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Spatial attention speeds discrimination without awareness in blindsight

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Abstract

An intimate relationship is often assumed between visual attention and visual awareness. Using a subject, patient GY, with the neurological condition of 'blindsight' we show that although attention may be a necessary precursor to visual awareness it is not a sufficient one. Using a Posner endogenous spatial cueing paradigm we showed that the time our subject needed to discriminate the orientation of a stimulus was reduced if he was cued to the location of the stimulus. This reaction-time advantage was obtained without any decrease in discrimination accuracy and cannot therefore be attributed to speed-error trade-off or differences in bias between cued and uncued locations. As a result of his condition GY was not aware of the stimuli to which processing was attentionally facilitated. Attention cannot, therefore be a sufficient condition for awareness.
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1. Introduction

James (1890) was one of the first authors to point out the close relationship between selective attention and consciousness. It is often assumed that this relationship is one of identity—what one attends to and what one is conscious of being one and the same thing—although James himself did not believe this (see Hardcastle, 1997). Attention and consciousness can be related, but not in identity, if attention is either not necessary for awareness (one can be conscious of things to which one is not attending) or if attention is not sufficient for awareness (one can attend to a thing without becoming aware of it). Paradigms such as inattentional blindness (Mack & Rock, 1998) and change blindness (e.g. Rensink, O'Regan, & Clark, 1997) suggest than attention is necessary for awareness (at least insofar as it is possible to withdraw attention absolutely from parts of the visual scene). We recently carried out a study with a patient with the neurological condition of blindsight in order to test the second possibility, that attention may not be a sufficient condition for awareness, and to test whether cues which do not themselves elicit any conscious response can nevertheless capture attention (Kentridge, Heywood, & Weiskrantz, 1999a). The present follow-up experiment reported here focuses on

the question of the sufficiency condition, and addresses a methodological issue that could make the interpretation of our earlier results ambiguous.

Blindsight is a condition in which patients with damage to their primary visual cortex or its afferents retain the ability to detect, discriminate and localise visual stimuli presented in areas of their visual field in which they nevertheless report that they are subjectively blind (see e.g. Weiskrantz, 1986). In a previous report (Kentridge et al., 1999a) we demonstrated that the blindsight subject GY showed a reaction-time (RT) advantage for the detection of targets presented in validly spatially cued (as opposed to misleadingly cued) locations within his blind field, using the classic methods of Posner (1980). As this performance advantage was not accompanied by awareness of targets in the cued location we suggested that attention to a target (reflected in the selective RT advantage) was not a sufficient condition for awareness of that target.

There is one potential problem with our interpretation. As we used a detection task with a single level of target probability throughout the experiment we could not distinguish between effects of cueing on response bias and discrimination. Although we could show that the speeding of RT to validly cued targets was not at the expense of a decreased likelihood of detecting targets, we could not show that the ability to discriminate the presence or absence of targets was unaffected. It may have been the case that fast RTs were only obtained at the expense of a decrease in accuracy, but

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that this was obscured by a concomitant change in response bias to any signal at the cued location. But, because it makes no sense to say that the cue in a trial where no target is presented is valid or invalid, it is not possible to measure this bias. It might, for example, have been the case that all of the false-positive responses were the results of misperception of targets at the cued location, but we could not assess this using a detection paradigm. While we feel this explanation is unlikely to account for our results, the implications of our conclusion are broad enough that any doubt needs to be resolved (see e.g. comments in Block, 2000; Lamme & Roelfsema, 2000; Zeman, 2001). We therefore modified our design to one in which the subject's task is one of discrimination rather than detection. In a discrimination task there need be no trials on which targets are absent so cue-validity is meaningful on every trial and the effect of any bias towards one particular response can be controlled for by counterbalancing. The current experiment therefore tests whether the RT advantages seen in the results of Kentridge et al. (1999a) were likely to be a result of speed-error trade-off or a result of spatially selective attention.

In addition to the key change in task, from detection to discrimination, in the current experiment we also now vary the interval between presentation of cues and targets. It is known that in an endogenous cueing task, such as the one we use here, the effectiveness of cues in normal subjects increases as the interval between onset of the cue and onset of the target (stimulus onset asynchrony, SOA) increases, reaching a maximum at an SOA of about 300 ms (see e.g. Müller & Rabbit, 1989). We therefore randomly interleaved trials with SOAs of 200 and 450 ms in order to assess whether a similar variation in cue effectiveness could be found in GY.

Finally, we did not ask GY to make trial-by-trial commentary on target awareness in the current experiment, to simplify the response requirements, in case making a commentary decision interfered with his response to the orientation of the target. Instead, we obtained verbal reports of awareness in pre-tests at a number of contrasts and conducted two blocks of trials in which both discrimination and commentary responses were collected without an instruction to respond rapidly, in order to establish a level of contrast at which we expected targets to elicit no awareness whatsoever. RT data were then collected without trial-by-trial commentary, but with verbal report of any awareness at the end of each block.

2. Method

2.1. Subject

GY, a 41-year-old man, has been fully reported elsewhere (Barbur, Ruddock, & Waterfield, 1980; Baseler, Morland, & Wandell, 1999; Blythe, Kennard, & Ruddock, 1987). He suffered unilateral damage to left striate cortex, confirmed by computerised tomography (Blythe et al., 1987) and mag-

netic resonance imaging (Barbur et al., 1980), as a result of a car accident at the age of 8 years. He has a right homonymous hemianopia but retains about 3° of macular sparing, consistent with the damage revealed by neuroimaging. GY gave informed consent to participate in the experiments.

2.2. Apparatus and procedure

Stimuli were generated using a Cambridge Research Systems VSG2/3 and displayed, against a $51.4 \, \mathrm{cd \, m^{-2}}$ background, on a Samtron SC-726 GXL colour monitor. A Cambridge Research Systems CB1 response box was used to collect responses and provide auditory signals to the subject.

A white fixation dot with a luminance of $96.5 \, \mathrm{cd \, m^{-2}}$ and a diameter of 0.38° was present on the screen throughout the experiment.

The sequence of events occurring within each trial is represented schematically in Fig. 1. Each trial began with a 150 ms presentation of a black arrow 0.77° in length, pointing towards one of the two possible target locations. Following the offset of the cue the fixation spot alone was presented for either 50 or 300 ms. Target presentation began at the end of this interval. The two possible target locations were both at an eccentricity of 6° from fixation, one was 30° (polar) to the right of the vertical meridian, the other 15° (polar) below the horizontal. These locations were chosen as they yielded comparable levels of performance in an earlier perimetric study of GY (Kentridge, Heywood, & Weiskrantz, 1997). The start of target presentation was accompanied by a 313 Hz tone, lasting for 200 ms, delivered
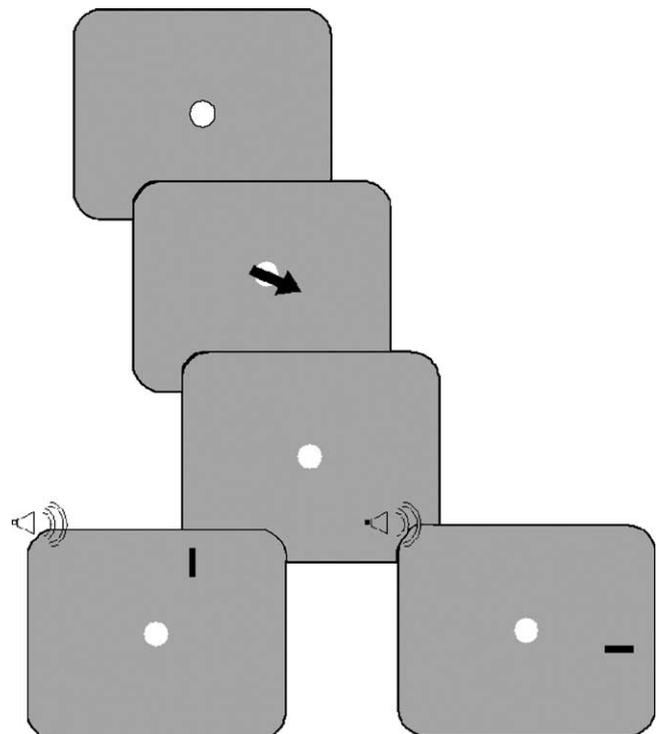

Fig. 1. A schematic view of the sequence of events in a single trial.

through a CB1 response box. The target was a dark bar $2°$ in length and $0.2°$ in width. The bar could be presented horizontally or vertically with its centre at either of the two target locations. The target was decremented in luminance to its peak contrast with a half-Gaussian profile over a period of 100 ms, starting 2 standard deviations away from the peak contrast. It then remained at peak contrast for 200 ms before a ramped offset, again with a 2 standard deviation half-Gaussian profile over a period of 100 ms. We used a ramped, rather than abrupt onsets and offsets, as the latter have been shown to contribute strongly to awareness of stimuli (Macknik & Livingstone, 1998).

On 80% of trials the target was presented in the location indicated by the cue, on the other 20% it was presented at the other location. Vertical and horizontal targets appeared equally often. Presentation order was randomised within successive sets of 80 trials.

GY was seated 57 cm from the screen and used a combined chin and forehead rest. GY's eye position was directly monitored throughout the experiment by one of the experimenters seated within 1 m of GY's eyes. Before the start of the experiment the sequence of events on each trial was explained to the subject and he was allowed to observe some trials in his unimpaired visual field. The experimenter took this opportunity to confirm that even small movements of GY's eyes away from fixation (about 2–3°) were readily detectable. GY was informed that a target was four times as likely to appear at the location indicated by the arrow than at the other location, and that targets of either orientation were equally likely. GY was instructed to respond as rapidly as he could on the response box as soon as the tone sounded, indicating whether the target (regardless of location) was horizontal (left button) or vertical (right button), guessing if necessary. A 200 ms 417 Hz tone indicated that the computer had registered the response. It was possible for GY to follow this response with a second commentary response indicating whether he had had any experience whatsoever, including non-visual experiences such as 'feeling something was there' accompanying the tone. This commentary feature was only used in the process of setting a suitable target contrast level for the experiment proper. GY was not given feedback on his performance. The experiment proper consisted of 560 trials split over four sessions (three of 160 trials and one of only 80 trials). The peak target contrast used was 15%—corresponding to a minimum target luminance of $40.9\,\mathrm{cd\,m^{-2}}$.

3. Results

3.1. Pre-test contrast-level setting

GY initially performed three short, 20 trial practice sessions in which the peak Michelson contrasts of the target were 100, 60 and 15%. He reported his target awareness as being "aware of about 40%, mainly in the upper location"

for the 100% contrast block, "only aware of one or two" for the 60% contrast block and "nothing is happening—I have no awareness or experience" during the 15% contrast block.

Two blocks (160 trials per block) were conducted in which a trial-by-trial commentary procedure was used with 60% peak-contrast targets. GY made only two positive commentary responses, both of which he indicated were miss-hits of the response keys. It was, however, clear that making the discrimination and commentary responses using the same keys caused considerable difficulties. As GY was discriminating orientation effectively even at the lowest contrast we conducted the experiment proper using the 15% contrast level and a verbal report on awareness at the end of each block rather than a trial-by-trial commentary.

The main experiment consisted of 560 trials conducted in three blocks of 160 trials and one block of 80 trials. GY maintained stable fixation throughout (as in previous studies he demonstrates consistent ability to maintain steady fixation). GY was questioned at the end of each block about his awareness of targets. Throughout the experiment he never reported being aware of any 15% contrast targets. When asked after one block whether it might have been a block of catch trials in which no targets were presented he replied that "I couldn't tell, there wasn't anything there, it might well have been [a block of catch trials]".

3.2. The effect of spatial cueing on reaction-time

We were prepared to use criteria in which trials with RTs of less than 250 ms would be rejected as anticipations and those of more than 2000 ms would be rejected as miss-hits of the keys, but no trials needed to be discarded on these grounds. Trials in which orientation discrimination was incorrect were, however, discarded from the RT analyses. As Fig. 2a shows, the RT advantage of 49 ms at the shorter SOA did not quite reach significance as a simple main effect (derived from an independent samples factorial ANOVA with factors cue-validity and SOA) ($F_{(1, 425)} = 2.32$, $P = 0.069$) and was smaller than the highly significant ($F_{(1, 425)} = 8.30$, $P < 0.005$) RT advantage of 94 ms at the long SOA. These RT advantages were reflected in a strong overall effect of cue-validity ($F_{(1, 425)} = 9.74$, $P < 0.005$), clearly demonstrating that attentional cueing was effective in reducing RT. There were neither effects of SOA ($F_{(1, 425)} = 0.2$, ns) nor of its interaction with validity ($F_{(1, 425)} = 0.96$, ns). The absence of a significant interaction indicates that the difference between the size of effects at the two SOAs may be due to chance rather than a systematic effect of SOA. A Levene test of homogeneity of variance between cells indicated no deviation from the homogeneity assumption of ANOVA (Levene $F_{(3, 425)} = 0.315$, ns).

3.3. The effect of spatial cueing on discrimination

Evidence exists that GY can discriminate the orientation of lines even in the absence of any explicit attentional
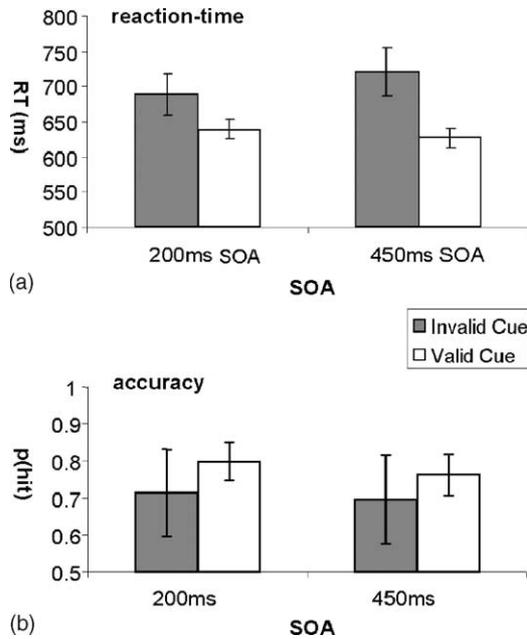
Fig. 2. (a) The effect of cueing on reaction-time. Error bars represent standard errors of the mean. (b) The effect of cueing on discrimination accuracy. Error bars represent 95% binomial confidence intervals.

cueing procedure (Morland, Ogilvie, Ruddock, & Wright, 1996). As Fig. 2b shows, the present results are consistent with this finding. GY discriminated target orientation at a rate much better than chance in all conditions of cueing and SOA (200 ms SOA, invalid trials: 40/56, valid trials: 179/224, 450 ms SOA, invalid trials: 39/56, valid trials: 171/224). The chances of finding even the poorest level of these performances by chance has a probability $P < 0.01$ (two-tailed binomial, after Bonferroni correction for four comparisons). The probabilities of finding the levels of performance shown in the valid conditions are vanishingly small. Crucially, for both SOAs, accuracy in valid trials *exceeds* that in invalid ones. Although these differences are not significant in chi-squared tests of correctness versus validity at either SOA (200 ms SOA, $\chi^2(1) = 1.89$; 450 ms SOA, $\chi^2(1) = 1.07$) it cannot be the case that RT advantages accompanying valid-cueing are obtained as a consequence of diminished accuracy.

4. Discussion

It is not possible to explain the RT advantage accruing to validly cued trials in terms of a trade-off against accuracy accompanied by a shift in bias. GY is clearly no less accurate (if anything he is more accurate) and is quicker at making orientation discriminations in validly cued locations. In conjunction with the results our earlier study the evidence is now very strong that a performance advantage can accrue to processing of stimuli presented at a cued location without those stimuli eliciting awareness.

Attention speeds processing of items at attended locations even though they remain unseen. These findings are also consistent with the fact that GY can take advantage of a temporal alerting cue to a target without that target eliciting awareness (Kentridge, Heywood, & Weiskrantz, 1999b). While the fact that, in GY, attending to an unseen location actually speeds discrimination of unseen targets at that location may be surprising, it should be no surprise that he, or any normal subject, can *direct* their attention to an unseen location. It might, however, seem odd that GY can attend to an *unseeable* location. We would argue, however, that although GY's lesion affects his vision, it is unlikely to affect parietal and other neural representations of space which play a vital role in spatial selective attention—the spatial map in which attention is allocated remains intact.

The subsidiary question we had hoped to address was whether the pattern of results would resemble those of normal subjects in a central-cueing experiment. Although the increase in RT advantage we found at the longer SOA is consistent with the prediction made, based on the time-course of voluntary attention in normal observers, it is not possible to draw a strong conclusion based on time-course, as the interaction between SOA and validity in the present data was not statistically significant. It is possible that, given the ramped nature of the targets, the effective SOAs were lengthened to such an extent that the short SOA was allowing better use to be made of the cues than would have been possible with abrupt targets. The lack of simple main effect at the short SOA does, however, give some indication of the uncued or neutral RT one might expect. Compared with this baseline the major effect of cueing at the longer SOA is to lengthen the RTs to invalid targets with a relatively small speeding to valid targets. Again, this is the pattern one would expect to observe in normal subjects (e.g. Posner, Snyder, & Davidson, 1980).

Although the conclusion that attention to stimuli (even if voluntarily controlled) is not a sufficient condition for awareness of them may appear to be at odds with some current theories of consciousness (see e.g. reviews by Baars, 2002; Posner, 1994), should we be surprised by it? Covert shifts of visual spatial attention have been characterised as sharing a common mechanism with preparation to overtly move ones eyes to the selected region of space (Rizzolatti, Riggio, DaScola, & Umiltà, 1987; Sheliga, Riggio, & Rizzolatti, 1994). As such, covert shifts of spatial attention might be seen as preparation for action which Milner and Goodale (1995) argue is mediated by an anatomically distinct part of the visual system that is not involved in visual awareness. Indeed, Milner and Goodale (1985, p. 183) suggest that there are "selective attentional mechanisms in the dorsal stream (and its associated subcortical structures) that are not obligatorily linked to awareness". The results of the present study are clearly consistent with this suggestion. It remains to be seen whether it is possible to produce stimuli which differentially activate dorsal and ventral streams to a sufficient extent to test the prediction in normal observers.

Milner and Goodale's hypothesis would also predict that when attention is used to select objects on the basis of properties other than spatial location then awareness must inevitably accompany attention. In such cases attention and awareness may be in identity. Nevertheless, the fact that the RT effects of spatial cueing are not accompanied by awareness of targets or by an opposing change in target discriminability, in this study, shows that visual spatial attention is not a universally sufficient condition for visual awareness.

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