The study of blindsight has, quite naturally, focused on the properties and basis of the visual function which remains in the condition despite subjects' lack of acknowledged visual awareness. In the course of testing one hypothesis about the basis of residual visual function in blindsight, we made a serendipitous discovery which prompted us to examine the role of some basic cognitive functions in blindsight—alerting and attention.

Campion et al. (1983) suggested that blindsight may be mediated by 'islands' of spared striate cortex rather than subcortical systems or pathways that bypass primary visual cortex. Variations in the effects of loss of blood or oxygen supply to an area of the brain, which could potentially leave undamaged islands, might, for example, be a consequence of the pattern of blood vessels in the region or variations in neural metabolic activity. The fact that residual visual function could be found throughout the scotoma of blindsight subjects appeared to be at odds with this explanation. It was, however, suggested that eye movements during testing may fortuitously bring stimuli to lie in retinal locations corresponding to islands of spared cortex sufficiently often for residual function to appear continuous across an extensive scotoma. A subsequent paper by Fendrich et al. (1992) lent considerable credence to this account. They found a subject in whom neuroimaging revealed a single island of spared cortex within an extensive cortical lesion. The patient reported that he was blind throughout his scotoma; however, Fendrich et al. found that he could perform a simple visual task within a very small region of the visual field within his scotoma. They surmised that this region corresponded to the island of sparing shown in the MRI scan. In order to accurately maintain stimulation of the same retinal, and hence cortical, locations across many trials during their perimetric testing, they used a technique in which an eye tracker is used to measure the direction of eye gaze and the image projected onto the eye is continually adjusted to compensate for any eye movements. The fact that their subject performed a visual task successfully while denying visual awareness conforms with the definition of blindsight, albeit blindsight restricted to a very small region of the visual field. The question that obviously arises from this finding is could a collection of such islands, an archipelago perhaps, account for the spatially extensive blindsight reported in such subjects as DB and GY? Larry Weiskrantz posed this question at a talk he gave inaugurating the Centre for Vision and Visual Cognition in Durham. As there was a variety of eye-tracking facilities in Durham, it seemed natural that we should collaborate in answering the question.
As we go on to describe, this collaboration has continued to develop as a succession of new questions about blindsight arose.

Fendrich *et al.* used image stabilization techniques to allow them to reveal a single, small, isolated island of residual visual function within a scotoma. Together with Weiskrantz, we set out to use similar methods to establish whether residual function in GY was restricted to a series of islands of spared vision (Kentridge *et al.*, 1997). We reasoned that if we selected a set of arbitrary locations within GY's blind field, we would be very unlikely to find spared vision in all of them if GY's blindsight depended on islands of spared cortex. We used stabilization methods and stimuli similar in size to the ones Fendrich *et al.* (1992) had employed. Although we initially found blindsight in only eight of the 15 locations we tested, when we went on to investigate whether the stimulus parameters we were using were optimal for discrimination without awareness in GY we found evidence for blindsight in all but two of the locations we retested (we performed these additional tests in eight of the original locations, six of which had not supported discrimination without awareness using the original stimulus conditions). We concluded that GY's blindsight could not reasonably be explained in terms of patches of spared cortex. Our experiment could not, however, rule out an explanation couched in terms of some diffuse incomplete damage to primary cortex. The results of neuroimaging experiments on another patient with spatially extensive blindsight, FS, militate against such an explanation. Stoerig *et al.* (1998) found no changes of activity during functional magnetic resonance (fMRI) imaging of the damaged visual cortex of FS after presentation of visual stimuli, whereas changes did occur in extrastriate cortex. The fact that a change could be detected in extrastriate but not striate cortex suggests that it is unlikely that the extrastriate activity depended upon an active, but partially damaged striate cortex projecting to extrastriate regions. Stoerig *et al.* (1998) used a range of analytical methods to detect activity changes with abnormal time-courses, but nevertheless failed to find evidence for islands of sparing, yet the spatial resolution of their images was sufficient to resolve stimulus-dependent changes of extrastriate activity in volumes of the order of 5 mm³. The evidence from our image-stabilization study with GY and Stoerig's neuroimaging results from FS suggest that blindsight in patients with spatially extensive residual vision does not depend on sparing in the geniculostriate pathway. At the same time, however, Gazzaniga's group had found islands of residual visual function without accompanying awareness in a number of additional patients (Wessinger *et al.*, 1997). The implication is that residual visual function without awareness can be mediated both by an extensively, but incompletely, damaged geniculostriate pathway and by parallel pathways which bypass a completely dysfunctional striate cortex. If this is the case, however, we need to ask why residual function in patients with isolated patches of spared cortex is restricted to areas of the visual field corresponding to those islands. Why can they not make use of the pathways which bypass striate cortex, which we assume mediate blindsight in GY and FS, and which must allow animals with striate cortex lesions to perform visual tasks?

A number of characteristics might distinguish between patients with isolated islands of spared function and those with extensive blindsight:

- the location and extent of the lesion;
- the age at which the lesion was acquired;
ATTENTION AND ALERTING: COGNITIVE PROCESSES SPARED IN BLINDSIGHT

- the stimulus parameters used to test for residual vision;
- the amount of testing the patient has experienced.

Variability in these factors may all contribute to the relatively small proportion of hemianopes in whom blindsight, either spatially extensive or localized in islands (Weiskrantz, 1980; Blythe et al., 1987; Schäli et al., 1999), has been discovered. In studies of human neuropathology it is not possible to locate the region of damage precisely and the resolution of the functional and anatomical imagery available varies greatly between studies. These factors can, of course, be well controlled in animal studies. Such studies have revealed a variety of differences in residual visual function following striate cortex lesions dependent upon the age at which the lesions occurred. Payne et al. (1996) review such differences, and suggest that they may be due to latent flexibility in the developing visual system. We chose, therefore, to investigate one specific finding which might clarify whether a patient with spatially extensive blindsight shared abilities typical of animals with early brain damage.

Moore et al. (1995) found that monkeys’ ability to discriminate the location of visual targets within areas corresponding to cortical lesions induced in adulthood was improved from chance if a warning signal in an undamaged area preceded the presentation of stimuli. By contrast, infant-lesioned monkeys performed the same task well above chance without the need for a temporal cue (Moore et al., 1996). By assessing the effect of temporal cues on GY’s ability to discriminate target locations in his blind field, we hoped to discover whether his blindsight resembled the abilities of early-lesioned animals.

Our experiment is reported in detail in Kentridge et al. (1999a). In this section we summarize the task and present some extensions to our original analysis and conclusions. GY’s task was simply to identify in which of two locations in his blind field a target was presented. He was also asked to make a second response on each trial, indicating whether he had any awareness of the occurrence of a target, regardless of its location. Each trial lasted for 10 seconds. Information about the approximate time at which a target might be displayed could be presented by brightening the central fixation cross, which, being within his region of macular sparing, he saw normally. Cues were provided on only 50% of trials. We provided these cues at four times relative to the presentation of the target, 1.5 or 0.5 seconds before or after the target. We found no differential effects of the 0.5 and 1.5 second delays and hence all our analyses simply compare conditions in which the cue precedes the target with ones where it follows the target. If GY’s blindsight was not optimal without cues, then we expected that his discrimination of target locations would be better when the cues preceded the target than when they followed. In order to assess the validity of the commentary key responses, in 20% of trials no target was presented. There were therefore five cue–target delays including the no-target condition. We provided these cues at four times relative to the presentation of the target, 1.5 or 0.5 seconds before or after the target. We found no differential effects of the 0.5 and 1.5 second delays and hence all our analyses simply compare conditions in which the cue precedes the target with ones where it follows the target. If GY’s blindsight was not optimal without cues, then we expected that his discrimination of target locations would be better when the cues preceded the target than when they followed. In order to assess the validity of the commentary key responses, in 20% of trials no target was presented. There were therefore five cue–target delays including the no-target condition. We provided targets of three contrasts (93%, 43%, and 22%), both to investigate whether the effectiveness of cueing was influenced by the extent to which targets gave rise to non-visual awareness and in order to avoid floor or ceiling effects in GY’s discrimination performance from hiding any influence of cueing. We separately repeated the experiment in GY’s good field, but used targets with a very low contrast (3%), which were near the threshold of GY’s abilities of detection. The results are presented in Figure 10.1.
It has been suggested that blindsight might simply be very poor normal vision (Campion et al., 1983). Apparently accurate residual vision in the blind field is explained in terms of a relaxation of the detection criterion subjects set themselves which compensates for poorer discrimination. We tested this proposition by comparing GY’s spatial discrimination performance and reports of awareness in his good and blind fields. In his good field, GY reported awareness of a target on 53 of the 300 trials where a target was, in fact, present and just one of the 80 trials where no target was present. In his bad field, in the low-contrast condition, GY reported awareness of a target on 13 of the 240 trials where a target was, in fact, present and two of the 60 trials where no target was present. His ability to discriminate target presence as indicated by his reports of awareness is much poorer in the blind field than in the good field near threshold. His location discrimination is, however, much better in the blind field (187/240 = 0.78 correct) than in the good (182/320 = 0.57). These results are consistent with those of Azzopardi and Cowey (1997) who showed, using a full parametric signal detection analysis, that GY’s discrimination was much better in a temporal forced-choice task than a simple target-detection task, while the performance of normal controls was similar in both tasks. The double dissociation we obtained between awareness and performance in GY’s good and bad fields and Azzopardi and Cowey’s (1997) signal-detection experiments both rule out a simple explanation of blindsight as poor normal vision.

The main purpose of our study was, however, investigation of the effects of temporal cueing on GY’s spatial discrimination accuracy. GY’s ability to discriminate target location...
ATTENTION AND ALERTING: COGNITIVE PROCESSES SPARED IN BLINDSIGHT

was significantly better than chance (binomial probabilities of $P < 0.005$ in all conditions) regardless of target contrast, the presence or absence of cues, or their timing relative to targets. He reported awareness of nearly every high-contrast target (98%) and a large proportion of medium-contrast targets (26%). We focus here on the data from medium- and low-contrast targets since his performance with high-contrast targets is essentially at ceiling in all cue conditions (see Figure 10.1) and almost always accompanied by awareness. In the medium-contrast condition, GY’s discrimination performance was still well above chance even when all of the trials in which he reported awareness were discarded. This was true for all cue conditions. When no cue was present, GY discriminated target location correctly on 85% (108/130) trials where he reported no awareness. When the cue followed the target, and was therefore not useful in predicting its occurrence, he was correct on 88% of the ‘unaware’ trials (50/57). When the cue preceded an upcoming target, however, GY was correct on nearly every trial (94%, 46/49). A similar breakdown of the low-contrast condition is even more striking. With low-contrast targets GY only reported awareness on 40% (131/320) trials. The pattern of results is not affected by the few trials in which he reported awareness. After discarding those 13 aware trials, we found the following results. With no cue, target location was discriminated correctly on 70% (80/115) of trials. When the cue followed the target the performance was 75% (43/57). However, performance remained near perfect (93%, 51/55) when the cue preceded target.

We can ask two questions about these data. First, do temporal cues improve GY’s residual vision? Second, is his performance better than chance without cues? The first question can be answered by comparing discrimination when cues precede and follow target presentation. GY’s performance with medium-contrast targets appears to be near, if not at, ceiling, so it would be inadvisable to combine the medium- and low-contrast data. As a consequence of the small error frequencies, one cannot, however, perform chi-squared tests on the separate medium- and low-contrast results. Instead, Fisher exact probabilities were computed with the aid of the infinite precision calculations of the Mathematica 3.0 software package. These reveal no significant difference between conditions when the cue preceded and followed medium-contrast targets ($P = 0.153$); there was, however, a significant effect of cue-target order with the low-contrast targets ($P = 0.000925$). Although these analyses show that temporal cues do aid GY’s spatial discrimination, it is also clear that his ability to localize target location when no cue is presented is still far better than chance—the binomial probabilities of obtaining his levels of performance purely by chance are vanishingly small for both the medium- and low-contrast targets ($P < 10^{-15}$ and $P < 10^{-5}$, respectively).

These results appear to give us a rather mixed message about the resemblance of GY’s performance to the infant- or adult-lesioned monkeys of the Moore et al. 1995 and 1996 studies. He resembles the monkeys lesioned in infancy rather than those lesioned in adulthood in Moore et al. (1996) in the way his performance does not depend entirely upon temporal cues. Nevertheless, GY’s uncued performance was poor compared with the uncued performance of the infant-lesioned monkeys in Moore et al. (1996). Procedural differences between our study and Moore et al. (1996) make quantitative comparison difficult. The Moore et al. (1996) task involved localizing one of 20 possible target locations per hemifield with an eye movement during a 3 second trial. Although the number of alternatives which
must be discriminated is larger, the shorter trial duration and the nature of the response measured may both favour discrimination without awareness or cueing. We should not, therefore, dismiss GY’s level of uncued performance as poor. In the Moore *et al.* (1995) the adult-lesioned animals failed to localize targets presented during a 3 second interval even when there were only two possible blind-field locations. The animals were not simply inaccurate in discriminating target location when they were not provided with an alerting cue; they failed to respond in any way to the targets. It seems reasonable, therefore, to conclude that GY’s abilities are far more similar to the infant-lesioned monkeys of the 1996 paper than the adult-lesioned monkeys of the 1995 paper.

Temporal cues, nevertheless, improve GY’s spatial discrimination. Moreover, they do so when he is unaware of the targets to which he is being cued. Moore *et al.* (1996) suggested that the presence of a fixation point in an unimpaired region of the visual field in conjunction with its active fixation by an animal may prevent or reduce the ability of visual targets in the blind field to elicit responses. This suggestion is consistent with the observation that activity of cells that map the location of a foveal fixation in the rostral pole of the superior colliculus inhibit the ability of stimulation in other areas of the collicular sensory map to generate saccadic eye movements (Munoz and Wurtz, 1992). Removal or dimming of a fixation stimulus prior to the presentation of a target reduces the latency of eye movements made to that target (Saslow, 1967). Although the findings of Munoz and Wurtz (1992) can account for the effect of a fixation dimming prior to target presentation on oculomotor responses to targets, it is hard to explain the effects of a change in fixation contrast prior to a manual response purely in terms of collicular processes, particularly when the response is a ‘symbolic’ button-press rather than a direct pointing response to a target. This leads us to conclude that the temporal cue was being used in a more general process of alerting or attentional disengagement rather than simply allowing disinhibition to occur in the eye-movement system.

The notion that alerting or attentional processes may influence blindsight was intriguing. It is clear that the topographic representations of space are preserved in blindsight, otherwise, blindsight subjects would only be able to discriminate the presence or absence of stimuli in their blind fields rather than also be able to saccade to them (Barbur *et al.*, 1988), point to them (Weiskrantz, 1990), or identify them with arbitrary button-press responses (Kertridge *et al.*, 1999a). The possibility that these representations may be subject to attentional processes such as alerting or covert orienting (Posner, 1980) was suggested to us by a comment GY made spontaneously during our original 1997 stabilized perimetry experiments (Kertridge *et al.*, 1997). Recall that GY’s task in that experiment was to discriminate the presence or absence of targets in a variety of locations within his blind field. GY is a very experienced subject, but in the vast majority of experiments he had participated in previously, stimuli were presented in locations on the horizontal midline. Quite by chance, during one of the breaks in testing, GY remarked that he had just realized that the stimuli were sometimes being presented well above the horizontal and so now he was trying to pay attention higher up in his blind visual field. This is an extraordinary remark since one’s intuition is that it is attention that gives rise to consciousness. Our subjective experience is that we are most conscious of that part of the world to which we are attending. This apparently close relationship between attention and consciousness was remarked
ATTENTION AND ALERTING: COGNITIVE PROCESSES SPARED IN BLINDSIGHT

upon from the birth of modern psychology (see, for example, James, 1890; Wundt 1912) and still influences many modern theories of consciousness. We followed the observation up in a series of experiments designed to establish exactly which aspects of attention continue to function in the blind region of GY's visual field. These experiments are reported in detail elsewhere (Kentridge et al., 1999b, 1999c).

The fundamental aim of these experiments was to discover whether GY could direct selective attention within his blind field. The subsidiary question of greatest interest to us was whether the process of directing attention to a stimulus would necessarily be accompanied by some form of awareness of that stimulus. Finally, we wished to investigate whether the answers to these questions were the same when the control of attention was 'automatic' or 'voluntary'.

We limited our studies to one simple form of attention—spatial orienting. In other words, our tasks involved selectively directing attention to specific spatial locations rather than attending to objects with specific intrinsic properties (such as redness). Milner and Goodale (1996) suggested that it is only this second type of attention in which is linked to consciousness. They propose that attention in the service of object identification gives rise to awareness. By contrast, attention in the service of object location need not give rise to awareness. As they put it 'there is more than one substrate supporting selective visual attention and that only one of these substrates is linked with conscious experience' (Milner and Goodale, 1986, p.183). On the basis of neuropsychological evidence, Milner and Goodale identify processes leading to object identification with pathways leaving the primary visual cortex and passing ventrally towards inferotemporal cortex. By contrast, processes associated with directing actions towards objects, and hence with their spatial characteristics, are identified with pathways leaving the visual cortex and passing dorsally towards the parietal cortex. Milner and Goodale (1996) suggest that access to the dorsal, but not ventral stream may be preserved in blindsight patients, and hence, attention without awareness may be demonstrable in blindsight.

Posner (1994) has suggested that a dissociation between attention and awareness can also be made in terms of the nature of attentional control. Posner suggests that the automatic direction of attention, in which a sensory stimulus captures attention for the processing of subsequent stimuli, can take place without awareness. Of necessity, the location of the stimulus that captures attention and the location to which attention is subsequently directed must be the same when attention is under automatic control. By contrast, when attention is directed voluntarily, the location of the stimulus that directs attention and the location to which attention is directed can differ. The relationship between the location or form of the cueing stimulus and the attended location is arbitrary and must be learned. Memories must therefore be invoked in order to guide attention. It has been suggested that it is the linked involvement of memory and sensory systems that gives rise to awareness (e.g. Edelman, 1989). Using brain-imaging, Posner identifies the voluntary control of attention with activity in anterior cingulate and dorsolateral prefrontal cortex and automatic direction of attention with parietal cortex.

All of our attention experiments are based on the same basic design. The ability to direct spatial attention is typically assessed by presenting a target preceded by a cue which may, or may not, indicate the correct location of the subsequent target (Posner, 1980). 'Valid' cues
produce more rapid responses to targets than misleading 'invalid' cues, which in turn may produce slower responses than a neutral condition. Conventionally, the subject's task is simply to respond as soon as they see a target stimulus appear. This, of course, is unsatisfactory for testing a blindsight subject who will be unable to see targets in his blind field. We therefore adapted the method so that a visual cue that signalled the likely target location was always followed by an auditory tone. On 50% of trials, a visual target was presented simultaneously with the tone; on the other 50% the tone sounded but no target was presented. The subject's task was simply to report, using a manual button-press, whether or not a visual target accompanied the presentation of the auditory tone. He was instructed to guess as quickly as he could whether or not a target was presented along with the tone. He was informed that no target would be present on 50% of trials. In all our experiments there were two possible target locations. On 68.75% of trials, when a target was presented a 'valid' cue correctly indicated the target location; on the remaining 31.25% the target appeared at the other location, i.e. it was preceded by a misleading 'invalid' cue. GY was allowed to inspect these locations using his good field prior to testing and was informed that on any trial when a target was presented, it was more than twice as likely to appear in the validly cued location than in the other location.

We varied two factors between experiments: the method by which the cue indicated the target location and the salience of the cues themselves. We used three cueing methods. In the first method the probable location of a target was indicated by an arrow presented at fixation (and hence visible to GY), pointing in the direction of the likely target location. As an arrow in itself has no meaning, its ability to cue a specific location depends on access to a learned interpretation. Effective use of a centrally presented arrow cue must therefore rely on the voluntary control of attention. Our second method used peripheral cues presented at or around the location at which a target was most likely to appear. As the target locations were within GY's blind field, this meant that both the cues and targets could not be normally perceived. As the cue and target locations are identical in this method, there is no need to engage a learned interpretation of the cue. The automatic capture of attention by such cues will lead to enhanced performance in validly cued trials when compared with misleading ones. Our final method was designed to investigate voluntary control of attention using cues presented in GY's blind field. It is doubtful whether GY's ability to discriminate shape, or even orientation, in his blind field is good enough to allow him to make use of symbolic cues like arrows in his blind field (e.g. Weiskrantz, 1997). Instead, we use a cueing method that depended simply on discriminating cue location, but in which the location of the cue did not correspond directly to that of the target. In this third method, a peripheral cue appearing at one of the two possible target locations indicated that a target was most likely to appear in the other location. Successful use of these cues relies on recall of this relationship between cue and target locations.

In addition to using the three cueing methods described above, we also used cues of high and low visual contrast. Our intention was to investigate differences between GY's ability to utilize cues with and without awareness. As we mentioned previously, GY does report some non-visual awareness of rapidly flickering or moving stimuli. We hoped that our high-contrast cues would elicit such awareness whilst our low-contrast ones would produce no experience whatsoever. Of course, there was no reason to make this contrast manipulation
bles, which in turn may affect his ability to perform his task. The subject's task is, of course, is unsatisfactory in his blind field. We therefore had a series of five experiments:

1. central cueing
2. direct peripheral cueing of target location with low contrast cues
3. direct peripheral cueing of target location with high contrast cues
4. indirect cueing where a low-contrast peripheral cue indicates that targets are likely to appear in the alternate location with low-contrast cues, and finally
5. indirect cueing with high-contrast cues.

In the first series of experiments we carried out (Kentridge et al., 1999c), we used rapidly flashing discs as both target and peripheral cue stimuli. In the low-contrast conditions the cues and targets were, in fact, physically identical. This is a potential source of problems since one could envisage simple temporal summation of cues and targets facilitating target detection in the valid condition of the direct peripheral cueing experiments (designs 2 and 3) and the invalid conditions of the indirect peripheral cueing experiments (designs 4 and 5). In all these cases the cue and the target appear in the same location. An alternative possibility is that cues may impair target detection by forward masking. If this were the case, then one would predict impairment of performance in the conditions where cues and targets appear at the same locations. Of course, neither temporal summation or masking could affect the results of the central cueing design (1).

The results we obtained showed a reaction-time advantage for validly cued trials in all but the low-contrast indirect peripheral cueing experiment. A number of factors nevertheless prompted us to refine our design. First, as we discussed above, temporal summation or masking may contribute to any differences found between valid and invalid conditions. Although it is not possible to account for both direct and indirect valid cue advantages simultaneously with either mechanism, the possibility that speeded reaction times with one or other cueing method were not the result of attentional mechanisms clouds interpretation of our results. We also found a great deal of variability in reaction times, which forced us to conduct our analyses based on the average reaction times for each cueing condition produced in each block rather than the individual times. This may have been due to the lengthy period over which these experiments were conducted. Finally, when we asked GY to provide trial-by-trial commentary on his awareness of cue and targets, it transpired that even our low-contrast cues were eliciting awareness on nearly 50% of trials. Although an analysis of reaction times that excluded trials in which he reported awareness still showed a reaction-time advantage, such a surprising effect clearly called for less equivocal evidence.

Our second series of experiments (Kentridge et al., 1999b) consisted of the same set of five designs, but modified to address the problems we encountered previously. First, all the testing was conducted over 2 days in an effort to reduce variability. Second, GY was asked to provide a commentary response indicating whether he had had any awareness of a target after each trial. He was also questioned about his awareness of cues at the end of each block of trials. Instead of using flashing peripheral cue and target stimuli, which were likely to elicit awareness, we used stimuli with gradual onset and offset (their change of luminance
over time followed a gaussian profile). These peripheral cues were not discs presented at one or other target location, but pairs of bars, one $2^\circ$ above a target location and the other $2^\circ$ below. These still indicate a target location unambiguously, but are well beyond the range over which blindsight subjects exhibit spatial summation of stimulus energy (Stoerig, 1993). They are also unlikely to produce any masking effect as they are distant from, and share no contours with, the disc-shaped target stimuli. Schematic examples of central and peripheral cueing trials are shown in Figure 10.2.

The results of the five experiments are presented graphically in Figure 10.3. The mean reaction times, accuracy of reporting the presence or absence of targets, and proportion of trials on which GY reported awareness are shown block by block for each experiment. Each block consisted of 128 trials and targets were present on 64 of them; of these, 44 (68.75%) were validly cued and the other 20 (31.25%) were misleadingly cued. For each experiment we analysed both the effect of cue validity on reaction time and on accuracy. If we found that reaction times were speeded by valid cues, but that this was at the expense of a decrease in accuracy, then it would be unsafe to conclude that the cues were being used to orient attention. For the reaction-time analyses, we discarded trials where no target was presented, where GY failed to report a target which was in fact present, where GY's fingers slipped from the button box (RTs greater than 1.5 seconds), or where GY was observed to move his eyes away from fixation during the trial. All trials apart from those in which GY moved his eyes were included in the analyses of detection accuracy.

The key statistical results are summarized in Table 10.1. In all cases, mean reaction times are faster across validly cued trials than misleading ones. Accuracy was never poorer in validly cued trials, only better than, or equal to, accuracy in misleadingly cued ones.

This is compelling evidence that GY can direct spatial attention within his blind field, under the control of cues in blind or spared regions of his visual field. The fact that clear valid-cue advantages were found in both direct and indirect peripheral cueing designs rules out explanations in terms of simple sensory interactions between cues and targets.

---

Figure 10.2 Stimulus sequences used in the spatial cueing experiment. (a) The sequence used in the central-cueing experiment. In this example the arrow is cueing the lower of the two possible target locations. The left frame at the bottom illustrates a trial where the target was presented at the location indicated by the cue, the middle frame one where it was presented at the other, misleading, location, and the right frame one where no target was presented. The sequences used in the other experiments are shown in (b). In this example the upper location is directly cued by the peripherally presented bars and the lower left, middle, and right frames again illustrate valid, misleadingly cued, and target-absent trials, respectively.
such as summation or masking. Although target stimuli presented at a validly cued location gain a selective processing advantage compared to those presented at the alternative location, GY’s commentary responses indicate that this selective processing is not necessarily accompanied by awareness. Therefore, the spatial selection of information by an attentional mechanism and its entry into conscious experience cannot be one and the same process. As we will see, in addition, the control of attention does not depend upon awareness of
cues whether it is automatic or involves direction of attention to locations remote from cues.

The first experiment used arrows as cues, presented at fixation within GY’s region of macular sparing, and hence fully visible to him (Figure 10.2a). Table 10.1 shows significant overall effects of cue validity on both reaction time and accuracy. The key question that concerns us, however, is whether evidence can be found for attentionally selective processing of stimuli in the absence of awareness of those stimuli. Analysis of the commentary responses show that validly cued trials are significantly more likely to give rise to experience than ones with misleading cues (χ²(1) = 8.8+, P < 0.005). When we separately analysed trials on which GY reported no awareness of the target, we nevertheless still found a significant effect of cue validity on reaction time (valid cue RT mean = 766 ms, σ =153 ms, n = 40; misleading cue RT mean = 853 ms, σ = 191 ms, n = 153; t(52.63) = 2.65, P<0.05). This evidence in favour of attention without awareness encouraged us to use less salient target stimuli in subsequent experiments. In every subsequent experiment, GY’s commentary indicated that targets never elicited any awareness whatsoever. He reiterated his lack of target awareness verbally during questioning following each block of trials.

The second experiment use low-contrast peripheral cues to directly indicate the likely target location. GY’s reaction time was significantly faster when the cue and target locations coincided than when they differed, but there was no difference between his ability to detect targets in the valid and misleading cueing conditions. In both conditions his performance was significantly better than chance (624/917 = 70%, P < 0.001 in the valid condition, 241/356 = 68%, P < 0.001 in the misleading condition). GY did not report awareness of a single target in his trial-by-trial commentary responses throughout the experiment. His responses to inquiries about his experience of cues indicated that he had no awareness of them, for example: ‘I’d be none the wiser if you weren’t putting any cues up just to confuse me.’ and ‘I just listen for the beep and press a button.’ These results clearly show that attention can be directed to locations cued within GY’s scotoma.

The next experiment (Figure 10.3c) again used low-contrast peripheral cues, but now a cue in one location indicated that a target was most likely to appear in the other location. Over the first three blocks of testing (384 trials), GY responded more quickly to targets in the misleading condition, that is, targets which appear in the same place as the preceding cue. His pattern of results then changes, and, although there is considerable variability between blocks, he now shows reaction-time advantages in the valid condition. He has become quicker at detecting targets that appear at the location remote from the cue than he.

---

Table 10.1 Key statistical results

<table>
<thead>
<tr>
<th>Cues</th>
<th>Effect on RT</th>
<th>Effect on accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>t'(101.78) = 7.47, P &lt; 0.001</td>
<td>χ²(1) = 28.79, P &lt; 0.001</td>
</tr>
<tr>
<td>Peripheral low-contrast direct</td>
<td>t'(146.88) = 9.08, P &lt; 0.001</td>
<td>χ²(1) = 0.646, NS</td>
</tr>
<tr>
<td>Peripheral high-contrast direct</td>
<td>t(829) = 2.50, P &lt; 0.05</td>
<td>χ²(1) = 15.59, P &lt; 0.001</td>
</tr>
<tr>
<td>Peripheral high-contrast direct</td>
<td>t'(151.19) = 14.50, P &lt; 0.001</td>
<td>χ²(1) = 2.617, NS</td>
</tr>
<tr>
<td>Peripheral high-contrast direct</td>
<td>t'(125.10) = 7.80, P &lt; 0.001</td>
<td>χ²(1) = 16.413, P &lt; 0.001</td>
</tr>
</tbody>
</table>

NS, Not significant.
is at detecting targets presented at the same location as the cue. Analyses using all trials (including the first three blocks) shows that this reaction-time advantage is statistically significant and is accompanied by improved detection accuracy. His performance was significantly better than chance in the valid (119/1750 = 68%, P < 0.001) and the misleading (476/793 = 62%, P < 0.001) conditions. In GY’s trial-by-trial commentary on his awareness of targets, he again did not report awareness of a single target. His remarks upon being questioned after each test block indicate that he had no awareness of cues either: ‘no awareness of cues;’ ‘no experience of anything;’ ‘still nothing there.’ These results again show that GY can direct attention within his blind field using cues of which he is unaware. Further, they show that the direction of this selective attention, as revealed by a reaction-time advantage in detecting stimuli presented at attended locations, does not give rise to awareness of those stimuli even when the relationship between cue and target location is not a simple identity.

The fourth design reverts to direct indication of the likely target location, but now using high-contrast cues. Cue validity again significantly speeded reaction time but did not affect accuracy, which was significantly better than chance in both conditions (618/1979 = 67%, P < 0.001 in the valid condition, 223/357 = 62%, P < 0.001 in the misleading condition). GY never reported any awareness of the targets, but his responses to questioning at the end of each block indicate that he was aware of the high-contrast cues and also show that this awareness gave him some knowledge of cue location as these examples illustrate: ‘I’m aware of the top cue most of the time and the right one occasionally.’ ‘I couldn’t describe what I experience, but I definitely know where the top one [cue] is, the other one doesn’t seem as far below the midline as I expected. No experience of the targets at all though.’ ‘Aware of something on about 65% of trials.’ The pattern of results is broadly similar to that found in Experiment 2. There is clear evidence for selective attention to a location without awareness of targets presented at that location in both Experiments 2 and 4. The absence of awareness of stimuli in the attended location occurs whether or not GY is aware of the cues indicating that location.

In the final experiment we again investigated GY’s ability to use cues that indirectly indicated the likely target location, as in Experiment 3, but now using high-contrast cues. The results again show a highly significant effect of cue validity on reaction time accompanied by increased accuracy. In both conditions GY’s performance was significantly better than chance (629/879 = 72%, P < 0.001 in the valid condition, 240/399 = 60%, P < 0.001 in the misleading condition). GY did not report awareness of a single target. His responses to questioning at the end of each block indicate that he was still aware of the high-contrast cues and their location, although this awareness was decreasing: ‘I’m aware of all of them at the top but virtually none at the bottom.’ ‘25–35% aware—it starts well but degrades very quickly.’ As we found in Experiment 3, GY is capable of directing attention to location remote from the cue without becoming aware of stimuli attended to at that location. There is, however, an important difference between the pattern of results obtained in Experiments 3 and 5. Prior to both these experiments GY had been performing tasks where cues directly indicated the likely target location. Even though the instructions given to him before Experiments 3 and 5 explicitly explained that the contingency between cue location and likely target location was reversed, in Experiment 3 GY nevertheless initially showed a
reaction-time advantage in the misleading condition, in other words, when targets were presented in the same location as the cue they followed. In Experiments 3 and 5 targets only appeared at the same location as cues on a small minority of trials. This misleading condition did, however, correspond to the direct cue-target contingency of the preceding experiment. It appears that GY was still behaving as if the direct-contingency of Experiment 2 was still operating for the first three blocks of Experiment 3. In Experiment 5, however, the reversed contingency was effective in speeding his reaction time from the first block. It is also apparent that in Experiment 3 there was a great deal of variability in the effect of cue validity, which was often small and sometimes even negative, whereas the effect found in Experiment 5 was larger and more consistent. GY summed up what may be the crux of these differences during one of the post-test debriefings in Experiment 5: 'When I’m aware [of the cue] I can try to attend to the other [i.e. valid] location . . . when I wasn’t aware of any of the cues [during experiments 2 and 3] I couldn’t try to switch my attention.' In other words, GY could only voluntarily direct his attention when he had awareness of cue location.

We had expected that the direction of attention to locations remote from the cue might be restricted to situations in which GY was aware of the cue, and could hence act voluntarily. Using cues near the threshold of detectability, McCormick (1997) found that normal subjects could direct their attention to directly cued locations without cue awareness, but could only direct their attention to locations indirectly indicated by a cue if they were aware of that cue. Direct and indirect cueing differ from one another in two ways; indirect cueing requires the application of an arbitrary rule relating cue and target location and the suppression of automatic orienting to the cue location. Our smoothly temporally modulated stimuli may have had a relatively weak capacity to automatically orient attention (Jonides and Yantis, 1988). Recent findings by Lambert et al. (1999) have shown that arbitrary relationships between peripheral cues and the target locations can be learnt implicitly and are effective in orienting the attention of normal subjects, even when they are unaware of the contingency, unaware of the peripheral cues, or unaware of both. In GY it appears to be the case that explicit knowledge of a cue–target relationship can only be used voluntarily when the cue gives rise to awareness. When he remains unaware of the cue he can only make use of it after a period during which, we suggest, implicit learning takes place.

We have shown that two fundamental processes of visual cognition, alerting and attention, remain operative in blindsight. What are the implications for our understanding of the neuroanatomical bases of these processes and of blindsight?

We have reviewed evidence indicating that GY’s blindsight is unlikely to be accounted for in terms of spared striate cortex. The evidence of Stoerig et al. (1998) showing a stimulus-induced increase in activity in extrastriate visual areas in a blindsight subject indicates that blindsight cannot be a purely subcortical phenomenon. Blindsight may, under some circumstances, be mediated by pathways that reach extrastriate cortical areas without passing through primary visual cortex. There are two possible sources, direct projections from the lateral geniculate nucleus to areas V2 and V4 (Cowey and Stoerig, 1989) and projections, possibly via the superior colliculus, to the pulvinar and on to areas MT (Standage and Benevento, 1983) and V4 (Ungerleider and Desimone, 1986). In addition, damage to striate cortex would, of course, leave purely subcortical visual processes unaffected.
ATTENTION AND ALERTING: COGNITIVE PROCESSES SPARED IN BLINDSIGHT

Attention and alerting are different processes. Fernandez-Duque and Posner (1997) have demonstrated behavioural dissociations between attention and alerting. It is also thought that their neural mechanisms of control and action differ (see, for example, Robbins and Everitt, 1994). Two issues need to be addressed in assessing the implications of our demonstrations of alerting and attention in blindsight to the neural bases of these phenomena. First, are the sites of action of alerting and attention likely to be affected by striate damage in blindsight? Second, are the systems which control alerting or attention likely to be affected?

The neural basis of alerting is thought to involve diffuse activation of wide areas of cortex (see, for example, Robbins and Everitt, 1994). In GY, alerting processes should therefore be able to act upon any stimulus-induced activity in cortical regions other than striate cortex, provided the systems that control and induce such activation are not compromised. It has been known since the mid-1980s that attention modulates neuronal activity in extrastriate cortex (Moran and Desimone, 1985). Recent evidence also suggests that attention modulates activity in striate cortex (e.g. Brefczynski and DeYoe, 1999; Martinez et al., 1999); however, measurements of the time-course of striate cortex activation by Martinez et al. (1999) suggest that attention does not act by modulating the initial passage of the incoming visual signal. The implication is that attentional effects in extrastriate areas are not dependent upon initial striate modulation. As such, we should not therefore be surprised that attention can operate in the absence of striate cortex, provided visual signals can still reach extrastriate areas and provided the systems which control and induce attentional modulation are not compromised.

Alerting is typically characterized as a midbrain process. A wealth of evidence implicates diffuse noradrenergic projections from the locus ceruleus to the cerebral cortex as the final pathway through which the alerting process acts (Aston-Jones and Bloom, 1991; Rajkowski et al., 1994). The parietal cortex, implicated in both altering and attention, has particularly dense noradrenergic innervation (Morrison and Foote, 1986). The locus ceruleus itself has few afferent projections, the majority coming from prefrontal cortex (Goldman-Rakic, 1987). In our experiment on temporal cueing, the alerting signal was presented to an undamaged area. There is no reason to believe that GY's damage should interfere with any response of prefrontal cortex and ultimately the locus ceruleus to this signal.

As we have noted, attentional control may be either exogenous (automatic) or endogenous (voluntary). The posterior parietal lobe is clearly implicated in the automatic capture of attention. Hemispatial neglect is a neuropsychological disorder usually caused by unilateral damage to the parietal lobe. Although parietal syndrome may have many components, including somatosensory and oculomotor deficits (see e.g. Cole et al., 1962; Ishiai et al., 1987) its most studied aspect is patients' inability to redirect their attention to the visual hemifield contralateral to their lesion (Posner et al., 1984). This attentional component has been specifically associated with lesions of the inferior parietal lobule (Galletti et al., 1997). Electrophysiological studies in monkeys have shown that attending to a location at which subsequent targets are likely to appear reduces the sensitivity of a majority of parietal neurons (in area 7a) to stimuli (Steinmetz et al., 1994) at the attended location. The implication is that the sensitivity of neurons in non-attended locations is enhanced in order to allow peripheral events to capture attention. Posterior parietal cortex receives many projections from the pulvinar (see, for example, Asanuma et al., 1985) in addition to

or words, when targets were experiments 3 and 5 targets of trials. This misleading contingency of the preceding contingency of Experiment 5, however, came from the first block. It variability in the effect of cue whereas the effect found in what may be the crux of Experiment 5, 'When I'm aware ... when I wasn't aware of much my attention.' In other awareness of cue location. Remote from the cue might therefore act voluntarily (1997) found that normal without cue awareness, but affected by a cue if they were either in two ways; indirect target location and the only temporally modulated orient attention (Jonides shown that arbitrary relationships implicitly and are they unaware of the in GY it appears to be the used voluntarily when he can only make use of the place.

Attention, alerting and attention control our understanding of is unlikely to be accounted for. For example (1988) showing a stimulus-sighting subject indicates that may, under some cortical areas without processes, direct projections and Stoerig, 1989) and and on to areas MT (Asanuma et al., 1985). In addition, functional visual processes...
those from striate and extrastriate cortex. It is reasonable to assume that it can be activated in blindsight in the absence of striate cortex.

Frontal areas are implicated in attentional tasks requiring voluntary control. For example, Corbetta et al. (1993) report activation of superior frontal cortex and anterior cingulate cortex in voluntary but not in automatic tasks. Visual signals could reach frontal areas of cortex via projections to extrastriate occipital regions, which bypass striate cortex. These frontal systems are also implicated in conscious decision processes (e.g., willed action, Frith et al., 1991) and the suppression of habitual responses (Jahanshahi et al., 1998). One might therefore expect the voluntary control of attention to be impossible without accompanying awareness. There are two aspects of awareness between which we need to make careful distinctions—awareness of the cue and awareness of the target. We found that orientation of attention to spatial location, as revealed by a subsequent processing advantage conferred upon stimuli presented at that location, did not also confer awareness upon those stimuli. We assume that activation of striate cortex is necessary for a stimulus to give rise to visual experience. This is a separate issue from the question of whether voluntary redirection of attention is possible without awareness, including a non-visual 'feeling of knowing', of the cue that guides that attention. It is the apparent lack of this form of cue awareness in our indirect peripheral cueing experiment that is surprising. There is, however, a possibility that a consistent relationship between cue and target positions may be encoded in the eye-movement system which does not engage frontal processes. The work of Glimcher and Sparks (1992), Kustov and Robinson (1996), and Basso and Wurtz (1997) has shown that arbitrary relationships between cue and target, which modulate both attention and eye-movement initiation, can be encoded within collicular-parietal systems involved in eye-movement control. These findings suggest that a simple cue–target contingency may not necessarily require involvement of frontal language and memory systems. The slower development of a valid cue reaction-time advantage where GY was unaware of cues, in comparison to the corresponding high-contrast cue experiment where he was aware of cues and reported that he was voluntarily attempting to shift his attention, may reflect differences between the relatively slow non-conscious acquisition of the cue–target location contingency and its voluntary use.

By using blindsight to study two of the most basic processes that influence responses to visual stimuli we have been able to examine the relationship between cognition and awareness in a way that would be near impossible in normal subjects. Nevertheless, the conclusions we draw from these studies do not apply solely to blindsight. We were able to demonstrate behavioural effects of both alerting and attentional cues on the processing of subsequent targets and found that the resulting enhancements were not accompanied by awareness. We conclude that whilst the direction of attention towards a stimulus may be necessary if it is to reach awareness (Mack and Rock 1998), the engagement of neither attention nor alerting processes is sufficient for awareness.

References

that it can be activated by voluntary control. For example, rectus and anterior cingulate could reach frontal areas of the less striate cortex. These (e.g. willed action, Frith et al., 1998). One might without accompanying to make careful find that orientation of advantage conferred upon those stimuli, us to give rise to visual voluntary redirection of ness upon those stimuli, however, a possibility be encoded in the eye of Glimcher and (1997) has shown that both attention and eye- systems involved in target contingency may systems. The slower unaware of cues, in we were aware of attention, may reflect differ- the cue-target location

Influence responses to influence recognition and awareness. The conclusion. We were able to on the processing of stimuli not accompanied by a stimulus may be the of neither


