The neuropsychological phenomenon of blindsight is observed when patients who are cortically blind exhibit residual visual processing capabilities for stimuli presented within their scotoma to which they are otherwise unaware. Cortically blind patients may also exhibit the phenomenon of pathological visual completion in which, paradoxically, they can become aware of a complete visual stimulus even when a significant portion of that stimulus falls within their blind hemifield. In this study, the ability of a blindsight patient (G.Y.) to use visual information to control reach-to-grasp movements to static objects presented within his blind hemifield was investigated. The results indicate that while G.Y. was insensitive to variations in object size when reaching for objects presented entirely within his blind hemifield, his ability to accurately grasp objects located within his blind field was vastly improved if part of the object to be grasped extended into his seeing hemifield. This finding demonstrates that visual awareness can facilitate the visuomotor processing of object form within G.Y.’s apparently blind field, and suggests that the primary deficit in blindsight may be an impairment of visual consciousness rather than an absolute loss of visual function. NeuroReport 10:2461–2466 © 1999 Lippincott Williams & Wilkins.

Key words: Blindsight; Hand movements; Reaching; Reach-to-grasp; Visual completion

Introduction

The phenomenon of blindsight has proven to be of considerable interest to neuroscientists because of its potential implications for delineating the neural correlates of visual awareness [1,2]. Blindsight is observed when patients who are cortically blind (typically following damage to primary visual cortex) exhibit residual visual processing capabilities for stimuli presented within their scotoma (blind region) to which they are otherwise unaware. Such residual capabilities can include saccadic and manual localization of target stimuli, and the discrimination of stimulus orientation and the direction of stimulus motion [2].

Demonstrations of spared visual capacity in brain injured patients, including those exhibiting the phenomenon of blindsight, together with psychophysical investigations of visuomotor performance in healthy adults (e.g., [3–5]) have provided evidence for a functional and anatomical dissociation between the visual processes used to guide action and those required for perceptual report. Thus, Milner and Goodale propose a distinction between a ventral stream of visual processing mediating visually guided action [6–8], and have argued that demonstrations of blindsight can be understood as a collection of residual visuomotor responses that depend upon relatively independent neural circuits linking subcortical structures with cortical regions associated with the dorsal visual processing stream [8]. Importantly, within this perspective visual awareness is assumed to be generated separately by processes linked to visual perception and object recognition, which lie within the ventral processing stream [9,10].

While the two visual systems viewpoint of Milner and Goodale can be seen as a useful heuristic, several lines of evidence suggest that there may be cross-talk between the mechanisms responsible for visual perception and those responsible for visually guided action [11,12]. Furthermore, several studies have also demonstrated that stimuli presented within the blind field of hemianopic patients, of which they are unaware, may nevertheless be processed to a high (semantic) level of visual description [13]; consistent with the position that blindsight may also reflect non-conscious visual perception as well as residual visuomotor mechanisms. Thus, Marcel demonstrated that the semantic interpretation of an ambiguous...
word presented within the seeing fields of two hemianopic patients was reliably and consistently biased by the meaning of words presented within their blind hemifields, of which they were unaware [13].

Cortically blind patients may also show the converse pattern of behaviour, in which stimuli presented within the patient's seeing field change how a visual stimulus presented within the 'blind' hemifield is processed. One important example of this pattern of behaviour is the phenomenon of pathological visual completion, in which hemianopic patients report seeing a complete visual stimulus even when a substantial part of the stimulus extends into the patient's blind hemifield [8,14–16] (for review see [17]). It is important to note that the phenomenon of pathological visual completion differs from blindsight in several important respects. Most importantly, whereas blindsight refers to the visual processing of a stimulus of which the subject is unaware, pathological visual completion refers to the situation in which the subject becomes aware of stimuli presented within the supposedly blind hemifield which, under other circumstances would remain outside of awareness.

The current study investigated whether the phenomenon of pathological visual completion (generally believed to be dependent upon mechanisms associated with object perception such as selective attention and spatial grouping [13,17]) extended to visuomotor processes associated with the control of hand action, and assumed to lie outside the realm of our conscious visual awareness [9,10].

Materials and Methods

Case report: At the time of testing, G.Y. was a 40-year-old man who had sustained brain injury as a result of road traffic accident when he was aged 8. G.Y.'s accident resulted in damage to the primary visual cortex (V1) of his left hemisphere, producing an almost complete hemianopia of the right visual field (he has a small area of macular sparing which extends ~3° into his right visual field). G.Y. has been tested on numerous occasions and consistently reports that he cannot see static stimuli presented under normal illumination within his blind field. He does, however, report having some awareness of high contrast transients, and of stimuli moving in excess of 10–15°/s [18,19].

There were two reasons for studying G.Y. within the current investigation: first, the characteristics of G.Y.'s residual vision and his brain pathology have now been investigated over a number of years, using a variety of psychophysical and brain imaging techniques (e.g. [18–22]). Second, G.Y. was one of the two patients studied by Marcel who were reported to exhibit visual completion for stimuli extending into their blind hemifield.

Procedure: During Experiments 1 and 2, G.Y. was seated at a matt black table and executed reach-to-grasp movements using his left or right hands to target objects (rectangular wooden blocks painted red) presented to the left or right of his mid-sagittal plane. Movements began from a single starting position located 10 cm in front of his body on the mid-sagittal axis. To avoid spatial uncertainty regarding target location, targets were presented at a single location in G.Y.'s seeing (left) or blind (right) hemifields, and he was provided with a large number of practice trials to enable him to learn the position of the target object. Targets were presented against a matt black background, perpendicular to an imaginary line running between the starting position and a point (~20 or +20 degrees) to the left or right of the mid-sagittal axis, at a height of 32 cm above the table top in each case. The distance separating the target from the starting position was 28 cm. Preliminary testing confirmed that, as previously reported for this subject [18,19], G.Y. was completely unaware of static objects presented at this location within his blind field.

In Experiment 1 target object orientation was manipulated. In this case the target object consisted of a 10 × 7 × 2 cm wooden block presented with its longest edge in one of four orientations (Fig. 1A). Clockwise these were 0° (vertical), 45°, 90° (horizontal) and 135°. G.Y. completed 12 trials (six with each hand) to each target orientation in his seeing and blind fields. Reaches into each field were blocked and presented within a randomised ABBA design. The order of presentation of target object orientations was randomised within each block. In Experiment 2 target object width was manipulated. Targets measured either 10 × 5 × 2 cm, 10 × 7 × 2 cm or 10 × 10 × 2 cm (Fig. 2). G.Y. completed 12 trials (six with each hand) trials to each target width in his seeing and blind fields. Reaches into each field were blocked and presented using a randomized ABBA design. The order of presentation of target object width was randomised within each block.

Throughout both experiments, G.Y.'s head was held in place with a chin rest and he fixated a white target sphere (1 cm in diameter) presented at a height of 32 cm on the mid-sagittal axis. To ensure that changes of fixation did not occur, G.Y.'s eye movements were continuously monitored using a head-mounted infra-red eyetracking device (Skalar), and any trials on which a change in fixation occurred were rejected. As G.Y. is highly experienced at maintaining fixation during testing, <1% of trials
were rejected throughout Experiments 1–3. G.Y.’s hand movements were recorded using electromagnetic sensors (Ascension Technologies Inc.), placed on the distal portion of the thumb and index finger of his reaching hand. Data were sampled at 100 Hz and analysed off-line using in-house software. Raw data were filtered using a 4th order dual-pass Butterworth filter with a cut-off frequency of 10 Hz.

In Experiment 3 target object width was again manipulated, however, targets were now presented across the mid-sagittal axis. Six target widths were used, increasing in width in 1 cm increments from $10 \times 5 \times 2$ cm to $10 \times 10 \times 2$ cm (see Fig. 3A). Targets were presented at a single location, located 28 cm from the starting position of the hand, on the mid-sagittal axis, at the same height as in Experi-
ments 1 and 2. The left hand edge of each target object was located 2.5 cm from the mid-sagittal axis, i.e. within G.Y.’s left (seeing) hemifield, while the remainder of each target extended different distances into his blind field. A circular fixation mark was fixed in an identical position on each object, 5 cm above the bottom edge of each target on the left hand edge (see Fig. 3A).

Results and Discussion

Experiments 1 and 2 examined G.Y.’s ability to process the attributes for static objects presented within his blind and seeing hemifields. In Experiment 1, G.Y. was required, while maintaining central fixation, to reach out and grasp, using a precision grip, wooden blocks presented randomly in one of four orientations (0°, 45°, 90° and 135°) within his blind or his seeing hemifield. G.Y.’s reach-to-grasp movements were recorded using an electromagnetic recording device, and the spatiotemporal pattern of his hand movements were reconstructed off-line. His ability to process object orientation was assessed by measuring the orientation of his grip (i.e. the opposition axis formed by his finger and thumb) immediately prior to making contact with the target object. As grip orientation is typically perpendicular to the principal orientation of the target object, G.Y.’s grip orientation was expected to vary systematically with object orientation. As can be seen from Fig. 1A, grip orientation for reaches to targets presented in G.Y.’s seeing field varied systematically with target orientation as expected. While grip orientation for reaches directed into G.Y.’s blind field were considerably more variable (Fig. 2A, lower panel) than those directed into his sighted field, linear statistical analyses, nevertheless, show grip aperture to be significantly correlated with target orientation (Fig. 1B) for reaches directed into both G.Y.’s seeing (R = 0.97, p < 0.0001) and blind (R = 0.58, p < 0.0001) hemifields. These findings confirm previous reports that blindsight may extend to orientation discrimination during reach-to-grasp movements [13,23].

Experiment 2 investigated G.Y.’s ability to process visual information signalling object size. In this experiment, the width of the target objects presented in G.Y.’s seeing and blind hemifields was manipulated. G.Y. executed reach-to-grasp movements toward three different sized wooden blocks (7.5°, 10° and 14.7° of visual angle) presented within his seeing or blind hemifields. To assess G.Y.’s ability to process visual information signalling object width, the maximum grip aperture (separation between finger and thumb) reached on each trial prior to object contact was measured. As can be seen from Fig. 2, for reaches executed by G.Y. toward objects

![Graph of grip aperture scaling experiment](image-url)

**FIG. 2.** Results of the grip aperture scaling experiment. The left panel shows details of the three different-width objects presented in the study. The right hand panel shows maximum grip apertures (finger–thumb opposition axes) for reach-to-grasp movements executed by G.Y. toward objects of different widths presented in his seeing and blind hemifields.
presented into his seeing hemifield, maximum grip aperture decreased systematically as object size decreased. In contrast, for reaches executed toward objects presented into his blind hemifield, maximum grip aperture did not vary with changes in object width. Instead, G.Y. appears to adopt a strategy in which he adopts a wide grip aperture on all trials regardless of the objects’ actual width. These differences were confirmed statistically using a repeated-measures ANOVA which revealed a significant interaction effect involving visual hemifield and target object size (F(2,22) = 31.5, p < 0.0001).

Walker and Mattingley [17] argue that methodological factors may often be critical in accounting for reports of pathological visual completion, a key factor being whether evidence of residual vision was adequately assessed. In this context, Experiment 2 demonstrated that under the experimental conditions of this investigation, G.Y. was unable to use residual visual information signalling object size to scale his grasp aperture during reach-to-grasp movements directed to objects presented within his blind hemifield (c.f. [13,23]).

Experiment 3 investigated whether pathological visual completion extended to G.Y.’s visuomotor responses. As was the case in Experiment 2, the width of the target objects presented for G.Y. to reach out and grasp was manipulated. In this experiment, however, the target objects were presented so that they spanned the mid-sagittal axis, extending from G.Y.’s seeing field into his blind hemifield (Fig. 3A). The experimental procedures used were similar to those of Experiment 2, and the magnitude of maximum grip aperture was again used to assess visuomotor processing of object size. On each trial G.Y. fixated a mark situated at the same position on the left hand edge of each object. Thus, in all cases, the right hand edge of each object extended into G.Y.’s hemianopic field, well beyond his region of macular sparing. Eye movements were recorded throughout the experiment using an infra-red oculo-motor tracking device, and trials where eye movements occurred were rejected. The results of this experiment are presented in Fig. 3B which shows the maximum grip aperture for each of the six object widths. Inspection of this figure shows quite clearly that, in contrast to Experiment 2, G.Y. systematically scales his grip aperture to the size of the target object (F(5,95) = 6.4, p < 0.0001). It should be noted that the left hand edge of each object was presented in the same position, and that none of the target objects were ever presented symmetrically across the mid-sagittal axis. For this reason it is unlikely that G.Y. was able to scale his grip aperture based upon some high level perceptual filling-in mechanism based upon inferences regarding the properties of symmetrical objects. Instead, it appears that G.Y.’s ability to accurately scale his grip aperture in advance of making contact with the target object, was most likely based upon residual visual processing in his blind field that somehow benefited from visual analyses carried out simultaneously within his seeing field. In order to reach this conclusion it is necessary to rule out obvious experimental artifacts. To ensure that G.Y. was not able to use subtle variations in the visual properties of the target objects to cue him to object size we ran several control conditions. First, prior to this experiment we had several control subjects estimate the size of the target objects (rating items on a 1–6 scale) based upon the cues that would be available to G.Y. when he fixated on the left hand edge of each object. In all cases subjects were at chance in estimating the object size. Second, after completing Experiment 3, G.Y. was debriefed on the experiment and was asked to maintain fixation and estimate the size of the target objects (rating items on a 1–6 scale) presented on the midline. As was the case with controls, G.Y. was at chance at explicitly estimating target object size.

Conclusions

Psychophysical investigations of visuomotor performance in healthy adults together with the spared visuomotor capacities of brain-injured patients presenting with profound visual (perceptual) impairments have led several authors to propose a distinction between a ventral stream of visual processing mediating visual perception (object identification and object recognition), and a dorsal stream of visual processing mediating visually guided action [3,4,6–8]. Central to this viewpoint is the claim that visual perception and the visual control of action depend upon functionally distinct and anatomically separable brain systems, and that visual awareness is generated by processes linked to visual perception which lie within the ventral processing stream [9,10]. The phenomenon of pathological visual completion is generally believed to be dependent upon mechanisms associated with object perception [13,17] and, therefore, linked to operations associated with the ventral visual processing stream. The current study investigated whether pathological visual completion extended, in the hemianopic patient G.Y., to visuomotor processing associated with the control of hand action. The finding that G.Y. was able to correctly scale his grip aperture to the size of the object to be grasped only when part of the target object was presented within his seeing hemifield, suggests that the phenomenon of pathological visual completion may extend to visuomotor processing.
References


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