistent except for 'V', and included letters with curves: 'D', 'P', 'B', 'U' and 'C' were correctly chosen more than once by each subject.

In view of Weiskrantz's (1986) review of research on D.B., the question arises as to whether either of the subjects could have consciously seen enough of the letters in the blind field (e.g. orientation) to choose the letter from the choice set. It is difficult to judge this, but two points are relevant. G.Y. said that he did not see the letters but that he did feel at the time that some were 'jagged' and some 'smooth'. T.P. denied seeing anything and was clearly frustrated at what she was asked to do. The evidence is inconclusive, but suggests that seeing orientation consciously did not play a big role.

Experiments 3 and 4. Words

Experiments 3 and 4 will be treated together since they both use words and rely on their lexical status, and since the contrast in their results and implied sensitivity is instructive.

Words are obviously more visually complex than their constituent letters, not only because they consist of several letters but because their identity relies on spatially ordered permutations of letters. However, current models of visual word recognition (McClelland and Rumelhart, 1981) suggest that visual processing of constituent letters is aided interactively by the presence of neighbouring letters, especially if they form a familiar pattern. As indicated above, two other features of words make them suitable for use with subjects who have deficits of consciousness. First, their higher-level contextualized representation may make them more accessible or easier for a subject to make use of (Coslett *et al*., 1993). Secondly, they can easily be used for indirect rather than direct measurement. The visual descriptions of spatially ordered permutations of structural descriptions of letters amount to lexical addresses. If a lexical address is visually computed, then if the lexicon is sufficiently intact lexical priming may result. This would allow measurement of the effect of a word in the blind field on semantic processing of a word in the sighted field. Of course, if no such effect is obtained, one can infer little, since several stages are involved. The attempt was encouraged by the fact that appropriate stimuli had already been identified in the author's earlier work on non-conscious perception of visually masked words in normal subjects (Marcel, 1980, 1983*a*). The important difference between the two present experiments is that in the first experiment subjects were required to make a decision about the relationship of a word presented in the blind field to words in the sighted field, whereas in the second experiment the subjects were not required to pay any attention to the word in the blind field, only its influence on a sighted-field task was measured. The results and discussion of the two experiments will be presented together after each is described.

Experiment 3. Stimuli and procedure

This experiment required discrimination of the meaning of a word presented to the blind field. The procedure and luminances on each trial were the same as in Experiment 2, except for the nature of the choice required. The subject sat looking into the same tachistoscope, and gaze was monitored in the same way. Again, each trial started when the subject said 'ready' and his/her gaze was on the fixation cross. An auditory click was followed after 1 s by a 20-ms exposure of a word to either hemifield. The words were printed in the same upper-case stencil as used in Experiment 2, except that the size used subtended 1° visual angle in height and up to 5° horizontally. The central edge of the nearest letter was 6° eccentric to fixation. This was followed by a return of the fixation field for 1 s and then by two words one above the other in the sighted field. The two words were of roughly equal graphic similarity to the target word (Weber, 1970; Experiment 1, Marcel, 1983*a*) but only one was close to it semantically. The subject was asked to decide or guess which of the words was closer in meaning to the word that had just been presented. On half of the trials the correct choice was the upper of the pair, on the other half the lower. Twenty two words were exposed to the blind field, and 22 different words to the sighted field. There were three runs of 44 trials in all, over three days. The 22 words shown in the blind field, together with the corresponding choice words, are listed in Appendix 2. A different but similar set of words was used for the sighted field. Again Dr Marie-France Beauvois, who was ignorant of the stimuli, recorded the subjects' choices. T.P. preferred having the 'choice' words read to her as well as seeing them. The upper word was always read first.

Table 4 *Experiment 3: choosing a word semantically related to that shown in the blind field*

Run	Two-alternative forced choices (Number correct out of 22)	
	T.P.	G.Y.
1	15	16*
2	12	18**
3	15	15
Chance level	11	11

*$P < 0.05$; **$P < 0.01$ (significance relative to chance level).

Experiment 4. Stimuli and procedure

This experiment examined whether the meaning of a word in the blind field biased the meaning of a semantically ambiguous word presented in the intact field and auditorily. The temporal and display aspects of the procedure were the same as in Experiment 3. However, after the initial 1-s fixation, a single upper-case word was presented only to the blind field. Visual characteristics of these words were the same as in Experiment 3, except that four words subtended 6° horizontally. After the 1-s post-exposure return to the fixation field, a single word was exposed in the sighted field for as long as necessary, and at the same time was spoken. All the subjects had to do was to indicate its meaning as fast as possible, preferably verbally. They could do this in any way they chose. For example if the word was 'BANK' they could say 'money', 'safe', 'robber'. They were also given a pair of phrases on top of one another on a card to the side of the tachistoscope from which they had to indicate 'which phrase most nearly represents the meaning which first came into your mind'. They could use either method on each trial. T.P. preferred to use verbal indication, although she did look at the written phrases and pointed to the one that corresponded to what she said. The critical point of the procedure was that the consciously seen words whose meaning had to be indicated consisted of 24 polysemous (ambiguous) words, both homophonic and homographic, with as nearly equal frequency of alternative meanings as possible, plus 16 words with only one meaning. For the 16 non-ambiguous words the preceding blind-field exposure consisted of a neutral unrelated word, but for the polysemous words it consisted of a word which biased one of its meanings (Marcel, 1980). A full run consisted of two blocks of trials separated by 1 h. In one block half the polysemous words had their more frequent meaning biased, and the other half the less frequent meaning. In the other block the other meaning of each polysemous word was biased. There were three runs of two blocks over three days. The ambiguous words, their biasing words and the corresponding choice of definitions are shown in Appendix 3. Dr Beauvois again served as a blind experimenter, presenting the choice cards and recording the responses.

Results and discussion of Experiments 3 and 4

In Experiment 3 both T.P. and G.Y. claimed that they had to guess on most trials. However, G.Y. said after each run that he did sometimes feel that he was aware of something. After the third run T.P. also said that she felt something and felt forced to choose one word. In Experiment 4 neither subject said they were aware of anything in the blind field, but both spontaneously said that they assumed that they were being shown something.

The results for Experiment 3 are shown in Table 4, those for Experiment 4 in Table 5. The data are only shown for the critical stimuli. In Experiment 3 there is no convincing or consistent effect. Both subjects did choose the appropriate word more often on each run. T.P. chose correctly on nearly 70% of trials in the first and third run, G.Y. chose correctly on 73% of trials on the first run and 82% on the second run. But there was no control in the sense that they were never shown words in the blind field appropriate to the incorrect alternative. Only G.Y.'s choices on the first and second runs differed significantly from chance ($P < 0.05$ and < 0.01). In contrast, the results of Experiment 4 are clear-cut (see Table 5). The apprehended meaning of the word shown in

Table 5 *Experiment 4: biasing the meaning of ambiguous words by preceding words presented in the blind field*

Run	Number of trials with appropriate bias (out of 24)			
	T.P.		G.Y.	
	Less frequent meaning	More frequent meaning	Less frequent meaning	More frequent meaning
1	18**	16*	21***	19***
2	20***	16*	22***	19***
3	19***	15	22***	20***
Chance level	12	12	12	12

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$ (significance relative to chance level).

the sighted field was reliably biased by that of the preceding word in the blind field in 11 out of the 12 runs ($P < 0.001$ in eight runs; $P < 0.01$ in one and $P < 0.05$ in two). Furthermore, it was the less frequent meanings which were biased more successfully. It is difficult to give a reason for this, but predominant meanings of polysemous words are idiosyncratic.

Two important points can immediately be made. First, it would appear that, as in the study of Marzi *et al*. (1986), indirect measures are more sensitive than direct measures of information computed from the blind field. Even though subjects guess (or claim to) in forced-choice procedures (and we do not know what is involved in a 'guess'), in so far as subjects address themselves to the information in question in the blind field, such procedures are direct. Non-conscious information can better manifest itself by its unattended influence than by subjects' attempts to utilize it. Indeed, as Marcel (1983*a*), Weiskrantz (1986), Coslett and Saffran (1989) and Mandler (1994) have suggested, the manifestation of non-conscious information may even be hindered by intentions to use it or to base responses on it. Thus, the results of Experiment 4 imply that the techniques of Experiments 2 and 3, whose effects, though small, were consistently in the appropriate direction, may underestimate the visual information extracted from the blind field. The second major point, then, that emerges from this set of experiments is that the quite complex visual descriptions which underlie the identification of letters and words appear to be extracted non-consciously from the blind field, even if imperfectly. What is more, the effectiveness of the non-conscious representation of shape implicated in this set of experiments is not restricted to its involvement in the control of bodily actions. This suggests a tentative response to two questions raised in the Introduction. Even if T.P. and G.Y. have some functional impairment in visual shape- or form-processing, their primary deficit is one of visual consciousness.

Conscious vision in the blind field

It was suggested in the light of Experiments 2, 3 and 4 that there is indeed a deficit of visual consciousness in blindsight, whether this is linked to, or separate from, any additional functional deficit(s) of visual processing. A question that naturally arises is whether the loss is a 'total' loss of visual consciousness in the blind field. It is often assumed to be so, especially by those who discuss blindsight without carefully reading the literature or working with the subjects. One can immediately respond negatively to the question in two ways. First, at least G.Y. is visually aware of the presence of sufficiently large (5°) and intense light stimuli in the blind field if they are flashed rapidly, but only as 'a dark shadow' or a flash, not their shape. In addition, both G.Y. (Barbur *et al*., 1980) and D.B. (Weiskrantz, 1986) are aware of moving stimuli (though not their shape) if the movement is sufficiently rapid and especially if it is sufficiently retinally eccentric. Further, Zihl and von Cramon (1985) have shown partial recovery, in the form of variable extents of decrease of the area of the scotoma with training, whereby subjects were aware of form and colour of static stimuli in parts of the field which were previously blind. The second response to the question of total loss of visual consciousness is that those subjects whose comments have been invited and recorded, when their attention is drawn appropriately, report awareness of even static visually presented stimuli, but not always a *visual* awareness. Weiskrantz (1986) reports many such comments from D.B. describing 'a feeling'. G.Y. has also frequently reported 'feelings'. In the present Experiment 2 when he was asked how he chose letters, G.Y. said that he closed his eyes for a moment before looking at the choice-stimuli and sometimes got a 'jagged' or 'smooth' feeling. As he said this he moved his hand over his stomach much as patients do when indicating a pain. When I asked him if it was 'a gut feeling', he said that sometimes it was vaguely visual, sometimes it was just a feeling and sometimes he felt it in his body. When he was then presented with a series of 'O's and 'Z's in his blind field without being told what was being presented or being offered a choice, his reports of 'jagged' and 'smooth' on each trial did correspond to the appropriate letter on 16 out of 20 trials.

In none of the above instances was there an indication of 'normal' seeing of static stimuli in the (unrecovered) blind field. However, at the time that these experiments were carried out there were two such phenomena, where there is an awareness of stimuli in the blind field provided that appropriate stimuli are presented to the intact field. Torjussen (1976, 1978) exposed vertical semicircles to either one or both hemifields, very briefly in one experiment, and by a bright photoflash that yielded after-images in the other. Subjects experienced the shapes in their hemianopic field but only when there was a corresponding shape presented to the symmetrical part of the good field. The second relevant phenomenon was mentioned by K. H. Ruddock, V. A. Waterfield and J. L. Barbur (personal communication) and is briefly described by Weiskrantz (1986) and Ruddock (1991). They had used the induction of illusory contours by Kanizsa figures (see Fig. 6 below) with G.Y., by positioning two of the three inducing figures that form the points of a triangle in the sighted field and the third in the blind field. The triangular segment in the blind field either completed the illusory triangle or was rotated so that it did not. G.Y. could apparently say whether he saw a triangle or not. What is important in these two cases is that subjects were visually aware of the shape of static stimuli in their blind field. What is of theoretical interest is the nature of the interaction with stimulation in the intact field which produces such conscious vision. Experiments 5 and 6 were designed to replicate and extend these procedures and findings.

Experiment 5. After-images

Apparatus, stimuli and procedure

For generating shaped flashes of light, a box was built (see Fig. 4) to house a Metz Mecablitz System flash gun, model 36 CT-2, introduced at the rear. On full power its output is ~75 J, yielding a brightness in colour temperature of 5600 K. At 360 V the rise time of the flash is ~200 ns and while its decay is a function of the capacitor discharge, the total duration of the brightest flash is $<$3 ms. The outside of the box is matt black, the inside is white (to reflect light). The inner opening of the front of the box is 8.5 inches high$\times$10 inches wide, and is covered by a slightly recessed pane of totally transparent plain plexiglass. This holds in its centre the end of an optic fibre ~1 mm thick which, when a circuit is made from four 1.5-V batteries, gives an orange red light which serves as a fixation point, but does not illuminate around it. Surrounding the end of the optic fibre is a 1 inch disc of black-painted thin foam rubber. The edges of the front opening protrude to stabilize placement of close-fitting metal panels, which cover the entire front of the box and are painted the same matt black as the rest of the box. The panels have magnetic strips along the inside of the top and bottom edges which contact magnetic strips on the corresponding outer edges of the box opening. Each panel has a central hole in it to fit around and expose the optic fibre fixation light, and each has a different slit or slits 0.1° (1.8 mm) wide cut in it. The typical maximum eccentricity of the slits is 8° when viewed at a distance of 1 m, at which distance a chin rest was provided. The visual angles subtended by the slits were chosen on the basis of Torjussen's (1978) findings. The slits provide the shaped flashes to induce after-images; they are shown in Fig. 5. Each panel has a bevelled screw at two diagonal corners to hold a sheet of transparent plexiglass over it. This sheet prevents the subjects from seeing the slits before they are lit or in case they look at the box at inappropriate moments (without the ambient lighting turned sufficiently low).

The stimuli are shown in Fig. 5 (left-hand column). In each case the slit is shown relative to the fixation light. Although some stimuli are reasonably self-explanatory, it is worth clarifying the following. Stimulus 4 had the semicircles separated by 1° each side of the vertical midline to avoid cueing and any advantage due to double- or cross-innervation in the midline of the retina. In Stimuli 5 and 6 the semicircles were asymmetrically separated from the midline by 1° and 3°, the larger eccentricity being in the blind field in Stimulus 5 and in the sighted field in Stimulus 6. Stimuli 7 and 8 examine repetition as opposed to symmetry, where the pattern in the blind field in Stimulus 7 extends to just over 1° from the fixation point. Stimuli 9 and 10 examine asymmetric patterns, where the pattern in the blind field falls on the 'average' area of where the mirror-image of the sighted-field pattern would fall. Stimuli 11 and 12, which are presented together, are the equivalent of Stimulus 9 but falling in the blind field nearer to (11) and further from (12) fixation than that in Stimulus 9. Stimuli 13–24 examine continuation versus mirror-image symmetry and controls. Thus, Stimuli 13 and 14 present single oblique lines in the upper and lower quadrants of the sighted field, Stimuli 15 and 16 present their equivalents alone in the blind field. Stimuli 17 and 18 present combinations of Stimuli 13–16 as upper and lower quadrant symmetry, and Stimuli 19 and 20 do the same but as upper and lower quadrant continuation. Finally, Stimuli 21–24 each present a single line in both hemifields (at the averaged point of symmetrical eccentricity), but where there is no figural relationship in Gestalt terms.

The room was light-sealed and darkened to almost zero on a continuous dimmer. Each time they started, the subjects dark-adapted for 3 min. They sat at a table with their chin on a rest 1 m from the box front. On each trial, when the fixation light was extinguished the subjects looked slightly away, the light was re-illuminated and they returned their gaze to fixation and said 'ready'. At this the flash gun was fired. (Previously, using low lighting and a low-light video camera, it was found that this was a reliable technique to ensure fixation and maintenance of it for the flashes.) The panel and masking plexiglass sheet were immediately removed and the room lighting raised sufficiently for the subjects to draw what they saw on a fresh sheet of a pad kept by their hand. The subjects were told to draw what they saw including the relative position of the fixation light, and not to guess. They made one drawing as soon as they were ready. After 15–20 s they were told to blink, then look at a white surface and again draw what they saw, and after another

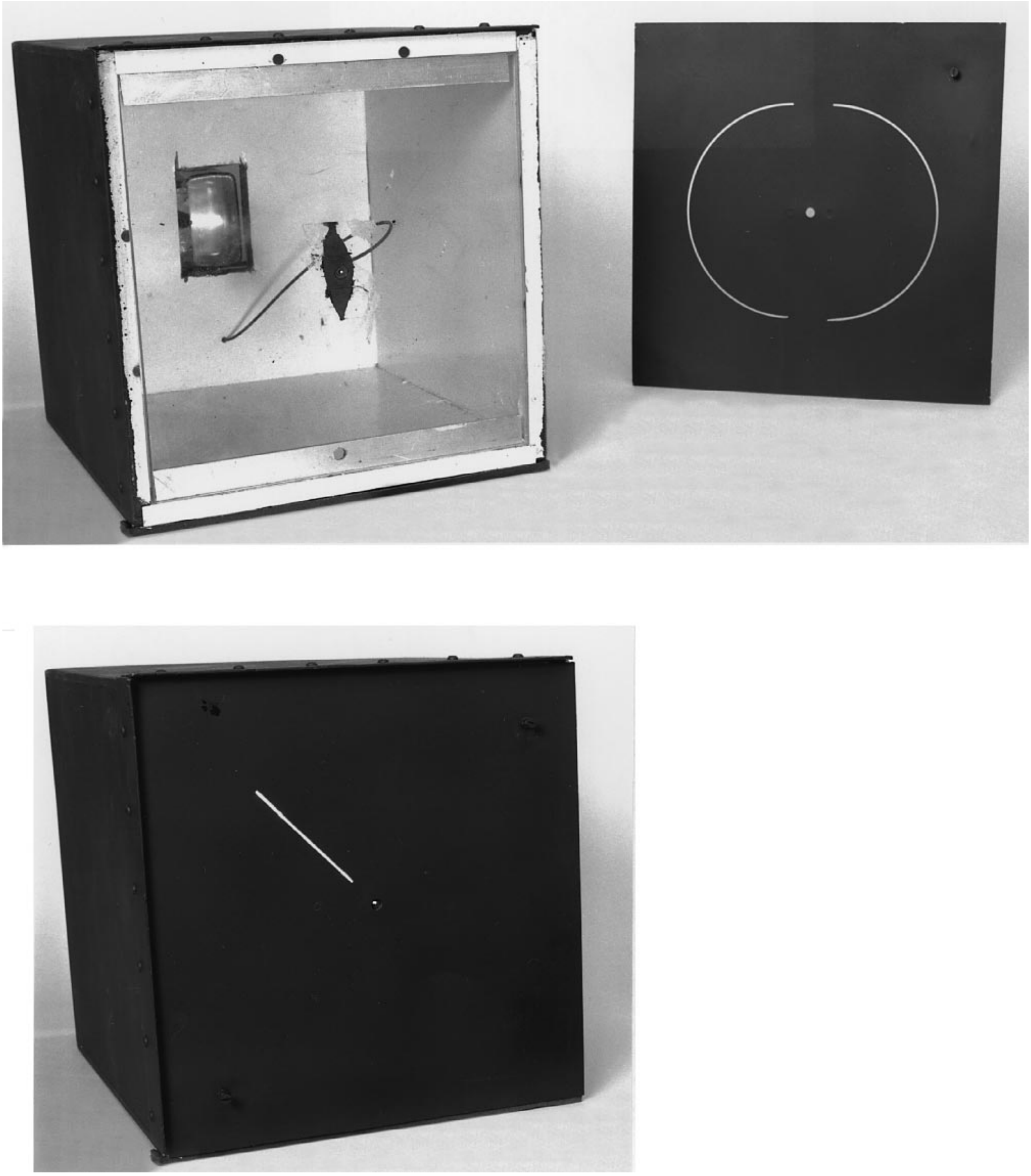
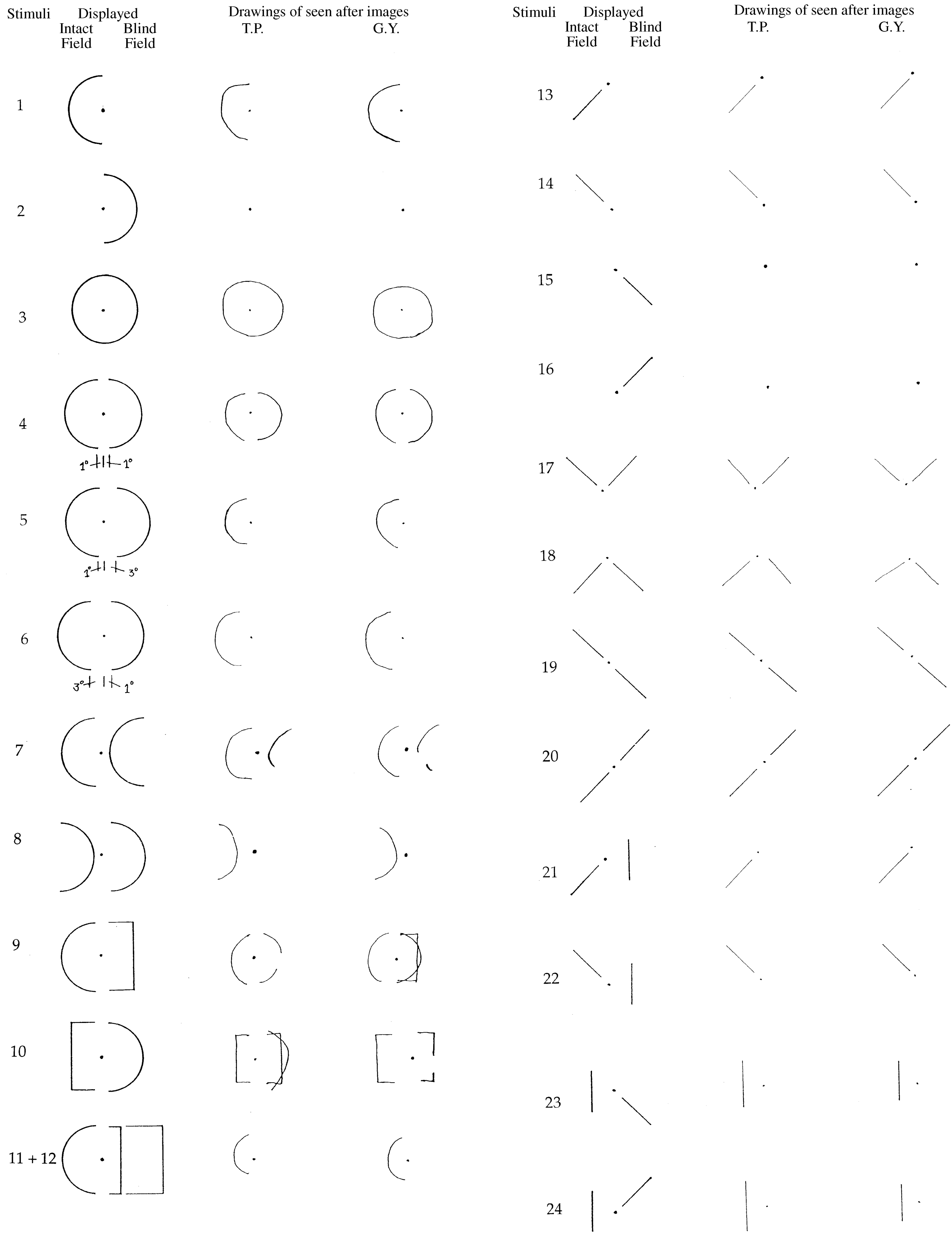


Fig. 4 The box and examples of front panels used to generate after-images in Experiment 5. The flash gun is at the rear interior of the box. The optic-fibre fixation light is held at the centre of the front opening. Panels with slits fit over the front opening.

20–25 s they were told to blink, look at a black surface and again draw what they saw. The whole series of patterns was presented three times on separate days, each time in a random order. Occasionally, if the subject was unsure, if fixation was not accurate (judged by the drawings), or if the subjects said they had blinked or were unready, the pattern was repeated later in the series. We found that even after a gap of 15 min an exposure could sometimes re-evoke the previous after-image. Therefore we left as much time as possible between trials, trying not to leave less than 15 min. This is why a complete series took a day, interspersed with other experiments.

After each trial, the subjects were asked for their comments, and at the end of each series were asked specific questions.


Stimuli
Displayed
Intact Field
Blind Field
Drawings of seen after images
T.P.
G.Y.
1
2
3
4
1° 1°
5
1° 3°
6
3° 1°
7
8
9
10
11 + 12
Stimuli
Displayed
Intact Field
Blind Field
Drawings of seen after images
T.P.
G.Y.
13
14
15
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They were asked if they were drawing what they saw or guessing, and whether what they saw on the left and right were the same or differed in quality in any way.

Results

There was essentially no interesting change in what the subjects drew in the three attempts at different delays following each presentation. Sometimes they found a white background better, sometimes a black background. Occasionally there appeared to be rapid fading, but they also sometimes obtained, even less frequently, a better after-image after the immediate drawing. What is important to bear in mind is that both subjects claimed to be drawing what they saw and denied guessing. Except for two patterns, Stimuli 9 and 10, they always said they were sure of what they saw. They both said that on almost all trials what they saw on the left and right seemed exactly the same in how it looked.

Figure 5 shows what each subject drew most frequently for each pattern over the three series of presentations. (Some of these results were published, with permission, by Weiskrantz in the 1989 Ferrier Lecture; see Weiskrantz, 1990.) In almost all cases each pattern gave the same result on all three presentations. T.P. was unsure of the blind field pattern of Stimulus 10 on two presentations and drew it correctly on the other presentation. G.Y. drew Stimulus 9 correctly on two presentations, and on one presentation drew a mirror image for the blind field (a semicircle) and then drew the correct square pattern over it. The results can be summarized as follows.

(i) What is shown in the sighted field is always seen correctly.

(ii) If there is a stimulus only in the blind field it is never seen.

(iii) If patterns are symmetrical across the hemifields they are seen completely, i.e. in both the blind and sighted fields, irrespective of continuity across the vertical midline.

(iv) If mirror-image patterns do not fall symmetrically in terms of retinal eccentricity, that in the blind field is usually not seen. Stimuli 5 and 6 were each drawn correctly on one presentation.

(v) Repetition (Stimuli 7 and 8) only yields conscious vision in the blind field if a part of the blind field pattern falls near fixation/the fovea. Stimulus 8 was seen once completely by G.Y.

(vi) Where the patterns in the two fields yield a ‘closed’ figure which is not mirror-image symmetrical but whose two halves fall on areas of symmetrical retinal eccentricity, the blind-field figure is sometimes seen accurately; sometimes there is ‘completion’ of the mirror-image of the sighted-field pattern and occasionally the subject sees both completion and in the blind field accurately, i.e. experiences in the blind field both a minor image of the sighted-field stimulus and the correct blind-field stimulus. (G.Y. said that he was unsure because he saw *two* shapes in the blind field but thought that there should only be one.) If such patterns do not fall on symmetrical eccentricities, that in the blind field is not seen even if it is close to the midline (Stimuli 11 and 12).

(vii) The two patterns do not have to form a ‘closed’ figure for that in the blind field to be seen, if they are symmetrical (Stimuli 17 and 18).

(viii) Most dramatically, continuation, with a gap, of two oblique lines from upper-left to lower-right quadrants and vice versa is sufficient to yield conscious vision in the blind field (Stimuli 19 and 20).

(ix) However, if the two stimuli form no coherent pattern, that in the blind field is not consciously seen (Stimuli 21–24).

Experiment 5 will be discussed together with Experiment 6 after the procedure and results of the latter have been presented.

Experiments 6A and 6B. Illusory contours spanning the sighted and blind fields

In the (unpublished) study by K. H. Ruddock and his colleagues of illusory contours from Kanizsa figures [see Weiskrantz (1986, pp. 135–6), for a brief description], G.Y. was only asked to respond ‘yes’ or ‘no’ as to whether the figure in the blind field completed a triangle or not; he was not asked whether he saw a triangle. Also, the inducing figures were arranged such that the triangle pointed upwards, with the triangular segment of the top inducing figure spanning the vertical midline. In the present study, Experiment 6A attempted to go further in three ways. First, the three inducing figures were oriented with two vertically aligned in the sighted field and one in the blind field midway between the others vertically, such that they formed a triangle with its vertex pointing horizontally (see Fig. 6). Thus, with the fixation point at a horizontal midpoint, no inducing figure spans the midline. Secondly, in the present study the subjects

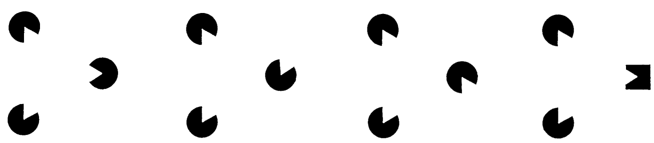

Fig. 6 Examples of Kanizsa inducing figures used in Experiment 6A. The inducing figure in the blind field (shown on the right) was a square on half of the trials and a disc on the other half. In both cases, on a third of trials the segment cut out of it pointed horizontally to complete a triangle, on the other two thirds of trials it pointed in two other directions: rotated 120° either clockwise or anticlockwise.

Fig. 5 Stimuli for after-images in Experiment 5, and the most frequent drawing out of three series made by each subject to depict what they had seen. For Stimulus 9, G.Y. twice drew two images for the blind field. For Stimulus 10, T.P. drew different images for the blind field. Stimuli 11 and 12 and their drawings are displayed together (see text).

were asked what they saw, rather than whether or not they saw a triangle. Thirdly, K. H. Ruddock (personal communication) reported that G.Y. said that he did not see the inducing figure in the blind field. In Experiment 6A here, the inducing figures in the sighted field were always black discs with missing segments; but that in the blind field was either a black disc or a black filled square of the same area with missing segments, each on half the trials (see Fig. 6). The subjects were asked on each trial not only to say what they saw, but whether the figure in the blind field was a disc or a square, guessing if necessary. In both cases the missing segment in the blind field figure was horizontally aligned on a third of trials, forming a triangle, or pointed at the two other orientations each 120° away from the horizontally aligned one on the other two thirds of trials (see Fig. 6).

Experiment 6A. Stimuli and procedure

The subjects sat facing a screen 8 feet away, on which the figures were front-projected from above their heads. Two slide projectors on top of one another were spatially co-ordinated. The temporal sequence were controlled by shutters in front of each lens which was moved by solenoids. A fixation point was continuously shown until each trial. The fixation point was at the horizontal midpoint between the vertex of the illusory triangle in the blind field and its (illusory) vertical base in the sighted field. The distance from base to vertex subtended 9.4° (4.7° in each hemifield). When a trial started, the subjects removed and returned their gaze to fixation and said ‘ready’. A re-settable voice key activated the projector control such that after a 100-ms delay, the inducing figure was projected for 150 ms, after which the fixation field returned. The pre- and post-exposure field was less bright than the inducing field (100 compared with 140 cd/m^2 at the eye). Fixation was not monitored because by this point it was clear that both subjects were good at fixation and were reliable in their reports, such that if they had moved their eyes, putting the blind field figure in the sighted field, their reports made it evident. Nevertheless, the point of the 150-ms exposure was to use a time that was short enough to lower the probability of eye movement while allowing enough time for induction of an illusory percept. Some training was necessary to achieve this, titrating from unlimited viewing to 100 ms, then using 150 ms. Thirty trials were given, 10 with the white segment in the blind-field figure pointing at each of the three orientations; on 15 trials the blind field figure was a square, on 15 a disc. On each trial the subjects were asked (i) to report what they saw in terms of any illusory figure, with which they had become familiarized over training; and (ii) to report or guess (saying which it was) the shape of the blind field inducing figure. During training it was found to be better to do the latter first since they had to guess, and any illusory percept obtained was not forgotten quickly. Two runs of 30 trials, each preceded by six warm-up trials, were given on separate days. The subjects were invited to make comments at any time. (The voice key was automatically de-activated after onset until re-set for the next trial.) After each set of trials the subjects were asked for their comments and asked specific questions about brightness of forms seen, their location and relationship to the background on each side.

Results

The results are shown in Table 6. Except for one trial, G.Y. never reported seeing a triangle when the blind-field inducing figure was inappropriate. When it was appropriate, he reported on eight out of 10 and nine out of 10 trials seeing a bright triangle extending across his visual field. It was difficult for G.Y. to describe a clear phenomenology for the whole figure. He said he sometimes inferred where it was relative to the fixation point. He said that the left-hand part was a brighter white than the background; but although the whole triangle was perceived as a continuous figure he could not say what the relationship of the right-hand part was to the background. However, he also said that he saw the right-hand part of the triangle ‘at the same place as the rest of it’.

Over the two runs, T.P. reported seeing a triangle on five out of 40 trials when the blind field inducing figure was inappropriate. But, although slightly less frequently than G.Y., she overwhelmingly reported seeing a triangle extending across her field when the inducing figure was appropriate (six out of 10 and eight out of 10). It seemed easier for T.P. to describe her phenomenology on these occasions. The triangle’s perceived relationship to the fixation point was veridical. She also said it often seemed brighter than the background on both sides, although on the right the background had no definite brightness. All of the triangle was seen as white. She said that the triangle was ‘out there’ ‘on the screen’ and seemed to be on top of, or above, something. It was evident that this experience made her excited and also worried.

Regarding the inducing figures in the blind field, both subjects said they never saw them. The number of correct guesses they made for each stimulus type (out of 15) is presented in the right-hand section of Table 6A. Their guesses reveal no access to, or influence of, any veridical discriminative non-conscious information. To summarize, it would appear that if a single figure can be constructed or induced that spans the area projected to the two hemifields, even if it is not bilaterally symmetrical, a conscious percept is achieved, or at least intentional reports can be based on it, while the individual figure in the blind field that plays a role in the induction of the percept remains at a non-conscious level and inaccessible to guesses as to its shape.

Experiment 6B

In Experiment 6A the segments in the black Kanizsa figures formed either a triangle or nothing, and the subjects knew this from the training trials. In such a situation a subject can view the display with a ‘criterial template’ in mind: ‘is it a

Table 6 *Experiment 6A: illusory contours from Kanizsa figures completing (or not) a triangle in the blind field, and discrimination of blind-field induction shape*

	Trials when triangle was seen (*n*)		Correct guesses (*n*)	
	Complete triangle	Incomplete triangle	Disc	Square
Trials per run	10	20	15	15
G.Y.				
Run 1	8	1	6	8
Run 2	9	0	4	7
T.P.				
Run 1	6	3	7	5
Run 2	8	2	9	5

triangle or not?'. Most perception of identity is concerned with the question 'what is it?' rather than 'is it an X?', and the former question demands more perceptual evidence than the latter. Therefore Experiment 6B attempted to use Kanizsa figures which always potentially induce one or other illusory figure rather than either inducing a figure or not.

The way it was achieved is illustrated in Fig. 7. The segments cut out of the discs in the sighted field (on the left) are the same in both cases. However, the position and shape of those in the blind field are not. In one case the whole figure induces an illusory hexagon; in the other case it induces an illusory pentagon. The hexagon is bilaterally symmetrical and the pentagon is not. Unfortunately this is only a small improvement on the former experiment; since there were only two illusory figures, subjects could use almost the same perceptual strategy with almost the same efficacy had they wished to and been able to.

This experiment was devised after Experiment 6A had been run, and unfortunately there was only time for a single session. The reason for this is that it was found that induction of the illusory figure required longer exposure times even after training, which were resisted because eye movements were not monitored. Eventually an exposure time of 250 ms was used. The procedure was exactly the same as in the former experiment, except that the inducing figures in the blind field were always discs and the subjects were not required to guess their shape. The hexagon subtended 12.8° horizontally, the pentagon subtended 10.4° horizontally.

Results

Table 7 shows the number of trials out of 10 that the subjects saw a hexagon or a pentagon when each inducing figure was presented. The results show that their percepts were significantly in accord with the inducing figures, though not as frequently as in Experiment 6A; but they never saw the inappropriate illusory figure. Both subjects said that they had not seen clear illusory figures on all trials. They said that they never saw the inducing figures in the blind field. Their other comments on the phenomenology of the illusory figures were the same as in Experiment 6A. Although this experiment is consistent with the former one, it was more difficult to induce the illusory figures, which is puzzling, since in the pentagon and more so in the hexagon there is more inducing information and the discs are closer together than in the case of the triangle.

Table 7 *Experiment 6B: illusory contours from Kanizsa figures in the blind field which completed a hexagon or pentagon*

Figure seen	Trials when figure was seen (*n*)	
	Hexagon presented	Pentagon presented
Trials (*n*)	10	10
G.Y.		
Hexagon	8	0
Pentagon	0	7
Nothing	2	3
T.P.		
Hexagon	9	0
Pentagon	0	7
Nothing	1	3

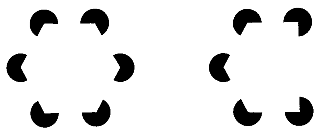

Fig. 7 Kanizsa inducing figures used in Experiment 6B.

Discussion of Experiments 5 and 6

The results of these two experiments raise several major points. The first point is that these procedures produce conscious vision of static stimuli in the blind field. The percepts experienced are veridical in the case of after-images and as veridical as those of normal subjects in the case of illusory contours. Concerning the latter point, Gellatly (1980) produced in normal subjects exactly the same effect as produced in the blind field here, i.e. when metacontrast masking was used around the discs, subjects saw the illusory triangle but were unaware of the inducing figures (the discs with cut out segments). In this sense (of what occurs in people with no neurological damage), the percepts in the present experiments were also normal. It could be argued that the method used to produce after-images is atypical of most vision: very fast onset of very bright stimuli. But that is the case for normal subjects also, and whatever mechanism or medium is responsible (non-striate cortex?) that mechanism is probably the same in the two populations and capable of producing conscious vision. In any case the method used to create illusory contours is in no sense abnormal. Further, both after-images and illusory Kanizsa figures are seen as located in the external world rather than experienced as retinal by normal subjects and the present subjects; they are percepts rather than sensations.

To the above extent then, even in the case of static stimuli, one can conclude that the loss of conscious vision in the blind field in blindsight is not total. One should add one note to this. Weiskrantz (1990) has described the present type of phenomenon as ‘completion’. The problem is that this term is often used to describe phenomena where the subject does not see veridically what is in the impaired hemifield or side, but completes what is seen veridically in the ‘good’ hemifield or on the ‘good’ side, or generates or infers a completion. This is not the case here. In the case of after-images the subjects saw *veridically* what was in the blind field irrespective of the particular figure in the intact field, so long as it made a ‘good’ figure. For Stimuli 17–20 in Experiment 5, the oblique lines in the blind field, no part of which was seen when presented alone, were veridically seen whether accompanied by a mirror-image or by a non-continuous alignment. In the case of illusory contours, the differential sensitivity in Experiment 6B to the type of closure in the blind field cannot be considered ‘completion’.

The fact of veridical conscious vision in the blind field also bears on issues of non-conscious perception, including that discussed in the Introduction. In Experiment 5, while nothing was seen if stimuli were only presented in the blind field (Stimuli 2, 15 and 16) these same stimuli were consciously seen veridically when accompanied by appropriate stimuli in the contralateral field. Further, as mentioned above, since what constituted ‘appropriateness’ could vary (Stimuli 9 and 10, and 17–20) and was not necessarily symmetrical, what was consciously seen in the blind field could not have depended *solely* on what was seen in the intact field. Therefore there must have been a veridical non-conscious representation of the stimulus in the blind field, which depended on the content of contralateral field percepts only for its becoming conscious. This conclusion seems inescapable.

One speculation should be discounted at this point. Conscious blind-field vision of shape in Experiments 5 and 6 might be thought to reflect the same mechanisms as G.Y.’s conscious vision of sufficiently rapid movement (Weiskrantz *et al*., 1995) or stimulus onset (Weiskrantz *et al*., 1991). It is tempting to associate the necessity, for conscious after-images in the blind field, of extremely fast onset of a large luminance difference, with the transience of such changes in conscious perception of criterially fast movement or onset. However, this cannot be adequate, since conscious blind-field perception of neither movement nor detection require appropriate stimulation in the sighted field, while shape perception does so. Further, in the production of conscious illusory contours across the fields, the luminance change was not rapid enough at onset or offset to be considered criterially ‘transient’. It must be recalled that the above-mentioned research producing conscious blind-field vision by stimulation restricted to that field has never produced conscious vision of static *shape*. Thus, conscious vision of static *shape* in the blind field appears to depend on different factors and mechanisms from that of movement or presence.

General discussion

To respond now to the issue raised in the Introduction, there is no reason to suppose that a non-conscious representation of the stimulus as implicated in Experiments 5 and 6, as well as in Experiment 4, is one that is only involved in action or motor control, or that it is involved in action at all. Such non-conscious representations, while not of objects, are of features of the external world and are the counterparts of those conscious perceptual experiences which one can report or which constitute the content of commentaries. In so far as this reasoning is valid, the dichotomy proposed by Goodale and Milner (1992) and Bridgeman (1992) is oversimple. That is, it is not the case that the only division is between conscious perception and that involved in action control. This has been recognized in Milner’s more recent (1995) paper. There is certainly a division between conscious and non-conscious representation (whether or not it is all-or-none). The logically putative distinction between two kinds of non-conscious perceptual representation, one that guides action and one that underlies perceptual experience, is a separate issue. The relevant evidence for the latter would be a double dissociation showing the independent presence of each without the other.

Experiments 5 and 6 also bear on the other question raised in the Introduction, that of a functional deficit in shape processing and how it is measured. On the basis of forced-choice discrimination, Weiskrantz (1986) speculated that form perception was radically impaired and that those shape discriminations that were possible were achieved on the basis of presence (or absence) of orientation. In the present set of studies one should be cautious in interpreting Experiment 1, since it is feasible, though it has been argued above to be unlikely, that hand-shaping for the spheres was based on absence of orientation plus presence of size information. In addition, it could be argued that the performance in that procedure is relevant only to action control. Although the results of Experiments 2 and 3 were only suggestive, those of Experiment 4 indicate that the shape and structural description of letters in words are represented sufficiently well to address an orthographic lexicon. It could be, though it is very unlikely, that for lexical addresses to be accessed in Experiment 4 only the oriented straight strokes of upper-case letters were registered ‘bottom-up’, the graphic identities of letters with curves being provided by an automatic interactive bottom-up and top-down process. However, this cannot be argued for Experiment 5, nor for Torjussen's (1978) study of which this was an extension. In these cases, curvature was seen accurately in the blind field and must have been processed, not only in the cases of Stimuli 2, 4 and 7, but also in the case of Stimulus 10 for T.P. Of course it does not follow that shape in these experiments was being processed by the means that might have been used had striate cortex been intact. But shape, in so far as it is implicated in Experiments 4, 5 and 6, *was* being processed. Indeed from the point of view of functional neuroanatomy, at least some of those extra-striate projections which remain intact must be capable of mediating some shape information, even if only by way of compensation.

A further issue on which especially Experiment 5, but also Experiment 6, bears is what underlies conscious perception as related to its non-conscious 'substrate'. What is it that makes the difference between perceptual representations in the blind field remaining non-conscious and their becoming conscious, in the sense of being experienced or of being reportable, and what does this say about the relationship in general?

There are two points relevant to these questions. First, what was necessary or effective for conscious vision in the blind field was that the relationship between the stimuli in the two fields was either a symmetry in retinotopic coordinates or their having joint figural properties in the Gestalt sense (Koffka, 1935) of forming a perceptual unity or whole, or the two properties together (as in the comparisons between Stimuli 4, 5 and 6; between 7 and 8; and 9 and 10 versus 11 and 12). To be specific, one can apply the approaches of Marcel (1983*b*) or Gregory (1970) which would characterize the process as follows. The non-conscious representation of the stimulus takes the form of a perceptual hypothesis, which is confirmed by its *consistency* with perceptual information in the other field. To the extent that it is confirmed by the presence of such consistency it becomes conscious. Of course this immediately raises the question of whether the perceptual information in the other field has to be itself conscious or merely present non-consciously. This would be settled by whether Experiments 5 and 6 would work in cases of *bilateral* blindsight.

There remains the issue of why, in Experiments 6A and 6B, the inducing figures in the blind field remained non-conscious, while the induced figure was conscious. Remember that Gellatly (1980), by differential visual masking, was able to render either the inducing discs non-conscious and the illusory triangle conscious, or the opposite. In the theory of masking as event perception (Marcel, 1983*b*), what is critical to what becomes conscious in perception is the segmentation of the field into events over space and time; especially in alternative figure–ground relationships one event becomes figural and focally conscious, which implies that the alternative event takes the role of ground and is less available to analytic consciousness while having 'ground' status. Further, such parsing is a function of attention. Now, in Kanizsa figures one only consciously sees the illusory figure if one also sees the black inducing figures as ground, with the illusory figure seen literally as on top of the inducing patterns; this is an entailment rather than a causal relationship. Seeing one as figure *is* to see the other as ground. In addition, the single figure formed by the illusory contours has a simpler perceptual description than the separate (unrelated) discs that would constitute the alternative figure. If the property of the blind field is that its potential for consciousness is more limited than in the normal state (of access to an intact striate cortex), then only one figure (the one affording the more economic description) will be conscious. This would account for the resistance to consciousness of the inducing figures.

The second point that is relevant to what differentiates conscious and non-conscious shape perception in the blind field is linked to the foregoing. However, it concerns the relationship between unilateral blindsight and simultaneous extinction in parietal lobe patients, and the properties of each in terms of (limited) attentional capacity. In Experiment 5, representations of stimuli in the blind field remained non-conscious if there was nothing in the good field that was in a symmetrical position or figurally related. In the phenomenon known as simultaneous extinction in parietal lobe patients these same factors are effective in aiding and in preventing conscious perception, one in reverse direction to here, the other equivalently. The general phenomenon is that if a single stimulus is presented on either side, it is consciously perceived; but if one is presented on the contralesional side at the same time as one on the ipsilesional side, then that on the impaired contralesional side is not consciously perceived, but is non-consciously represented (Bisiach and Vallar, 1988). Interestingly, Ward *et al*. (1994) have shown that if the two stimuli, one on each side, form a good Gestalt by symmetry or closure, then the vulnerable contralesional stimulus tends not to be 'extinguished' and both stimuli (or what is now the single 'figure') are consciously perceived. Thus, whereas in unilateral blindsight stimuli in the good field aid those in the impaired field to consciousness, in extinction the reverse is true, but in both cases bilateral figurally related stimuli produce conscious perception in the impaired field or side. (In blindsight this can also be true within a hemifield across a scotoma; and in extinction, although the relationship is lateral, it can obtain within as well as across hemifields.) To some extent, unilateral occipital damage and unilateral parietal damage produce opposite interactions, facilitatory versus inhibitory. However, in both of them the lateral effects on conscious perception are mitigated by figural unity. Although the role of attention has not so far been invoked in blindsight, it has been in extinction, especially in its relationship to neglect. Figural unity (reducing the number of separate perceptual objects) is just what should help perception if attention is abnormally limited, with one side being a weaker competitor. It is tempting to apply this conceptualization, in an extreme form, to blindsight. It has long been proposed, since William James in 1890 (see James, 1950, Vol. 1, Ch. 12), that attention and consciousness are intimately related. Cortical blindness with blindsight may be a disorder involving an attentional impairment, either (i) *due to* a loss of domain-specific (i.e. visual) consciousness or (ii) *producing* a loss of domain-specific consciousness.

The foregoing speculation links up with two questions which L. Weiskrantz (personal communication) has frequently raised informally. The first is whether subjects with blindsight are able to attend selectively within the blind field or scotoma. A blindsight subject can reach for, and move their eyes to, a single stimulus in the blind field, and can make some choices about it. Suppose there were two stimuli in the blind field. Could the subject attend to or respond to one of them *selectively*? What has been said above relates more to the limited capacity of attention than to selectivity. However, it suggests that, if unaided, the blind field is insufficiently parsed to provide a basis for selective attention when there is more than one target or dimension. Alternatively, intentional selective attention may require some minimal conscious representation if there are competing targets. The second, related, question is that of bilateral blindsight. Would the same effects obtain? For example, just in terms of the present studies, are the effects in Experiments 5 and 6 due to conscious perception of stimuli in the good field or merely due to bilateral stimulation or stimulation (conscious or not) outside as well as inside a scotoma? For neurological reasons bilateral blindsight, especially without compromising deficits other than cortical blindness, is extremely rare. However, cases have been tentatively recorded, but without the appropriate and relevant research. Indeed, one case (though possibly with complications) has recently come to the attention of the present author.

As a final comment on Experiments 5 and 6, the bilateral stimulation in intact and impaired fields that produced conscious vision in the blind field was simultaneous. A question for future research is the effect of positive and negative asynchronies of stimuli in sighted and blind fields. This question applies equally to extinction and neglect. This question is relevant to neural mechanisms as well as to psychological processes. For example, if stimulation in the sighted field precedes that in the blind field, will there be an advantage due to the temporal characteristics of ‘priming’ or a disadvantage due to temporal characteristics of inhibition or prior engagement of attention?

Links between blindsight and other neuropsychological syndromes are not restricted to the specific one made here. Weiskrantz (1988) has discussed the parallels with non-conscious memory in anterograde amnesia, and that parallel has been drawn with several other syndromes (Milner and Rugg, 1992). In connection with this, the relationship between other research on T.P. and that here is instructive. She was reported by Patterson and Kay (1982) as a letter-by-letter reader, with good but slow letter identification and no comprehension problem, but with a marked anomia which she could circumvent in conversation. In 1980–1, the time she took to read orally was 7.6 s for three- and four-letter words, 11.7 s for five- and six-letter words and 15.5 s for seven- and eight-letter words. Yet she scored 76% correct ($d' = 0.66$) on a lexical decision task with only a 500-ms exposure. The authors state ‘Most letter-by-letter readers have a right homonymous hemianopia, which means, in principle, that visual information is received only by the right hemisphere’. However, in a series of papers, Saffran and colleagues (Shallice and Saffran, 1986; Coslett and Saffran, 1989; Coslett *et al*., 1993) have shown that the shorter the exposure time and the more the patient can treat words as single semantic objects (as opposed to several single-letter objects), then the more evidence of non-conscious reading and comprehension is obtained. In the 1993 paper of Coslett *et al*., a patient with a dense homonymous hemianopia who was a letter-by-letter reader was given 250-ms exposures of single words, with pre-fixation at the word centre. His semantic categorization ranged between 85% and 100% correct. Unfortunately there were no recordings of eye movements; so one cannot estimate to what extent the stimuli were falling in the blind hemifield. The crucial points to emerge from this are that: (i) a number of letter-by-letter readers with right-sided hemianopias may have blindsight; (ii) several of them appear to be recognizing visually presented words non-consciously, but to be attempting to use consciously available but deficient strategies; (iii) they appear to have a problem in multiple object recognition in conscious perception, but not non-consciously, which is strikingly similar to what is proposed here for blindsight. An important point noted by Coslett and Saffran (1989) is that the less such patients try and the less they attend focally, the better they do. Exactly the same was found with T.P., especially in a psychological experiment on orientation and spatial frequency conducted principally by Arnold Wilkins, but not reported here. Trying seemed to have the effect of narrowing her attention and of preventing the manifestation of non-conscious representations. This is well illustrated in the contrast between Experiments 4 and 5.

Concluding discussion

These studies were started with several questions in mind. The first question, whether blindsight is a deficit of consciousness, can only be answered affirmatively if that of which subjects are not conscious can be shown to be represented non-consciously. Classically, what blindsight subjects lack awareness of in the blind field is a differentiated static perceptual field. That is, although they may be aware of sufficiently rapid movement, they are not aware of the static visual world articulated into figural forms. (The parameters distinguishing static and transient stimuli in blindsight have been quantified and the evidence presented by Weiskrantz *et al*., 1995.) In order to infer that such a static representation exists non-consciously, it is not enough to show that subjects can reach with appropriately shaped hands for objects of which they are not consciously aware. The reason is that such actions may depend on perceptual representations of form which enter only into movement control, not into conscious perception of forms, as in Goodale and Milner's (1992) or Jeannerod's (1994) conception. Action may not be a more sensitive measurement; it may be assessing the presence of something else. Although the present Experiment 1 suggests that blindsight subjects have sufficient shape information to grasp objects without groping (if enjoined to do so), nothing in these studies tells whether or not that information is the non-conscious representation of shape which underlies the conscious perception of shape. Jeannerod's (1994) argument for the non-identity of these representations is inapplicable because he states 'one has to assume first that the iconic representation, because it achieves the semantic processing of objects, can be accessed consciously, whereas the pragmatic representation is largely automatic' (p. 10). He assumes what needs to be shown. What is necessary is a double dissociation of non-conscious representations. However, the work of Castiello *et al*. (1991) cited in the discussion of Experiment 1 does suggest that the two types of non-conscious shape information are separate. Nonetheless the later experiments here do bear on the presence of a non-conscious representation that underlies conscious static object perception in these subjects.

Experiment 4 strongly implies that structural descriptions of letters, containing curves and oriented strokes, in spatially ordered permutations are veridically perceived non-consciously. Experiments 5 and 6 suggest that strokes and edges including curves, as well as corners and edges are veridically perceived non-consciously. If this had not been the case in Experiment 5, then the same stroke in the blind field would have been consciously perceived differently according to different shapes presented consciously in the intact field (Stimuli 9 and 10, and 17–20), and they were not so affected. These experiments, then, answer two questions. First, they imply that static shapes that are not involved in action are to some extent perceptually processed accurately and represented non-consciously. Secondly, by implying this they further suggest that a (the?) major problem is one of consciousness. Weiskrantz, while enthusiastic in promoting blindsight research has always been cautious in interpretation and inferring capacities. Yet he has seriously suggested and explored blindsight as a problem of consciousness. The present experiments may not be definitive, but they do appear to be entirely consistent with his interpretation.

One of the other questions raised at the outset was the extent to which supposed functional deficits of vision are tied to measurement procedures. It would appear that they are indeed heavily tied to ways of measurement. The techniques used here show differential sensitivity. In two essays, Weiskrantz (1990, 1995) has reviewed a wide variety of ingenious techniques which yield not always consistent answers as to the severity of deficit of a single capacity. Nonetheless, as indicated at the start, some of the differences in sensitivity of measurement *per se* imply a functional deficit. First, if a capacity can be manifested in less ways than in a normal subject, then that amounts to a functional deficit. Perceptual processing of shape, or of any perceivable feature, is not merely a passive sensitivity or an inert representation. Increasingly it is being shown that brain systems compute multiple perceptual representations for different purposes and different usages. There is no single perceptual property to be called 'shape'; rather there is 'shape for X' and 'shape for Y'. Further as both Weiskrantz (1988) and I (Marcel, 1988) have pointed out, no matter how well a perceptual property is non-consciously represented, people who are not conscious of that perceptual property do not use it in intentional action and even resist such use (although one cannot be confident about this characterization in humans until a bilateral case is investigated).

A further sense of the presence of a functional deficit in blindsight emerges from the answer to the final question raised in the Introduction. This is the question of the presence and nature of any link between a deficit of consciousness and one of perceptual function. In the preceding paragraphs shape perception and consciousness have been treated as separate. That is, while it has been argued that there is a deficit of visual consciousness, it has been argued that the non-conscious registration of aspects of shape measured by the present experiments is not severely deficient. However, the discussion of the relationship between conscious and non-conscious perception of blind-field stimuli in Experiments 5 and 6 appealed to an intimate connection between consciousness, attention and form perception. One aspect of perception of form, or of perceptual identity, is articulation and segmentation of the input or field. Particular segmentations amount to the articulation of forms. In Duncan and Humphreys' (1989) theory of visual search and attention, the first stage is one of segmentation: 'Parts that are to be described within the same whole must be linked together (Gestalt grouping) or, complementarily, boundaries must be drawn between parts that are to be described separately.' (p. 445). Focal attention is conceived to operate on these parts. These 'parts' are perceptual objects which have shape. Yet the very process which yields such figure–ground segmentation is itself attentional (Hochberg, 1970). In a busy field, to attend to one thing over another is frequently to make alternative groupings, as in structurally ambiguous figures or simultaneous speech in audition. Perceptual consciousness amounts to two things. The basic one is the capacity for having phenomenal content in a particular modality. The other is to experience a differentiated field in a modality. When a retinal image is stabilized one gradually loses the visual structure and it is eventually not subjectively evident that one is seeing at all; likewise if a 'Ganzfeld' is imposed on one's vision, such as a homogeneously lit half of a table-tennis ball over each eye. The proposal outlined in the discussion following Experiments 5 and 6 was that attention in blindsight is radically limited such that even a single stimulus only in the blind field (as in conventional perimetry) fails to achieve figural status. It can only achieve figural status if it can be treated as part of an already established figure, i.e. one established in the field of the intact hemiretinal projection. Such a functional process is what gives us conscious perceptual content. And this content consists, at least partly, in form or shape. To the extent that perceptual consciousness and perceptual attention are linked in such a fashion, then (insofar as blindsight as a deficit of consciousness is also a deficit of attention) blindsight is also a functional deficit. If perimetry were carried out with bilaterally symmetrical stimuli, one might (as the reverse of extinction) fail to find a visual field defect.

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Appendix 1 *Experiment 2: the single letters exposed in the blind field, each with its six choice letters*

V	N	Z	M	O	D	R	P	R
	V	Y		K	X		A	D
	D	R		M	W		U	V
U	L	E	H	E	R	P	K	E
	Q	D		U	D		S	Z
	U	J		H	N		D	P
T	C	D	L	L	I	X	F	T
	T	Y		K	R		B	S
	E	L		S	G		X	K
O	D	B	N	X	Z	D	X	K
	C	O		H	N		M	N
	T	X		I	Y		P	D
W	M	W	B	E	P	K	E	Z
	D	O		B	S		X	K
	X	K		V	X		Q	G
C	C	O	Z	N	Z	Y	Y	V
	D	S		S	B		P	F
	V	H		V	Y		H	N

Appendix 2 *Experiment 3: words shown in the blind field each with its two choice words for semantic similarity*

Blind field stimulus	Two-alternative forced-choice stimuli
TREE	VIOLIN, FOREST
UNDER	PEEL, OVER
APPLE	FRUIT, DRESS
NURSE	BRIDGE, DOCTOR
HORSE	PONY, POOL
SLEEP	RULER, DREAM
LAMB	SHEEP, DRESS
CHURCH	TARTAN, PRIEST
STARS	MIND, MOON
CATS	DOGS, FOOL
BIRD	ROBIN, COURT
BABY	CHILD, FIELD
FEAR	WANDER, AFRAID
FAST	BOOK, SLOW
SWEET	BITTER, NOTICE
CHAIR	WEEDS, TABLE
LIGHT	CARD, DARK
TAKE	GIVE, MASK
GRASS	GREEN, STEAM
FACE	POST, NOSE
BUTTER	BREAD, CLASS
COLD	FROST, POINT

The choice words are equally graphically similar to the target word on Weber's (1970) Index of Graphic Similarity.

Appendix 3 *Experiment 4: ambiguous words to be defined, with corresponding biasing stimuli and choice definitions*

Biasing stimuli shown in the blind field	Ambiguous words shown in sighted field	Choice of definitions displayed later
HEAVY, DARK	LIGHT	SMALL WEIGHT, LAMP
NEGRO, SPEED	RACE	COMPETITION, HUMAN TYPE
FIRE, CARDS	POKER	GAME, FOR STIRRING FIRE
INCH, TOE	FOOT	MEASURE OF LENGTH, BOTTOM OF LEG
DANCE, THROW	BALL	ROUND TOY, LARGE DANCE
LEG, COW	CALF	BELOW KNEE, YOUNG COW
FRUIT, TIME	DATE	DAY OF MONTH, STICKY FRUIT
GOLD, YOURS	MINE	MY POSSESSION, FOR COAL
BELL, CIRCLE	RING	ROUND BAND, TINKLING SOUND
TREE, HAND	PALM	TYPE OF TREE, PART OF HAND
MONEY, RIVER	BANK	GROUND BESIDE STREAM, TO KEEP CASH
VAMPIRE, BALL	BAT	FOR HITTING BALLS, FLYING ANIMAL
TRAFFIC, SWEET	JAM	ON TOAST, BLOCKAGE
HEAD, CHURCH	TEMPLE	RELIGIOUS BUILDING, SIDE OF HEAD
HOUSE, SMOOTH	FLAT	LEVEL, PLACE TO LIVE
SHIP, ANGRY	STERN	BACK OF BOAT, SERIOUS OR HARSH
WALRUS, SHUT	SEAL	CLOSE TIGHT, ANIMAL WHICH SWIMS
FLOWER, LIGHT	BULB	GIVES LIGHT, FOR GROWING PLANTS
CUT, LOOK	SAW	PERCEIVED WITH EYES, CUTTING TOOL
BIRD, FOOD	SWALLOW	EAT, BIRD
LIGHT, WOOD	BEAM	TIMBER, RAY OF LIGHT
WATER, HIT	TAP	STRIKE GENTLY, FOR LIQUID
BOX, BODY	CHEST	BREAST, CASE
SKIN, CONCEAL	HIDE	ANIMAL SKIN, MAKE INVISIBLE