

Inhibitory Tagging of Locations in the Blind Field of Hemianopic Patients

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This study evaluated the potential contribution of extrageniculate visual pathways to oculomotor orienting reflexes in hemianopic patients. It tested whether extrageniculate pathways mediate inhibition of return (IOR)—a phenomenon characterized by slowed target detections at recently stimulated locations (Posner & Cohen, 1984). Because hemianopic subjects cannot overtly respond to stimuli presented within their hemianopic field, we utilized a spatial cueing paradigm that capitalized on the fact that IOR operates in spatiotopic coordinates. Subjects moved their eyes so that a cue and a target presented at the same spatial location were imaged successively onto blind and seeing portions of their retinas. One hemianopic patient showed a similar IOR effect from cues presented within both the seeing and the hemianopic fields. With a second hemianopic patient, only presentations of the cue to the subject's seeing field produced IOR. The explanation for this discrepancy is not evident. These observations highlight both the potential value and the pitfalls inherent in using "blindsight" as a window into human consciousness. © 1997 Academic Press

INTRODUCTION

In humans and nonhuman primates, most of the nerve fibers leaving the retina proceed through the lateral geniculate nucleus in route to primary visual cortex. This geniculostriate pathway is functionally dominant in human vision. Humans who become hemianopic due to destruction of the primary visual (striate) cortex are rendered clinically blind in the entire hemifield contralateral to the lesion and cannot see even salient signals, such as a waving hand, within the area of the scotoma (the blind area). They are unable to report such events and deny any awareness of them. In no other animal, including monkeys, do striate cortex lesions produce such profound and lasting blindness.

Despite this blindness, there is some evidence of preserved visual function within the hemianopic region. For example, experiments utilizing forced choice discrimination tasks have revealed that some hemianopic subjects can make above-chance judgments regarding the presence, movement, orientation, and location of stimuli presented within the area of the scotoma although the subjects deny seeing the stimuli (Barbur, Ruddock, & Waterfield, 1980; Stoerig & Cowey, 1989; Weiskrantz, 1987). This phenomenon has been labeled "blindsight" (Weiskrantz, 1986) to reflect the fact that subjects appear to show residual visual processing in the absence of conscious awareness.

The demonstration of blindsight has excited interest within both cognitive science

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and neuroscience. Students of cognition have been intrigued by the phenomenon because it affords precious insights into the nature of human consciousness (Marcel, 1980). Neuroscientists have endeavored to understand the physiological mechanisms that might mediate it. Although there is general agreement that some patients exhibit residual vision within the area of the scotoma, much debate has centered around the neuroanatomical substrate subserving blindsight. Two primary hypotheses have been advanced. The first contends that blindsight, at least in some instances, may be due to residual function within the primary (geniculostriate) visual pathway and that it reflects degraded cortical vision near the perceptual threshold. Support for this claim comes from recent findings by Fendrich, Wessinger, and Gazzaniga (1992) and by Wessinger, Fendrich, and Gazzaniga (in press) showing that with a two-alternative forced choice methodology several hemianopic subjects could detect and discriminate stimuli, for which they experienced no phenomenal awareness, in only a restricted portion of their hemianopic fields. The authors interpret this nonuniform distribution of residual function within scotomas as evidence that corresponding islands of functioning cortex within the patient's lesion are mediating performance. They argue that other anatomical structures that are not damaged would likely produce a uniform pattern of performance across the area of the scotoma.

A second hypothesis maintains that some instances of blindsight may be mediated by phylogenetically primitive extrageniculate pathways. These pathways are dominant in nonmammalian vision and proceed from the retina to midbrain structures such as the superior colliculus (Stein & Meredith, 1991). A set of results reported by Rafal, Smith, Krantz, Cohen, and Brennan (1991) supports this hypothesis. They found, in three patients, that a distractor signal presented within the area of scotoma slowed saccadic eye movements toward targets appearing in the intact ipsilesional visual field. Importantly, the saccades were slowed only when the distractor signals appeared in the temporal hemifield and the interference was specific to oculomotor responses. The restriction of the effect to distractors appearing in the temporal hemifield corresponds with the observation in cats that the superior colliculus is innervated primarily from the nasal hemiretina, which represents the temporal hemifield.² The specificity of the effect to oculomotor responses is also indicative of collicular function as this structure plays an important role in oculomotor behavior (Sparks & Glimcher, 1992; Stein & Meredith, 1991).

The patients tested by Rafal et al. (1991) did not exhibit blindsight as conventionally demonstrated. In a two-alternative forced choice discrimination task using the same stimuli that were employed in the saccade task, none of the patients was above chance at reporting the presence or absence of these stimuli in the blind field. The absence of conventional blindsight was a stringent selection requirement for patients in this study because its goal was to probe for evidence of extrageniculate vision that could not be attributed to residual cortical vision below the subjective threshold. It was concluded that, while some blindsight findings that have been reported may have been mediated by spared striate cortex, other visuomotor behaviors spared in the

² It is, however, the case that this anatomical asymmetry is much less complete in monkeys (Perry & Cowey, 1984; Williams, Azzopardi, & Cowey, 1995), and that temporal-nasal asymmetries might reflect mediation by extrageniculate pathways other than the retino-tectal pathway.

hemianopic field could be attributed to extrageniculate visual pathways (Zihl & Von Carmon, 1979).

The current experiment in hemianopic patients uses another visuomotor reflex, inhibition of return, as a putative marker of extrageniculate function. Posner and Cohen (1984) first demonstrated that a peripheral visual signal in normal adults not only reflexively summons attention and activates the oculomotor system (Posner & Cohen, 1980), but also generates a subsequent inhibitory tag that slows detection at the stimulated location. There are three sources of converging evidence for the extrageniculate mediation of inhibition of return (IOR). First, patients with progressive supranuclear palsy (PSP), a degenerative disorder of the midbrain, exhibit a deficiency in making vertical eye movements and do not show IOR in the vertical plane (Posner, Rafal, Choate, & Vaughn, 1985). Second, under monocular viewing conditions normal subjects show larger IOR for cues presented in the temporal hemifield than the nasal hemifield (Rafal, Calabresi, Sciolto, & Brennan, 1989), corresponding with the larger direct innervation of the superior colliculus by the nasal hemiretina. Finally, IOR can be activated by signals in the temporal hemifield of newborn human infants whose visual capacities are almost entirely limited to those mediated by extrageniculate pathways (Simion, Valenza, Umilta, & Dalla Barba, 1995; Valenza, Simion, & Umilta, 1994).

We studied IOR not only to seek further evidence for human extrageniculate vision, but also to investigate whether a spatiotopic representation of the external visual world that is independent of eye position can be maintained when vision is outside of awareness. Posner and Cohen (1984) demonstrated that IOR was mapped in "environmental" rather than retinotopic coordinates. They showed that, after a peripheral luminance change, the location tagged by the cue remained inhibited even if the eyes moved between the disappearance of the cue and the appearance of the target. Physiological studies in monkeys have shown that collicular visuomotor programs may be mediated by "spatiotopic" rather than retinotopic coordinates (Glimcher & Sparks, 1992; Mays & Sparks, 1980). Our experiment was designed to determine whether visual signals in the blind field of hemianopic patients would activate an inhibitory tag (an IOR) that would be maintained in a spatiotopic, rather than retinotopic, representation of space.

Measurement of IOR

In a typical experiment investigating IOR, a peripheral noninformative cue presented at one of several locations precedes the appearance of a target that requires a speeded response (Posner & Cohen, 1984). At short cue target intervals, target detection is typically faster at a cued location than a noncued location. This facilitation is thought to reflect a reflexive shift of attention toward the cued location that hastens the subsequent processing of the target. This pattern, however, is reversed at long cue target intervals where target detection actually becomes slower at the cued location than the noncued location. This slowing is the signature of the IOR phenomenon. In the present study, of course, we could not use the standard procedure for measuring IOR, because a hemianopic subject cannot see, and therefore cannot overtly respond to, a target presented within the area of the scotoma. Instead, we

used a paradigm that capitalized on the fact that IOR operates in environmentally based coordinates.

In our experiment, the hemifield in which peripheral cues appeared were blocked, and the cued and noncued locations were vertically aligned within that field. Following the presentation of a peripheral cue and before the appearance of a target, a central arrow appeared that signaled patients to initiate a saccade to a fixation point located midway between the cued and the noncued locations. After several practice trials neither patient had difficulty executing saccades to this prespecified location when it was within their blind visual field. In those blocks in which the cue was displayed within a subject's scotoma, the saccade displaced both the cued and the noncued locations into the subject's intact visual field, so that the patient was aware of, and could respond to, the subsequent target. Note that whether the peripheral cue appeared contralesionally or ipsilesionally, the target always appeared either above or below central fixation due to the execution of the saccade.

Critical Comparisons

The critical measure was whether the detection of a target would be slowed if it appeared at a cued location relative to a noncued location within the hemianopic field (i.e., the IOR phenomenon). This comparison was also made for cues appearing in the ipsilesional seeing field so that we could be confident that under normal viewing conditions patients showed IOR that was maintained in spatiotopic coordinates.

PATIENT F.N.

F.N. is a right-handed 57-year-old male who suffered a right posterior cerebral artery stroke in 1988. Magnetic resonance images (MRI) shown in Fig. 1 indicate the extent of the lesion. The lesion involved areas of the calcarine fissure (striate cortex), the precuneus, the lingual gyrus, the fusiform gyrus, and the posterior hippocampus. A second stroke in the left hemisphere damaged parts of the calcarine fissure and parts of the fusiform gyrus. The stroke produced a dense left homonymous hemianopia and a superior right homonymous scotoma. Figure 2 shows visual fields obtained in 1995 with Humphrey automated perimetry. Added onto the perimetry are the areas where Wessinger et al. (in press) reported "islands" of spared vision (circles) and our stimulus locations (squares). Both additions indicate only position and not the actual size of the islands or our stimulus. One island is centered 9° lateral and $1^\circ 10'$ superior to fixation and the other is centered 16° lateral and $1^\circ 10'$ inferior to fixation. The area of each island covers less than $2^\circ 20'$ square (Wessinger et al., in press). Although the visual field regions where we tested have remained blind, a comparison of perimetric fields taken at different times following F.N.'s stroke indicates that there has been a modest spread of his region of macular sparing.

APPARATUS

Stimuli were generated on a 17-in. Apple color monitor controlled by an LC-III Apple computer. Luminance measurements were taken with a Spectra PR1500 spotmeter. Data collection was controlled by an external Biopac Systems Macpacq data

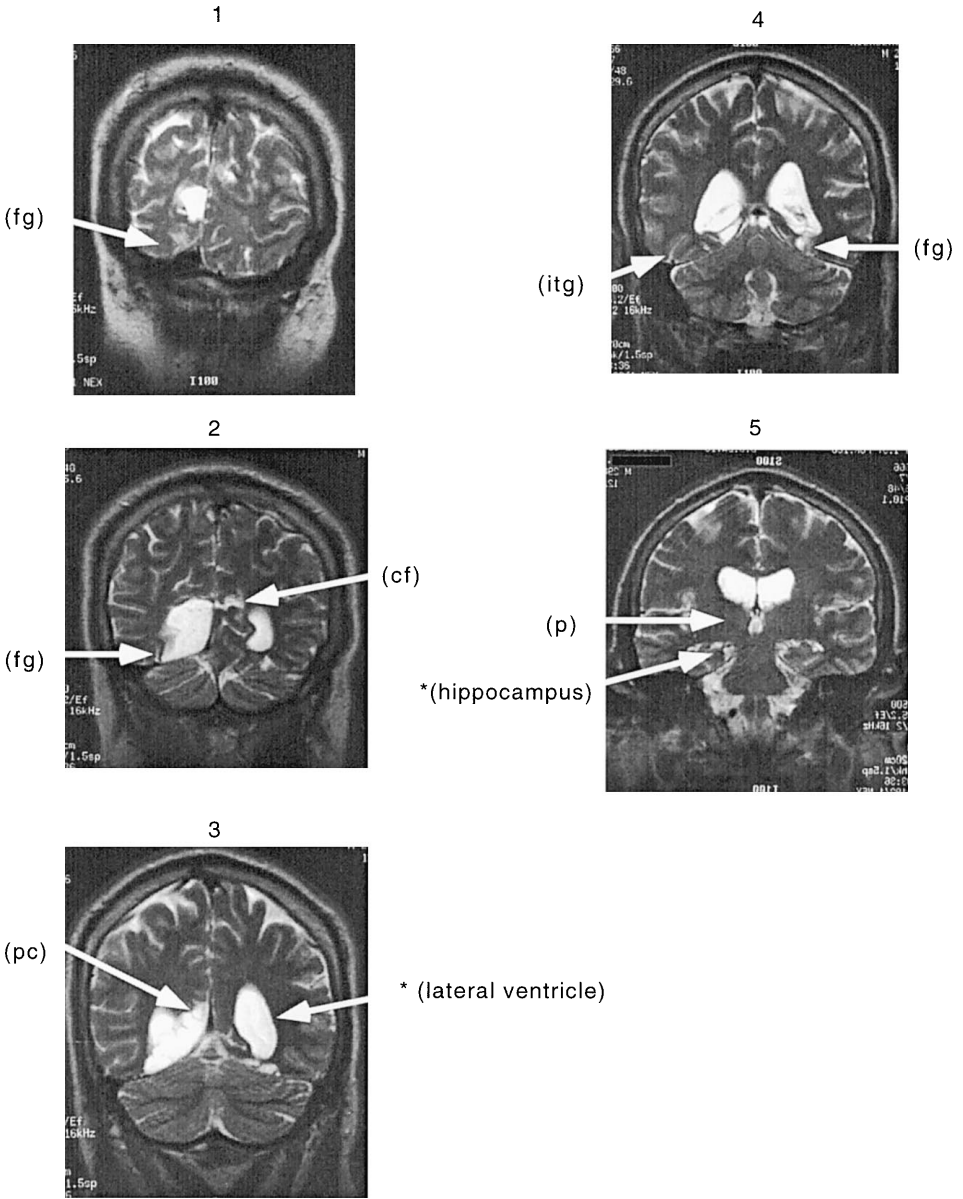


FIG. 1. T2 weighted coronal MR images showing the extent of F.N.'s lesion. The lesioned areas and the fluid-filled ventricles appear white. The white arrows indicate the location of the calcarine fissure (cf), precuneus (pc), pulvinar nucleus of the thalamus (p), fusiform gyrus (fg), and the inferior temporal gyrus (itg).

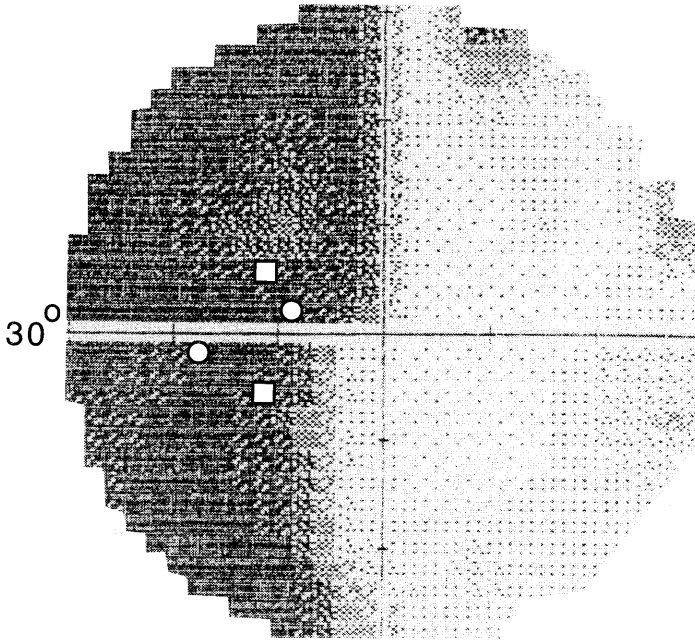


FIG. 2. F.N.'s visual fields obtained with a Humphrey automated perimeter. Dark regions depict areas in which vision is impaired. The darker the region, the more it is impaired. Added on to the perimetry are the areas where Wessinger et al. (in press) report islands of spared vision (white circles) and our stimulus locations (white squares). Both the circles and the squares indicate only location and not the actual size of the island or our stimulus.

acquisition unit that allowed responses to be sampled with millisecond (ms) accuracy. Subjects responded by pressing a button connected to the Macpacq. Eye position was recorded with a double Purkinje image eyetracker with $1'$ arc of resolution. The eyetracker was connected to an IBM PC-AT computer via a Data Translation digital to analog/analog to digital (DA/AD) interface board. The IBM collected, stored, and analyzed the eye-position record from the eyetracker. The IBM was also connected to the Macintosh via the Macpacq and DA/AD board. Using the output from the eyetracker, the IBM triggered the Macintosh to display the peripheral cue and central arrow only if the eyes were positioned within 1° of central fixation, and the target only if the eyes were positioned within 1° of the peripheral fixation point.

STIMULI

The constant display consisted of a white central fixation point, flanked by two white peripheral fixation points, 11° to the left and right, and four unfilled $4^\circ \times 4^\circ$ black peripheral boxes. The centers of these boxes were positioned equidistant from the central fixation point 5° above and below the horizontal meridian and 11° to the left and right of the vertical meridian. This display is illustrated in Fig. 3. The background was gray (20 cd/m^2). The peripheral cue was a $1^\circ \times 1^\circ$ black (2 cd/m^2) unfilled box that could appear at the center of one of the four placeholder boxes. The

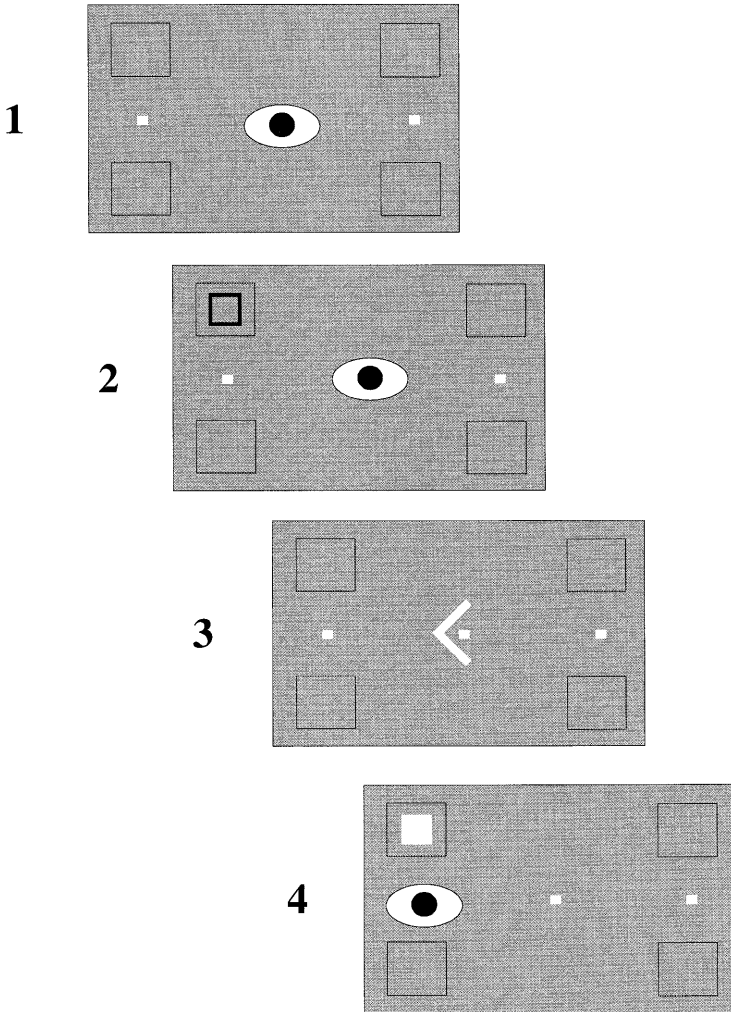


FIG. 3. The stimulus display and the sequence of events in the cueing task, including the location upon which the patients fixated during each stimulus event. At the beginning of a trial the eyes were at central fixation (1). If the eyes remained at fixation a peripheral cue appeared (2). Following the offset of the peripheral cue, a central arrow appeared indicating to shift the eyes to the peripheral fixation point (3). When the eyes were at the peripheral fixation point for 100 ms a target appeared either at the cued or noncued location within the cued hemifield (4).

target was a $0.5^\circ \times 0.5^\circ$ white (79 cd/m^2) square that could appear at the center of one of the four peripheral cue locations. The central white arrows that signaled subjects to saccade subtended $2^\circ \times 1^\circ$.

PROCEDURE

In each session F.N. sat 57 cm from the display monitor with his head position maintained by a bite bar. Because our eyetracker is a right-eye machine, he viewed

the display monitor monocularly with his right eye. His left eye was patched. Trials in both the cueing experiment and a preliminary localization task were initiated by the experimenter. The experiment was conducted in a dark room.

Forced Choice Localization Task

Patient F.N. previously participated in a study in which his hemianopic field was mapped for islands of spared vision within the area of the scotoma (Wessinger, Fendrich, & Gazzaniga, in press). Our goal was to avoid presenting cues in these islands, as we were interested in probing for extrageniculate vision. To ensure that performance was *not* sampled at island locations we had patients perform a preliminary forced choice localization task. In this task, F.N. was asked to determine at which of two locations a cue appeared within his hemianopic field. The cues used in the localization task were identical to those used in the subsequent cueing task and they appeared in the same locations: 11° to the left and either 5° above or below fixation. These are locations where Wessinger et al. previously found no indication of residual vision. However, in the localization task the “cues” did not serve a “cueing” function: they were themselves the stimuli to be detected.

Thirty-six localization trials were run: 12 trials in which the cue appeared at the top-left position, 12 trials in which the cue appeared at the bottom-left position, and 12 no-cue trials. During the localization trials the subject maintained fixation on a central point. At the start of each trial, a 100-ms warning tone sounded. Approximately 500 ms after the tone's offset (except during no-cue trials) a peripheral cue appeared for 200 ms at one of the two possible target locations within the hemianopic field. As in the subsequent cueing experiment, the presentation of the cues was contingent on F.N. maintaining accurate fixation. Therefore, the actual intervals between trial events were variable and those indicated reflect the shortest possible intervals that could occur. Three hundred milliseconds after cue offset a warning tone sounded for 200 ms, signaling F.N. to verbally indicate the location of the cue. Following his response, two warning tones indicated that the trial was over and that he should prepare for the next trial. During the no-cue trials, the sequence of audible signals was the same. The purpose of these trials was to determine whether F.N. had a bias in reporting one of the two locations.

In each of the five sessions we conducted, F.N. was never significantly above chance at reporting the location of the cue. Furthermore, he showed no systematic bias in reporting one of the two locations on no-cue trials. Given that we intentionally selected locations where Wessinger et al. did not find islands these findings are not surprising.

Cueing Task

Before initiating a cueing block, F.N. was informed of the hemifield in which the peripheral cues would appear and the direction in which he was to make a saccade. He was also informed that the target was equally likely to occur at the cued and noncued location within the cued hemifield (i.e., the cue was uninformative). Instructions emphasized both response speed and accuracy; i.e., F.N. was to press the re-

sponse key as quickly as possible when target onset was detected and to withhold a key press response in all other situations.

A trial began after F.N. established central fixation. A 100-ms warning tone sounded, and ~ 500 ms after tone offset a peripheral cue appeared for 200 ms at one of the two possible target locations within the tested hemifield. Approximately 300 ms after cue offset a central arrow appeared for 300 ms, indicating that F.N. was to saccade to the peripheral fixation point in the cued visual field. However, using the output from the eye-tracker, the IBM triggered the Macintosh to display the peripheral cue and central arrow only if the eyes were positioned within 1° of central fixation for at least 100 ms. The subject's saccade was monitored, and 200 ms after the eyetracker verified that his gaze was directed to within 1° of the peripheral fixation point, and had been maintained at this location for at least 100 ms, the target appeared at either the cued or the noncued location within the cued hemifield. The target was extinguished when a key press response was made with the index finger of the right hand or when 1500 ms had elapsed from the target presentation. Catch trials, in which there was no target, occurred approximately 12% of the time in blocks including no-cue trials and approximately 17% of the time in blocks without no-cue trials (see below). Locations of the cue and target were randomized for each test trial.

A practice block was given at the beginning of each session. Following the practice block we typically ran two blocks with the cues appearing in the contralesional hemifield (hemianopic field) and two blocks with the cues appearing in the ipsilesional field (intact visual field). Blocks were presented in an ABBA order across sessions, beginning with a block in which the cues appeared in the ipsilesional hemifield.

Patient F.N. participated in 11 blocks in which cues appeared in the contralesional field and 11 blocks in which cues appeared in the ipsilesional field. In the first 14 blocks (7 contralesional and 7 ipsilesional) there were 68 trials within each block: these were composed of 10 repetitions of each combination of cue location (top and bottom) and target location (top and bottom), for a total of 40 target present trials (20 valid trials and 20 invalid trials), 20 trials in which a target appeared without a preceding cue, and 8 no-target catch trials. The remaining blocks were identical except that they did not include the 20 no-cue trials. These no-cue trials were initially included because we noticed in pilot runs that F.N. detected targets faster following a contralesional cue than an ipsilesional cue. We speculated that this might be due to (a) contralesional cues producing a whole field facilitory effect, (b) ipsilesional cues producing a whole field inhibitory effect, or (c) a compensatory strategy on the part of F.N. If cues were producing whole field facilitory or inhibitory effects, we reasoned that target detection RTs on no-cue trials would be similar in the contralesional and ipsilesional cue blocks. This did not occur: target detection was faster on no-cue trials when they were embedded in a contralesional cue block than an ipsilesional cue block, suggesting that the speeded RTs were not due to the appearance of the cue per se, but rather reflected a compensatory strategy on the part of F.N. Therefore, the no-cue trial data for FN are not discussed further.

Trials in which F.N. responded before the target appeared, and trials in which an eye position error produced a delay exceeding 1 s, were repeated at the end of a block.

TABLE 1
Mean RTs in Milliseconds (ms) for Patient F.N.

	Scotoma (contralesional)	Seeing (ipsilesional)
Cued location	307	342
Noncued location	294	329
No cue	306	366

Note. Data are shown as a function of cue field (contralesional and ipsilesional) and cue validity (cued, noncued, and no cue). The no-cue data represent seven blocks each in the contralesional and ipsilesional field.

RESULTS

For all conditions and test sessions a trimmed mean reaction was calculated for correct responses in the range of 100 to 1500 ms. These means are shown in Table 1. Trimming was accomplished by eliminating trials more than 3 standard deviations from preliminary means. Anticipatory responses ($RT < 100$ ms) occurred on 6/1000 trials and misses (failures to respond on a target present trials) occurred on 5/1000 trials. F.N. responded as if a target was present on 7/176 of the catch trials (false alarms). The analysis of variance (ANOVA) had Cue field (contralesional and ipsilesional) and Cue validity (cued and noncued) as factors.

There were main effects of Cue field [$F(1, 10) = 15.18, p < .005$], and Cue validity, [$F(1, 10) = 5.35, p < .05$], with target detection faster at a noncued location (311 ms) than at a cued location (324 ms), and faster following a contralesional cue (300 ms) than an ipsilesional cue (335 ms). More importantly, the two factors did not interact, [$F(1, 10) = 0.009, p = .922$], indicating that contralesionally presented cues led to IOR that was equivalent to that produced by ipsilesionally presented cues. Planned comparisons of the condition means support this conclusion. Following a contralesional cue, target detection is 13 ms slower at the cued location than the noncued location ($[t(1, 10) = 3.11, p < .05]$), while following an ipsilesional cue target detection is 12 ms slower at the cued location than at the noncued location ($[t(1, 10) = 2.36, p < .05]$).

DISCUSSION

The data for F.N. are remarkable. Cues appearing within the area of the scotoma led to IOR effects similar to those arising from cues appearing in the intact visual field. Because we selected cue locations where F.N. did not have islands of residual vision (Wessinger et al., in press), the data suggest that a spatiotopically based IOR may have been mediated by retino-tectal function. Thus, the data provide converging evidence that signals appearing within the area of a scotoma can elicit a reflexive orienting effect (Rafal et al., 1991). However, because we were interested in establishing the underlying anatomy of the IOR effect we observed, we attempted to replicate our findings with another hemianopic subject from the Wessinger et al. study. To

anticipate the data, this patient showed IOR only when cues were presented in his intact visual field.

PATIENT C.L.T.

C.L.T. is a right-handed 58-year-old male who suffered a right posterior cerebral artery stroke in 1987. Magnetic resonance images shown in Fig. 4 indicate the extent of the lesion. The lesion involved areas of the calcarine fissure (striate cortex), the lingual gyrus, the fusiform gyrus, the inferior temporal gyrus, and the hippocampus. A second lesion involved part of the right pulvinar nucleus of the thalamus. The stroke produced a dense left homonymous hemianopia, with some sparing in the central portion of the left inferior visual quadrant (quadrant macular sparing). Figure 5 shows visual fields obtained with Humphrey automated perimetry. Added on to the perimetry are the areas where Wessinger et al. reported an island of spared vision (circle) and our stimulus locations (squares). Both additions indicate only the location and not the actual size of the island or our stimulus. The island is centered 11.5° lateral and 7° superior to fixation and covers an area less than 2° square (Wessinger et al., in press).

EXPERIMENT

All experimental stimuli and procedures were identical to those used with patient F.N., except that the stimuli were generated on a 14-in. Apple color monitor controlled by an IICx computer. C.L.T. was tested at Dartmouth College.

Forced Choice Localization Task

In each of the three sessions C.L.T. participated in, he was either below or at chance at reporting the location of the cue in the forced choice localization task. Like F.N., C.L.T. showed no systematic bias in reporting one location over the other on no-cue trials. Again, these findings are not surprising as the cue locations (11° out horizontally and 5° out vertically) were locations where C.L.T. previously showed no indications of residual vision (Fendrich et al., 1992; Wessinger et al., in press).

Cueing Task

C.L.T. participated in 9 blocks in which the cues appeared in the contralesional field and 9 blocks in which the cues appeared in the ipsilesional field. As was the case for F.N. (blocks 1–14) the 68 trials within a cued hemifield were composed of 10 repetitions of each combination of cue location (top and bottom) and target location (top and bottom), for a total of 40 target present trials (20 valid trials and 20 invalid trials); 20 trials in which a target appeared without the preceding peripheral cue, and 8 catch trials. Like F.N., C.L.T. was overall faster to detect targets when they followed contralesional cues than ipsilesional cues. As was the case with F.N., on no-cue trials this pattern did not change, suggesting that the speeded RTs were not due to the appearance of the cue per se, but rather reflected a compensatory strategy on the part of C.L.T.

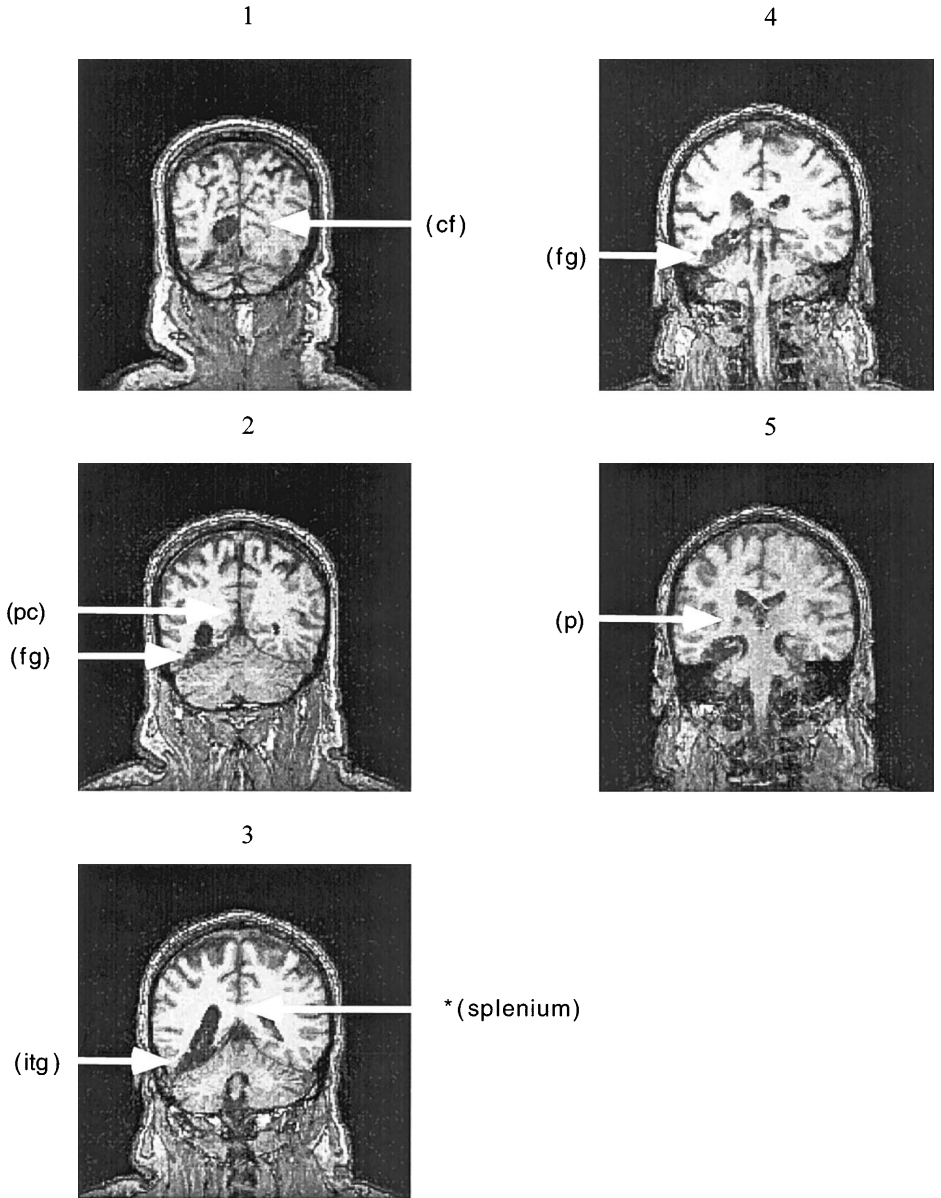


FIG. 4. T1 weighted coronal MR images showing the extent of C.L.T.'s lesion. The lesioned areas and the fluid-filled ventricles appear black. The white arrows indicate the location of the calcarine fissure (cf), precuneus (pc), fusiform gyrus (fg), inferior temporal gyrus (itg), and the pulvinar nucleus of the thalamus (p). Notice that C.L.T.'s lesion extends laterally relative to F.N.'s lesion (1) and includes parts of the inferior temporal gyrus but not of the precuneus. C.L.T. also has a lesion in the right pulvinar nucleus of the thalamus (5).

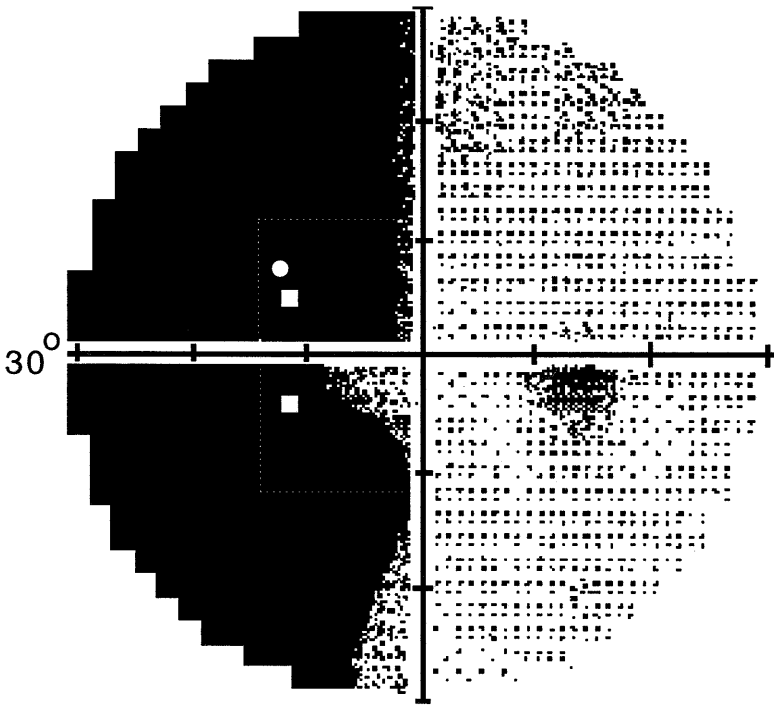


FIG. 5. C.L.T.'s visual fields obtained with a Humphrey automated perimeter. Dark regions depict areas in which vision is impaired. The darker the region, the more it is impaired. Added on to the perimetry are the areas where Wessinger et al. (in press) report islands of spared vision (white circle) and our stimulus locations (white squares). Both the circles and the squares indicate only location and not the actual size of the island or our stimulus.

RESULTS

The mean RTs and the ANOVA were extracted in the same way as with patient F.N. The RTs for each condition are shown in Table 2. Anticipatory responses ($RT < 100$ ms) occurred on 2/1080 trials and misses (failures to respond on a target present trials) occurred on 2/1080 trials. C.L.T. never responded on catch trials.

TABLE 2
Mean RTs in Milliseconds (ms) for Patient C.L.T.

	Scotoma (contralateral)	Seeing (ipsilateral)
Cued location	399	494
Noncued location	403	439
No cue	399	479

Note. Data are shown as a function of cue field (contralateral and ipsilateral) and cue validity (cued, noncued, and no cue).

There were main effects of Cue field [$F(1, 8) = 34.33, p < .001$], and Cue validity [$F(1, 8) = 19.87, p < .005$], with target detection faster at a noncued location (419 ms) than at a cued location (445 ms), and faster following a contralesional cue (401 ms) than an ipsilesional cue (463 ms). In contrast to patient F.N., there was a significant Cue field \times Cue validity interaction [$F(1, 8) = 20.89, p < .005$], reflecting the fact that following an ipsilesional cue, target detection was significantly slower [$t(1, 8) = 5.52, p < .001$] at a cued location (491 ms) than at a noncued location (434 ms) whereas following a contralesional cue, target detection at a cued location (399 ms) and a noncued location (403 ms) did not significantly differ [$t(1, 8) = 0.66, p = .52$]. Thus, C.L.T. showed IOR only at a cued location presented outside his hemianopic field.

DISCUSSION

The results in patient F.N. demonstrate that signals in his blind field can generate an inhibitory tag that slows the subsequent detection of targets at that spatial location after an eye movement has brought it into his seeing field. He did not show blindsight in a two-alternative forced choice (2AFC) localization task at the locations where signals produced this IOR. Thus, he was both unaware of the signals that activated the inhibitory tag and he had no access to information about their location, even to the extent that it could aid in their discrimination near the subjective threshold. F.N. has, however, previously shown blindsight in two other regions of his hemianopic field (Wessinger et al., in press). Together these findings highlight a distinction between at least two forms of residual vision in a scotoma and demonstrate that blindsight should not be regarded as a single entity or homogeneous phenomenon.

Although the different forms of blindsight represent vision without awareness and are of interest to students of consciousness, they may well have different physiological explanations. The islands of blindsight found in these two patients (Wessinger et al., in press) with a 2AFC detection task, may well reflect visual processing insufficient to generate subjective percepts within spared regions of striate cortex. The generation of IOR, however, is more likely to be mediated by subcortical extrageniculate pathways.

This dichotomy between the two types of residual vision is consistent with the special role of extrageniculate subcortical pathways in mediating visuomotor reflexes. Rafal et al. (1991) demonstrated that signals in the blind field activate the oculomotor system by showing that they slowed saccades to targets in the seeing field ipsilateral to the visual cortex lesion. This inhibitory effect was specific to oculomotor responses, was manifest only when the distractor signals were in the temporal hemifield, and was generated by stimuli that did not produce blindsight as measured in a 2AFC present-absent discrimination task.

Inhibition of return, the marker task used in the current study, has also been closely linked to midbrain visuomotor reflexes. It is disrupted by degenerative lesions of the peri-tectal region of the midbrain in patients with progressive supranuclear palsy (Posner et al., 1985) and is more robust when activated by signals in the temporal hemifield of normal adult subjects (Rafal et al., 1989). Further evidence that IOR is closely related to the oculomotor system was derived from the observation that IOR

could be produced by making a voluntary saccade, even in the absence of a peripheral visual signal (Posner et al, 1985, Rafal et al, 1989), and that it could even be activated by *preparing* a voluntary saccade, even if the saccade is not actually executed (Rafal et al., 1989).

The current results in patient F.N. provide further evidence for extrageniculate, subcortical mediation of visuomotor behavior in hemianopic humans (Rafal et al., 1991; Zihl et al., 1979). In addition they provide new information about the spatial coordinates in which subcortical visual systems represent the visual field. The previous studies of Rafal et al. (1991) and Zihl et al. (1979) were not informative on this issue, and the results could have been consistent with a very simple retinotopic representation. Posner and Cohen (1984) had shown that IOR could be mapped in spatiotopic (they used the term "environmental") rather than retinotopic coordinates. Using an adaptation of their procedure, the current experiments sought to determine whether environmental IOR could be generated in the absence of conscious awareness by signals in the blind field of hemianopics.

The studies of Mays and Sparks (1980) and Glimcher and Sparks (1992) demonstrated spatiotopic, not retinotopic, coding of oculomotor programs in monkey superior colliculus. Thus there is physiological evidence that midbrain visuomotor center can maintain a spatiotopic map of the visual field. It is not clear from these studies, however, whether this spatiotopic map can be derived exclusively from extrageniculate input to the colliculus, or whether cortico-collicular processing provides the visual afferents on which the spatiotopic map of the colliculus is generated. The current results in F.N. would seem to indicate that, if cortico-collicular input is needed to produce the spatiotopic representation, the striate cortex is not needed. This implication is puzzling, however, in view of certain anatomical findings. Investigations in animals indicate that projections from the retina to the colliculus go almost exclusively to its superficial layers. The intermediate and deep layers of the colliculus that mediate oculomotor behavior do not appear to receive much direct innervation from the retina. Moreover, they do not appear to receive much in the way of projections from the superficial layers. Thus, the regions of colliculus that are relevant to the current observations seem to obtain their primary visual input via cortico-collicular projections. There appear to be species differences with respect to the origin of these projections. In cats, cooling of striate cortex does not influence the visual responsiveness of cells in the deep layers of the superior colliculus, but cooling of posterior suprasylvian cortex abolished visual responses in deep layers of colliculus (Ogasawara, McHaffie, & Stein, 1992). In monkeys, however, cooling of striate cortex abolishes visual responses in deep layers of the colliculus (Schiller & Stryker, 1974). Thus, in primates, including presumably humans, the visuomotor neurons in the intermediate and deep layers of the colliculus may depend upon functioning striate cortex for their visual information. Notice that this suggestion is at odds with both our current findings in patient F.N. and with Rafal et al's. (1991) findings.

Developmental studies in human infants using a double-step saccade paradigm (Johnson, Gilmore, & Csibra, in press) have shown that babies do not begin to manifest a spatiotopic reference frame until about 6 months; prior to that age, the second saccade in the double-step paradigm is executed on the basis of retinotopic coordinates. Johnson and Gilmore suggested that the emergence of a spatiotopic, egocentric

reference frame is dependent upon maturation of parietal cortex. Whether this parietal representation requires input from primary striate visual cortex, or whether it can work with extrageniculate visual information from the colliculus (possibly via pulvinar nucleus of the thalamus), is an open question.

At present, we cannot explain why F.N. showed IOR in response to blind field stimulation while C.L.T. did not. We do note that while C.L.T.'s visual fields are stable, F.N.'s have continued to show a gradual improvement since his stroke. This raises the possibility that there is more diffuse cortical sparing in F.N. than in C.L.T. However, the fact that the extent of damage to primary visual cortex (calcarine fissure) is similar in both patients (Fig. 1 and 4) argues against this explanation. Another possibility is that the difference in behavior is related to differences in the extent of the extrageniculate lesion in the two patients. While the precuneus was involved in F.N. and the inferior temporal gyrus (ITG) was spared, the opposite was true for C.L.T. An attractive explanation of the difference between the two patients, however, lies in the presence of a lesion in the lateral pulvinar in patient C.L.T. The IOR effect measured in our experiment requires a spatiotopic representation of the visual field. While IOR may be generated through the retino-tectal pathway, the colliculus may not, itself, maintain a spatiotopic representation. Rather, the inhibitory tag generated in the midbrain may need to be transmitted to parietal cortex through the pulvinar to be encoded in spatiotopic coordinates. The pulvinar lesion in C.L.T. may prevent the transmission of the inhibitory tag to a cortically based spatiotopic representation. In any case, the question of why some patients show blindsight in a given task and some do not—a major problem in this field of inquiry—is in principle amenable to analysis. This analysis proceeds from the logic that the demonstration of blindsight has two requirements: First, the task must be one that can be done using visual information accessible through extrageniculate pathways; second, the cortex involved in the response required by the task must also be spared in the patient. Thus, a given patient may fail to demonstrate blindsight not because striate cortex is required for processing visual information, but because the extrastriate cortex necessary for the task at hand happens also to be lesioned in that patient.

Finally, there is also the possibility that the behavior observed in patient F.N. reflects a reorganization of subcortical visual pathways as a compensation for injury. This would account for the fact that the visuomotor regions of his superior colliculus seem to have access to a spatiotopic coordinate representation of visual space. In this case, patient F.N. may be idiosyncratic and C.L.T.'s results more representative of the operation of the normal human visual system. However, only the study of additional patients can clarify which patient is the exception and which is the rule.

What should be pointed out is that the inconsistencies of the current results are, unfortunately, typical of the blindsight literature. Most patients with hemianopia do *not* have blindsight, as indexed by above-chance discrimination performance without awareness. Most blindsight investigations have reported single cases. Few have attempted to study unselected groups of hemianopic patients in an effort to define the factors that account for blindsight in some patients and not in others. Given this state of affairs, the investigation of blindsight remains an exciting enterprise of enormous potential value to both cognitive and neural science, but one that is vexing and perplexing with more questions raised at this point than answers provided.

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