Effects of temporal cueing on residual visual discrimination in blindsight

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Abstract

We tested the ability of a blindsight patient, GY, to identify in which of two locations a target was presented in a spatial two-alternative forced choice paradigm (spatial 2AFC). On each trial the subject was asked to make a second manual response indicating whether he had had any awareness of an event occurring during the trial. A cue, presented at the fixation location, could signal the 0.4 s period over which the target appeared within the 10 s duration of each trial. Targets of three contrasts, 93, 43 and 22% were used. We found that GY's ability to discriminate the location of targets in his blind field remained significantly above chance, with and without cueing, for each contrast. Cueing, did, however, significantly improve his performance for low contrast targets. When he performed a similar task with near threshold contrast targets in his spared visual field his discrimination was at chance unless the presentation of targets was cued, despite his reporting more awareness for these stimuli than he did for low-contrast stimuli in his blind field. These results are compared with those previously reported in monkeys who received lesions to their visual cortices as infants or adults. We conclude that (1) GY's blindsight is qualitatively different from near-threshold normal vision. (2) In common with infant-lesioned monkeys his blindsight remains even in the absence of temporal cues. (3) Residual vision is subject to modulation by attentional processes, or arousal, associated with temporal cueing. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The term 'blindsight' refers to the residual ability of patients to detect, localize and discriminate visual stimuli that are presented in dense field defects caused by destruction, or deafferentation, of primary visual cortex. However, awareness is covert since patients lack phenomenal vision and deny seeing the stimuli to which they respond to so effectively [13, 14]. The dissociation of awareness and performance sheds light both on the organisation of the visual system and on the neural correlates of consciousness [6].

There is some uncertainty as to what proportion of subjects with scotomata caused by visual cortex lesions actually demonstrate blindsight [15, 16]. There are a number of reasons for this, among them the inherent difficulties in testing by 'forced-choice guessing', the common extension of the lesions beyond V1 (which in monkeys degrades residual capacity), or, contrariwise, the incompleteness of the V1 lesion itself. When residual capacities are demonstrated in the complete absence of V1, obviously they must be mediated by extra-striate pathways. But in some cases there may be small, spatially restricted regions of intact primary visual cortex which are not large enough to support visual awareness [7], which could provide an alternative basis for residual function to that of mediation by extra-striate pathways. There is a view that blindsight is found only when there are fragments of intact V1. However, this cannot be a general explanation, either for the results with monkeys (where the completeness of V1 lesions is directly confirmed) or for a human case of blindsight where 'islands' of residual function are not found [8], despite careful controls with eye-tracking. Finally, animal evidence makes it clear that the age at which at striate cortex lesion occurs is an important variable in determining final outcome of residual capacity.

The current study draws on the findings of recent animal experiments showing differential effects of early vs late V1 lesions in monkeys. A human subject, GY suffered his V1 lesion in childhood, at the age of 8 years. Moore et al. [10] found with mature animals that target detection within areas corresponding to cortical damage was

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improved from chance if a visual warning signal presented in an intact region of the field preceded the presentation of stimuli. In contrast, infant-lesioned animals performed the same task well above chance without the need for an alerting cue [11]. If this difference between early and late lesioned monkeys reflects differences observed in human blindsight observers, then we might also expect to find that the residual vision of GY is not wholly reliant on cueing. It is the results of such a study that we now report. In addition to testing the effects of temporal cueing in GY's right 'blind' hemifield, we also evaluate its effect in his undamaged left hemifield using near-threshold stimuli.

2. Subject

GY is an 40-year-old male who acquired a dense right-field hemianopia at the age of 8 years as a consequence of a road accident. He has been extensively studied and further details are available elsewhere [2, 4]. Head-damage caused by the accident resulted in intracranial haemorrhage which was followed by unilateral, localised degeneration of the left occipital lobe. GY is clinically blind in his right hemifield but retains about $3°$ of macular sparing. This homonymous hemianopia is consistent with computerised tomography (CT) [4] and magnetic resonance images (MRI) [3] which show complete unilateral damage to the left striate cortex with the exception of tissue associated with the macular sparing.

3. Method

The task was to identify in which of two locations a target was presented in a spatial two-alternative forced choice paradigm (spatial 2AFC). In addition, on each trial the subject was asked to make a second manual response indicating whether he had had any awareness of an event occurring during the trial.

The experiment was conducted in blocks of 100 trials, using an Apple Powerbook 5300cs computer driving an Apple 12″ Color CRT monitor. The subject was seated 57 cm from the display and used a combined chin and head rest. Throughout each trial the subject was required to fixate a central cross subtending $0.75°$, with luminance of 2.5 cd.m^{-2} against a background of 71.5 cd.m^{-2} (93% contrast). Fixation was monitored with an infra-red camera and stability was judged by the continuous monitoring of the magnified image. The two possible target locations were both at an eccentricity of $6.3°$ ($6°$ above and $2°$ right of fixation and $2°$ above and $6°$ right of fixation), well outside GY's region of macular sparing. A target was a $1.5°$ diameter disc presented for 0.4 s.

Three target contrasts, high (2.5 cd.m^{-2}, 93% contrast) medium (28.5 cd.m^{-2}, 43% contrast) and low (45.5 cd.m^{-2}, 22% contrast) were used in separate blocks of trials (3 blocks of high, 4 of medium and 4 of low contrast). The order of block presentation was random.

Each trial lasted for 10 s. Information about the approximate time at which a target might be displayed could be presented by brightening the fixation cross to a luminance of 40.5 cd.m^{-2} (28% contrast) for 0.2 s. Such cues could occur at one of five evenly spaced presentation times during each trial (1.5, 3.15, 4.8, 6.45 or 8.1 s). The target could appear 1.5 or 0.5 s before or after a cue was presented. In addition, 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. In each block there was one trial of each of these conditions, for each cue presentation time, in each target location ($5 \times 5 \times 2 = 50$ trials). Another 50 trials matched these conditions exactly apart from the fact that no cue was presented. The overall design, excluding the no-target trials, therefore has the following independent variables: cue-present (yes/no), cue-target order (cue-precedes target, cue-follows target), cue-target delay (0.5 s, 1.0 s), where stimuli are presented at every cue-presentation time and each target location, for each condition. The order of trials within a block was randomised.

On a second occasion the subject's left field was tested with stimuli having near threshold contrast. The procedure was identical to the right-field tests with the exception of the target locations, $6°$ above and $2°$ left of fixation and $2°$ above and $6°$ left of fixation, and luminance of 67.5 cd.m^{-2} (yielding a contrast of 3% against a 71.5 cd.m^{-2} background). Only this one very low contrast was tested in the left-field over four successive blocks of trials.

4. Results

The good and bad field results were analysed separately. As no effects of the length of cue-target delay were found this factor has been collapsed in the following analyses. The proportion of correct responses in each remaining condition is shown in Fig. 1.

4.1. Right-field analyses

Two-tail binomial tests of the overall level of performance in the right field showed that it remained significantly above chance in all conditions, even after Bonferroni correction for 16 comparisons (12 right field tests and 4 left field tests). The performance obtained in the low-contrast condition in which the cue followed the target would only have been expected by chance with a probability of less than 0.005 (after correction), in all other cases the probability was below 0.0005 (after correction). Removing all trials in which awareness was reported in the low-contrast condition leaves performance above chance at the same significance levels
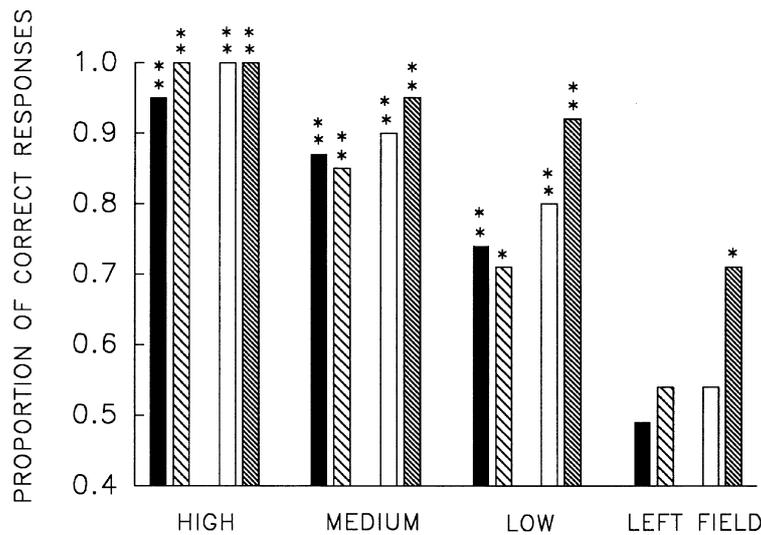
Fig. 1. The proportion of correct discriminations are shown for high (93%), medium (43%) and low (22%) contrast targets presented in the subject's right visual field and near-threshold (3% contrast) targets presented in his left visual field in a spatial 2AFC task. The first pair of bars in each set shows performance with no cue present, the second pair show performance when the target precedes and when the target follows the cue (the presentation times of targets in the first pair of bars are matched with those in the second pair). Each bar is derived from 40 trials in the medium and low contrast and left field conditions and 30 trials in the high contrast condition. Symbols above the bars indicate the 2-tail binomial probability after Bonferroni correction for 16 comparisons of obtaining these scores by chance. Two asterisks indicate $P < 0.0005$, one asterisk indicates $P < 0.005$. Bars with no asterisk above them represent scores which do not differ significantly from chance.

($P < 0.005$ and $P < 0.0005$ after correction) in all conditions.

It appears by inspection that in the medium and low contrast conditions there is some improvement in performance when any cues are presented (the second pair of bars in each condition is higher than the first pair) but that this increase is far more marked when the target follows the cue (the final bar in each condition is highest). These conclusions are confirmed by a hierarchical loglinear analysis of frequencies from the medium and low contrast conditions which show significant interactions between cue-presence and discrimination ($\chi^2 = 12.583$, df 1, $P < 0.0005$) and between cue-presence, cue-target order and discrimination ($\chi^2 = 5.766$, df 1, $P < 0.05$). There is also a significant interaction between target contrast and discrimination ($\chi^2 = 12.583$, df 1, $P < 0.0005$). There were no other significant effects in the loglinear analysis.

The proportion of trials when a target was present and produced some awareness were 98% (225/240), 26% (84/320), 4% (13/320) in the high, medium and low contrast conditions respectively. Awareness was only reported in one of 220 trials where no target was presented. The extremity of these proportions prohibits loglinear analysis of any further detailed breakdown of these commentary data.

4.2. Left-field analyses

The overall level of performance in the left field is at chance in all but the effective cueing condition (where the target follows a cue) where the two-tail binomial probability of finding the observed performance (57/80 = 71% correct) by chance is less than 0.005 after Bonferroni correction for 16 comparisons. Removing all trials in which awareness was reported reduced performance to chance levels in all conditions (in the effective cueing condition performance was reduced to 59% correct (32/54), which is not significantly different from chance even before Bonferroni correction).

A hierarchical loglinear analysis of frequencies from the left field data shows significant interactions between cue-presence and discrimination ($\chi^2 = 4.210$, df 1, $P < 0.05$) and between cue-presence, cue-target order and discrimination ($\chi^2 = 4.210$, df 1, $P < 0.05$). There were no other significant effects in the loglinear analysis.

The proportion of trials when a target was present which produced some awareness was 17% (53/320) overall. There was 30.0% (24/80) awareness in trials where the target followed a cue, but only 9% (29/240) in trials where there was no cue or one which followed the target. Awareness was only reported in one of the 80 trials where no target was presented.

5. Discussion

The answers to three questions can be sought in the results of this experiment. First, does GY have residual vision in the absence of cueing? Second, does cueing improve his residual vision? Third, do the answers to these two questions differ in his right and left visual fields?

GY's performance in his blind field remained significantly above chance in all conditions, including those where cues were not presented, or where they followed the appearance of the target. In this he resembles the monkeys sustaining a lesion in infancy rather than those operated on in adulthood [11]. Although GY's uncued performance was above chance, it was poor compared with the uncued performance of the infant-lesioned monkeys reported by Moore et al. [11]. It is not possible to determine whether this reflects a true difference between GY's abilities and those of the infant-lesioned monkeys since there are a number of procedural differences between the present experiment and that of Moore et al. [11]. In particular, the present experiment is two-alternate forced choice whereas the latter study used a localisation task with 20 target locations per hemifield and recorded an eye-movement response to a target location rather than a manual indication of target location, and finally, the trial duration in the present experiment is longer than that used by Moore et al. [11] (10 s vs. 3 s). It is quite possible that, although the number of alternatives which must be discriminated among is larger in the design of Moore et al. [11], its shorter trial duration and the nature of the response both favour discrimination without awareness or cueing.

The results clearly show that the presence of a cue improved GY's residual vision in all cases where it was not already near perfect. This improvement was present in both of the lower contrast conditions, showing that it did not depend on the subject having awareness of events in his scotoma (even though his discrimination performance and the proportion of aware trials differed greatly between these levels of contrast). Although the effect was largest when the target followed the cue there was still some advantage when the target preceded the cue, suggesting that the cue may have facilitated GY's ability to monitor recently processed events as well as prepare to monitor the processing of upcoming ones.

The effect of cueing on performance might be interpreted as showing that GY's performance is, in some ways, similar to that of the adult-lesioned monkeys described by Moore et al. [10]. Analysis of GY's performance with near-threshold targets in his intact visual field shows, however, that temporal cueing improves discrimination in normal as well as residual vision. Performance of the infant-lesioned monkeys in Moore et al. [11] was near ceiling and no evidence is presented as to whether it could have been improved by cueing. The presence of a cueing effect per se cannot therefore be used to distinguish between different types of residual vision or normal near-threshold vision.

Regardless of the inferences one can draw about similarities between GY's performance and that of early and late-lesioned monkeys it is clearly of interest that GY's ability to make discriminations without awareness can be improved by an alerting cue. It remains to be seen whether this is an example of attention without awareness (see [9], p. 1122 for a discussion of possible roles for attention without awareness in spatial localisation) or simple arousal.

It has been suggested that blindsight is simply normal vision with poor discrimination [5]. High levels of blind-field performance are explained as being a result of a relaxation of the detection criterion subject sets themselves, which compensates for poorer discrimination. If this were the case then one might expect to find correlations between measures of discrimination obtained from commentary-key and 2AFC performance, in good and bad fields, for approximately similar levels of performance—for example, between the low-contrast blind field condition and the near-threshold good-field one. 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, in his reports of awareness, is much poorer in the blind field than in the good field near threshold (although it is, of course not good in either case, the non-parametric measures of discrimination A' [12] being 0.5002 and 0.5084 for the blind and good fields, respectively). His 2AFC location discrimination is better in the blind-field $(187/240 = 0.78)$ than in the good $(182/320 = 0.57)$ even though his discrimination of target presence, revealed through awareness commentary, is poorer. These results are consistent with those of another study [1] which 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 control subjects was similar in both tasks.

We can conclude that GY's blindsight is qualitatively different from near-threshold normal vision; that, in common with infant-lesioned monkeys his blindsight remains even in the absence of temporal cues; and finally, that it is subject to modulation by attentional processes, or arousal, associated with temporal cueing. Whether the same is true of the blindsight found in islands of spared cortex [7, 17] remains to be seen.

Acknowledgement

References

[1] Azzopardi P, Cowey, A. Is blindsight like normal, near-threshold vision? Proceedings of the National Academy of Sciences U.S.A. 1997;94:14190–4.

[2] Barbur JL, Ruddock K, Waterfield VA. Human visual responses in the absence of geniculo-calcarine projection. Brain 1980;103:905–28.

[3] Barbur JL, Watson JDG, Frakowiak RSJ, Zeki S. Conscious visual-perception without V1. Brain 1993;116:1293–302.

[4] Blythe IM, Kennard C, Ruddock KH. Residual vision in patients with retrogeniculate lesions of the visual pathways. Brain 1987;110:887–94.

[5] Campion J, Latto RM, Smith YM. Is blindsight an effect of scattered light, spared cortex, and near threshold vision? Behavioral and Brain Sciences 1983;6:423–48.

[6] Cowey A, Stoerig P. The neurobiology of blindsight. Trends in Neurosciences 1991;114:140–5.

[7] Fendrich R, Wessinger M, Gazzaniga MS. Residual vision in a scotoma: implications for blindsight. Science 1992;258:1489–91.

[8] Kentridge RW, Heywood CA, Weiskrantz L. Residual vision in multiple retinal locations within a scotoma: implication for blindsight. Journal of Cognitive Neuroscience 1997;9:191–202.

[9] Milner AD. Cerebral correlates of visual awareness. Neuropsychologia 1995;33:1117–30.

[10] Moore T, Rodman HR, Repp AB, Gross CG. Localization of visual stimuli after striate cortex damage in monkeys: parallels with human blindsight. Proceeding of the National Academy of Science, U.S.A. 1995;92:8215–8.

[11] Moore T, Rodman HR, Repp AB, Gross CG, Mezrich RS. Greater residual vision in monkeys after striate cortex damage in infancy. Journal of Neurophysiology 1996;76:3928–33.

[12] Pollack I, Norman DA. A nonparametric analysis of recognition experiments. Psychonomic Science 1964;1:125–6.

[13] Pöppel E, Held R, Frost D. Residual visual function after brain wounds involving the central visual pathways in man. Nature 1973;243:295–6.

[14] Weiskrantz L. Blindsight: a case study and implications. Oxford: Oxford University Press, 1986.

[15] Weiskrantz L. Blindsight revisited. Current Opinion in Neurobiology 1996;6:215–20.

[16] Weiskrantz L. Consciousness lost and found. Oxford: Oxford University Press, 1997.

[17] Wessinger M, Fendrich R, Gazzaniga MS. Islands of residual vision in hemianopic patients. Journal of Cognitive Neuroscience 1997;9:203–221.