Sources of Blindsight

In their 1992 report, R. Fendrich *et al.* describe a patient (CLT) with an incomplete hemianopia who could detect and discriminate, but not consciously see, visual stimuli at isolated positions within his field defect (*1*). A nuclear magnetic resonance (NMR) scan of CLT's brain showed a small island of spared striate cortex in the damaged occipital lobe. Fendrich *et al.* hypothesize that this example of blindsight (and possibly others) is mediated by this striate cortical tissue.

There are three other hypotheses about blindsight; these place its anatomical basis in the retinocollicular pathway (*2, 3*), the sparse direct geniculo-extrastriate cortical projection (*4*), or the entirety of the retinal projections that survive damage to the striate cortex and its degenerative consequences (3, 5). The hypothesis favored by Fendrich *et al.* (*1*), previously advocated by Campion *et al.* (6), assumes that remnants of striate cortex that survive within areas of naturally occurring damage mediate blindsight. Fendrich *et al.* actually found two small islands of residual vision within the tested absolute portion of the field defect. At one position, CLT's detection of targets was 64% correct (chance would be 50%) and at the other it was 65%. Despite this small difference, the first island was dismissed because it did not yield statistically significant data after Bonferroni correction (for the first island, $n = 66$, as compared with $n = 166$ at the second). Fendrich *et al.* do not provide a topographical correspondence between the islands of blindsight and the island of tissue, nor do they point out that the other areas of reduced vision (in which CLT reported seeing the stimuli and showed a different pattern of residual functions) need a striate cortical substrate. In addition, Fendrich *et al.* seem to assume that the presence of visual cortical tissue on the NMR scan implies that this tissue is visually responsive, but only a functional NMR scan with excellent resolution within striate cortex (*7*) could possibly show visual responsivity. The evidence is therefore not sufficient to prove that CLT's residual vision is mediated by surviving remnants of striate cortex.

It is possible that such remnants participate in the mediation of residual vision. This, however, cannot be a *general* explanation of blindsight because residual vision has been observed after cerebral hemispherectomy (*8*); after complete surgical striate cortical ablation in nonhuman primates (*2, 3*); and after surgery in which the removed tissue excludes the possibility of remnants (9). In patients with traumatic or vascular lesions of the striate cortex, the presence of small remnants could be ruled out by pathology or by high resolution NMR imaging. So far, no postmortem studies of blindsight patients have appeared, but scans showing the absence of such tissue within lesions are now available (*10*). In addition, the behavioral properties of blindsight cannot be explained by this hypothesis.

If islands of striate cortical tissue were responsible, then blindsight should be demonstrable only within the topographically corresponding islands of visual function. However, both saccadic and manual localizations of stimuli presented briefly in visual field defects produce data that show a statistically significant correlation between stimulus eccentricity and the amplitude of the hand or eye movement (*11*). Stimuli are usually spaced 5° to 10° apart on one meridian, which implies that several such islands would have to remain visually responsive. The unexplained finding of Fendrich *et al.*, that CLT was unable to saccade to his island of vision, shows that such an explanation is unlikely; saccadic localization has often been reported, which implies that it is a robust residual visual function.

A study of eccentricity-dependent residual target detection in visual field defects showed that four out of five patients were able to respond to stimuli presented at 40° eccentric positions (*12*). For Fendrich *et al.* to be correct, nature would have had to spare islands of tissue at all of these positions. In another study, signal detection was tested at five positions in one patient, namely, 20°, 30°, 40°, and 50° eccentric in his incomplete hemianopic field, and at the position of the optic disc within this same field (*13*). Detection was statistically significant at all positions other than that of the optic disc. Thus, patients show significant detection or discrimination at visual field positions that are picked because they have the eccentricity appropriate for the tested function, and because they are well within the defect, to avoid artifacts from stray light scattered into the functional visual field. It seems unlikely that islands of blindsight would be distributed systematically in a naturally occurring lesion or that one could readily find them.

Fendrich *et al.* point out (*1*) that blindsight researchers use automized perimetry with a spatial resolution no better than 6°, so small functional islands could easily be missed within a field defect. Fendrich *et al.* used a computer setup with a spatial resolution of one stimulus per 2.5° horizontally and 2° vertically out to an eccentricity of 30° and complemented this with a Purkinje image eyetracker that eliminated shifts of fixation by stabilizing the retinal image. To my knowledge, no one has used automized perimetry with a resolution of only 6° for this kind of research. The Tübinger perimeter I use allows both static and kinetic perimetry of unlimited spatial resolution out to an eccentricity of 90° in both hemifields. In most studies, a patient's fixation during perimetry and during tests of residual visual functions is controlled with eye- or video-monitoring that allows a quantification of the amplitudes of fixation shifts (*14*). Not only are these small in practiced patients, but the microsaccades needed to retain a perceptual image of the fixation point do not move the test stimuli into functional portions of the field, as the stimuli are usually 10° or more from its border. Such saccades should enlarge islands of functional vision, as one can easily demonstrate by looking through a tiny peephole: When the eye is moved with the peephole, the area seen is enlarged. Thus, islands of vision should be easier to detect without an image stabilizer. It would have been desirable for Fendrich *et al.* to have performed manual perimetry for comparison with results they obtained with the use of the automized system and its eyetracking device. It would also have been useful to know whether perimetry without image stabilization would have enabled CLT to see something in the island of residual vision. Fendrich *et al.* do not comment on the fact that CLT did not see anything. If residual vision is mediated by striate cortical tissue, this requires an explanation, and so does the paradoxical implication that the nine or so retinofugal pathways that survive striate cortical ablation and its degenerative consequences are without function.

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10. Information about such scans can be obtained from me (P.S.) and from K. H. Ruddock, Department of Biophysics, Imperial College, London, United Kingdom, whose scans of a well-studied patient (GY) show no striate cortex outside the region corresponding to his macular sparing.
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There are two noteworthy aspects of the report by Fendrich *et al.* (*1*). First, investigators should determine, in cases of blindsight, if fragments of primary visual cortex are intact. Researchers have been aware of the importance of validating lesion limits in these patients, but only recently has it been possible for brain images to provide such detailed information (although Fendrich *et al.* could not say whether striate cortex fragments actually corresponded to islands of blindsight measured psychophysically). Second, Fendrich *et al.* used an image stabilization technique to assess the visual fields in which the position of the stimuli remained unchanged on the retina (the response of the system was significantly faster than the time associated with rapid saccades). This technique might warrant wider application; however, its limitations should be recognized. Fendrich *et al.* contrast it with "conventional computerized perimetry," in which "test stimuli are spaced about 6° apart," which is said to limit the accuracy of retinal positioning. But none of the published blindsight research, to my knowledge, has used such inflexible computerized perimetry. In my research, the stimuli are placed or moved to wherever in the field I wish and to whatever degree of precision I desire; and the size and properties of the stimuli vary over a much wider range, apparently, than were I using a Purkinje image eyetracker. Moreover, with brief presentations of the stimuli, eye movements can be discounted. Concomitant monitoring of eye position and movements can be achieved to a fine degree (*2*). The statements by Fendrich *et al.* about localization accuracy are a red herring: The gain is trivial in relation to the size and resolution of the hemianopic fields being assessed. What is different about their study is that they sought to examine possible patchiness of residual function, not that their method is essential for doing so.

Fendrich *et al.* suggest that islands of blindsight might be related to fragments of tissue found in the scan. Such a patchiness of the residual capacity, even within this limited retinal field, raises two questions. Is patchiness a general feature of blindsight fields? If so, what might be its neural basis? Patient CLT's blindsight "islands" were not far removed from the macular zone and might well have been in it. The technique used by Fendrich *et al.* did not permit them to present stimuli with eccentricity of more than 15° from the vertical meridian of the field. Other blindsight subjects have been intensively studied over the entire extent of their hemianopic fields in tens of thousands of trials with no indication of patchiness. Under some conditions, detection sensitivity in blindsight is actually higher in peripheral than in central vision, where it can be at chance (*3*). Fendrich *et al.* do not provide CLT's commentaries about the "two additional locations," nor do they explain the discrepancy with much published evidence about the positive effect of increasing stimulus size, nor do they describe what variations in stimulus orientation were used to produce negative results in one condition but positive results in a closely related test.

With regard to the possible neural basis of patchiness, not only is the projection from lateral geniculate to extrastriate cortex patchy, but after striate cortex damage there are major transneuronal retrograde changes in the relative distributions of types of retinal ganglion cells, and this has provided one basis for analyzing the neurobiology of blindsight (*4*). The density of ganglion cells in the retina is itself substantially reduced in both monkey and man.

Finally, evidence of residual visual function in hemispherectomized patients, typically associated with early brain damage, points to subcortical transmission. It is still unclear whether early brain damage is a prerequisite. In other sensory systems there are examples of adaptive changes in mature monkeys and humans (*5*, *6*).

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2. The total *range* of eye deviations from fixation with my patient GY was 40 arc min, even with stimuli lasting much longer than those in (*1*) [L. Weiskrantz, A. Harlow, J. L. Barbur, *Brain* **114**, 2269 (1991)].
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Response: Stoerig states that our data from NMR images were "not sufficient to prove that CLT's residual vision is mediated by surviving remnants of striate cortex." NMR images were not the basis for our statement in this regard. We argued that, because CLT's residual vision was limited to a small retinal island, a corresponding island of spared tissue was implied. One would expect a secondary visual system to mediate vision throughout the patient's blind field. We agree that the presence of tissue in NMR scans need not imply this tissue is visually responsive. In addition, because of volume averaging, small islands of responsive tissue might not be resolved by NMR (a caveat for those using NMR images to demonstrate the absence of spared tissue). Other techniques can complement NMR, and we recently found, with the use of positron emission tomography (PET), that there is a region of metabolic activity associated with the spared cortex which NMR revealed near CLT's right occipital pole (Fig. 1).

Stoerig indicates that residual cortex cannot account for residual vision in destriate nonhuman primates, human surgical patients with striate tissue ablation, and human hemispherectomy patients. We respond to each of these points.

With respect to the primate findings, destriate monkeys retain considerable vision, which is probably mediated by the retinotectal system (*1*). However, the very strength and consistency of the visual capabilities of these monkeys (*2*, *3*) suggest that their extrastriate vision may not be a proper model for that of humans.

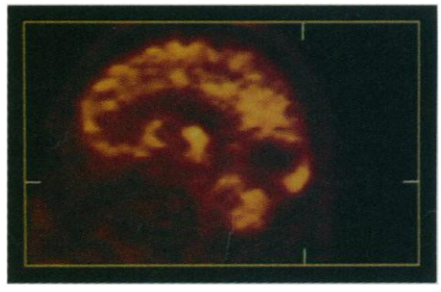

Fig. 1. Sagittal section through patient CLT's right hemisphere imaged by PET with ^{18}F-2-deoxyglucose. A large region of markedly reduced activity is present in the occipital lobe, extending into the temporal lobe. A focus of metabolism is visible at the occipital pole.

Certainly, portions of the visual field from which the striate cortex has been totally excised cannot have striate-mediated vision. However, whether the cortex for a given field location has been totally removed may be unclear because of variability in cortical morphology across individuals (*4*), variability in the mapping of cytoarchitectonic regions onto anatomically defined cortical regions (*5*), and uncertainty about the amount of cortex actually removed by the aspiration method often used with human patients.

Finally, the residual vision of hemispherectomy patients cannot be attributed to the projections to extrastriate cortex that that researchers have said account for blindsight in other types of patients. In those hemispherectomy patients who have thus far shown evidence of residual vision, brain pathology was present at an early age (*6*, *7*). This is commensurate with the possibility of cortical rearrangements, which occur in cases of agenesis of the corpus callosum (*8*). The presence of macular sparing in some of these patients (6) is in accord with this possibility.

Both Stoerig and Weiskrantz question the utility of our stabilization procedure. Image stabilization permits repeated stimulus presentations to a precise retinal location. Without it, eye motions would cause presentations at a single spatial location to scatter over the retina. Since CLT's island of sparing was small, even minimal fixation instabilities might have caused presentations to the critical position in CLT's visual field to sometimes miss the critical retinal region. The island might not have been found had we not employed stabilization to cancel the effects of eye motions.

We did not state that other blindsight investigators do not perform careful perimetry. Nevertheless, it seems that small islands of sparing could easily have been missed. Our perimetric mapping of CLT's central visual field required more than 5000 trials, and islands of vision could have fallen between our test points. In earlier studies of blindsight, eye motions were often monitored during the initial mapping of patient fields by visual inspection, which does not permit rigorous fixation control. We do not agree with Stoerig's statement that the Tübinger perimeter allows "unlimited" resolution. The accuracy of a manual perimeter is determined by the limited ability of the operator to set and reset stimulus positions. Manual perimetry has, in fact, been shown to be a process fraught with opportunities for artifact (*9*, *10*). When Balliet *et al.* (*10*) used manual perimetry, they found training could shrink visual scotomas [as previously reported by Zihl (*11*)]. However, when these investigators switched to automated perimetry, they found little or no effect of training.

Stoerig argues that scattered islands of vision would not be likely to produce the correlations that have been reported between stimulus positions within perimetrically blind regions and subject pointing, or saccadic responses, or both. While this point has merit, these correlations are generally weak and are often based on erratic data from specific subjects (*12*). There is also inconstant evidence for the detectability of targets in cortically blind regions. In Stoerig's signal detection study of five patients (*13*), no patient exceeded chance performance when the stimulus eccentricity was 20° or less. In a study by Stoerig of signal case detection (*14*), there was a decline to near chance performance when the stimulus eccentricity was 30°.

In addition, the regions of residual function produced by cortical sparing might be relatively large and still go undetected by standard perimetry. As Campion *et al.* have pointed out (*15*), standard perimetry depends on "yes" responses by the patient and is therefore subject to criterion effects that may mask minimal function. If such function was in fact missed, but detected in a subsequent task, "blindsight" would result. Our results with CLT are commensurate with this argument.

Weiskrantz comments that the blindsight island in our patient "might well have been in" CLT's region of macular sparing. It can be seen in our published perimetric map that the island is isolated (diagonally) from the region of central sparing by at least 5° of total blindness. Weiskrantz also raises the possibility that our finding with CLT might have been "idiosyncratic." We have now carried out preliminary mapping of the blind field in five other hemianopic patients. In one patient there is evidence of an isolated region of spared vision; in another there is evidence of a probable island of spared function (*16*).

The hypothesis that blindsight is often the result of vestigial striate function in local regions accounts for the fact that it has been reported in a relatively small number of patients. It is possible that some of the manifestations of blindsight have their basis in nonstriate processing. Our observations with CLT indicate, however, that the absence of awareness cannot be used as an exclusive marker for nonstriate vision. Thus, whenever the presence of residual striate function is a possibility, accounts of blindsight in terms of nonstriate systems must be regarded as suspect.

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