The New York Review of Books

The New York Review of Books
NOVEMBER 19, 1987

Review

The Case of the Colorblind Painter

By Oliver Sacks, Robert Wasserman

WORKS DISCUSSED IN THIS ESSAY

Some Uncommon Observations About Vitiated Sight
by Robert Boyle
J. Taylor (London, 1688)

"Disorders of Complex Visual Processing"
by Antonio R. Damasio. in M-Marsel Mesulam, ed., *Principles of Behavioral Neurology*
F.A. Davis, 405 pp., $55.00

Caspar Hauser
by Anselm von Feuerbach
Simpkin & Marshall (London, 1834)

The Intelligent Eye
by Richard L. Gregory
McGraw Hill (1971, out of print)

Physiological Optics Society of America, Washington, DC, 1924
by Hermann von Helmholtz. original edition 1856–1867, translation published by The Optical
"The Retinex Theory of Color Vision"
by Edwin H. Land in *Scientific American*
Vol. 237

Vision: A Computational Investigation into the Human Representation and Processing of Visual Information
by David Marr
W.H. Freeman, 397 pp., $25.95 (paper)

"Retinex Theory and Colour Constancy," article by J.J. McCann
in Richard L. Gregory, ed., *The Oxford Companion to the Mind*
Oxford University Press, 856 pp., $49.95

"Colour Vision: Eye Mechanisms," article by W.A.H. Rushton
in Richard L. Gregory, ed., *The Oxford Companion to the Mind*
Oxford University Press, 856 pp., $49.95

Remarks on Colour
by Ludwig Wittgenstein
University of California Press, 126 pp., $7.95 (paper)

"The Construction of Colours by the Cerebral Cortex" an article by S. Zeki
in *Proceedings of the Royal Institution of Great Britain*
Vol. 56, 231-257 pp.

"Selective Disturbance of Movement Vision after Bilateral Brain Damage"
in *Brain*, article by J. Zihl et al.
Vol. 106 pp.

Colourful Notions series The Nature of Things (1984)
A film written and produced by John Roth

1.

Early in March 1986 one of us received the following letter:

> I am a rather successful artist just past 65 years of age. On January 2nd of this year I was driving my car and was hit by a small truck on the passenger side of my vehicle.
>
> When visiting the emergency room of a local hospital, I was told I had a concussion. While taking an eye examination, it was discovered that I was unable to distinguish letters or colors. The letters appeared to be Greek letters. My vision was such that everything appeared to me as viewing a black and white television screen.
>
> Within days, I could distinguish letters and my vision became that of an eagle—I can see a worm wriggling a block away. The sharpness of focus is incredible.
>
> BUT—I AM ABSOLUTELY COLOR BLIND.
>
> I have visited ophthalmologists who know nothing about this colorblind business. I have visited neurologists, to no avail. Under hypnosis I still can't distinguish colors. I have been involved in all kinds of tests. You name it.
>
> My brown dog is dark grey. Tomato juice is black. Color TV is a hodge-podge. Etc., etc.

This seemed an extraordinary letter. The artist was not born colorblind, which is what one immediately thinks of when people say they are "colorblind." When one speaks of colorblindness, one usually is speaking of an inborn defect in seeing particular colors. This condition was described in the 1780s by John Dalton, who suffered from it himself, and it is sometimes called "Daltonism." Probably it has always existed, and indeed been quite common: it is estimated that between 4 and 5 percent of men have the common red-green colorblindness, while it is much rarer in women. Extremely rarely (the estimated incidence is only one in five million), people may be born wholly colorblind. The cone cells of the retina, of which there are three groups, respond differentially to wavelengths, and serve as our primary color receptors. In those born partially or totally colorblind, some or all of one type of light-sensitive cones, occasionally two types, are missing, or missing their light-sensitive pigment.

But clearly none of these conditions applied to our correspondent, Jonathan I. He had seen normally all his life, had been born with a full complement of cones, or color receptors, and presumably still had these. He had *become* colorblind, after sixty-five years of seeing colors normally. And he did not just confuse some colors or see them as gray, as is usually the case with the congenitally colorblind. He had become totally colorblind—as if "viewing a black and white television screen." All this came on suddenly when he had an accident. The suddenness of the event was incompatible with any of the slow deteriorations that can befall the retinal cone cells, and suggested, instead, a mishap at a higher level, in those parts of the brain specialized in perceiving color.

Total colorblindness caused by brain damage, so-called acquired cerebral achromatopsia, though described by Robert Boyle[1] as much as three centuries ago, remains a rare, intriguing, and important condition. It is important because (like all neural dissolutions and destructions) it can reveal to us the mechanisms of neural construction, specifically how the brain constructs color. Doubly intriguing is its occurrence in an artist, a painter in whose life color has been of primary importance, and who can directly paint as well as describe what has befallen him, and thus convey the full strangeness, distress, and reality of the condition. Through such a case we can trace not only the underlying cerebral mechanisms or physiology, but also the subjective experience, the phenomenology of color.

Color is not a trivial subject: it has not only excited the great natural philosophers—Newton, Young, Helmholtz—and incited Goethe's *Farbenlehre*, but it has intrigued philosophers as well. Wittgenstein thought color especially important, not least because it escapes notice ("The aspects of things that are most important for us are hidden because of their simplicity and familiarity"). Color, normally, is hidden from us, precisely because we take it for granted. This, doubtless, is one of the reasons why Wittgenstein's *Remarks on Colour* are so largely based on conversation with the colorblind, with those whose color world is at odds with our own. But what would Wittgenstein have thought, and said, and asked, had he met someone wholly colorblind, with an acquired cerebral colorblindness, an artist like Mr. I.?

2.

When we first saw him, on April 13, 1986, Jonathan I. was a tall, gaunt man, showing obvious recent weight loss. He spoke intelligently and well, both analytically and vividly, but in a soft and rather lifeless voice. He rarely smiled; he was manifestly depressed. We got a sense of inner pain, fear, and tension, held in with difficulty beneath his civilized discourse.

We learned that his accident had been accompanied by a transient amnesia. He had been able, evidently, to give a clear account of himself and his accident to the police at the time it happened, late on the afternoon of January 2. He then went to his studio to see someone interested in his work but cut short this meeting because of a steadily mounting headache. Arriving home, he complained to his wife of having a headache and feeling confused, but made no mention of the accident. He then fell into a long, almost stuporous sleep. It was only the next morning, when his wife saw the side of the car stove in, that she asked him what had happened. When she got no clear answer ("I don't know. Maybe somebody backed into it") she knew that something serious must have happened.

Mr. I. then drove off to his studio, and found on his desk a carbon copy of the police accident report. He had had an accident, then, but somehow, bizarrely, had lost his memory of it. Perhaps the report would jolt his memory. But lifting it up, he could make nothing of it. He saw print of different sizes and types, all clearly in focus, but it looked like "Greek" or "Hebrew" to him. A magnifying glass did not help; it simply became *large* "Greek" or "Hebrew." (This alexia, or inability to read, was still present five days later, but then apparently disappeared.)

Feeling now that he must have suffered a stroke or some sort of brain damage from the accident, Jonathan I. phoned his doctor, who arranged for him to be seen and tested at a local hospital. Although, as his original letter indicates, difficulties in distinguishing colors were detected at this time, in addition to his gross alexia, he had no subjective sense of the alteration of colors until the next day.

That day he decided to go to work again. It seemed to him as if he were driving in a fog, even though he knew it to be a bright and sunny morning. Everything seemed misty, bleached, grayish, indistinct. His bewilderment and fear now became a feeling of horror. He was flagged down by the police close to his studio: he had gone through two red lights, they said. Did he realize this? No, he said, he was not aware of having passed through any lights. They asked him to get out of the car. Finding him sober, but apparently bewildered and ill, they gave him a ticket and advised him to seek medical advice.

Mr. I. arrived at his studio with relief, expecting that the horrible mist would be gone, that everything would be clear again. But as soon as he entered, he found his entire studio, which was hung with brilliantly colored paintings (see illustration of his pre-accident work on page 33), now utterly gray and void of color. His canvases, the abstract color paintings he was known for, all were grayish or black and white, unintelligible. Now to horror there was added despair: even his art was without meaning, and he could no longer imagine how to go on.

The weeks that followed were very difficult. "You might think," Mr. I. said, "loss of color vision, what's the big deal? Some of my friends said this, my wife sometimes thought this, but to me, at least, it was awful, disgusting." It was not just that colors were missing, but that what he did see had a distasteful, "dirty" look, the whites glaring, yet discolored and off-white, the blacks cavernous — everything wrong, unnatural, stained, and impure.[2]

Mr. I. could hardly bear the changed appearances of people ("like animated gray statues") any more than he could bear his own changed appearance in the mirror: he shunned social intercourse and found sexual intercourse impossible. He saw people's flesh, his wife's flesh, his own flesh, as an abhorrent gray; "flesh-colored" now appeared "rat-colored" to him. This was so even when he closed his eyes, for his preternaturally vivid ("eidetic") visual imagery was preserved but now without color, and forced on him images, forced him to "see" but see internally with the wrongness of his achromatopsia. He found foods disgusting in their grayish, dead appearance and had to close his eyes to eat. But this did not help very much, for the mental image of a tomato was as black as its appearance.

He knew the colors of everything, with an extraordinary exactness (he could give not only the names but the "numbers" of colors as these were listed in a Pantone chart of hues he had used for many years). He could describe the green of Van Gogh's billiard table in this way with exactitude. He knew all the colors, but could no longer see them, either when he looked or in his mind's eye, his imagination or memory.

The "wrongness" of everything was disturbing, even disgusting, and applied to every circumstance of daily life. Thus, unable to rectify even the inner image, the idea, of various foods, he turned increasingly to black and white foods—to black olives and white rice, black coffee and yogurt. These at least appeared relatively normal, whereas most foods, normally colored, now appeared horribly abnormal.

He encountered difficulties and distresses of virtually every sort in daily life, from the confusion of red and green traffic lights (which he could now distinguish only by position) to a virtual inability to choose his clothes. (His wife had to pick them out, and this dependency he found hard to bear; later, he had everything classified in his drawers and closet—gray socks here, yellow there, ties labeled, jackets and suits categorized, to prevent otherwise glaring incongruities and confusions.) Fixed and ritualistic practices and positions had to be adopted at the table; otherwise he might mistake the mustard for the mayonnaise, or, if he could bring himself to use the blackish stuff, ketchup for jam.

He particularly missed the brilliant colors of spring—he had always loved flowers, but now he could only distinguish them by shape or smell. The blue jays were brilliant no longer; their blue, curiously, was now seen as pale gray. This odd pallor replaced even the most intense blues. He could no longer see the clouds in the sky, their whiteness, or off-whiteness as he saw them, being scarcely distinguishable from the azure, which was bleached, for him, to a pale gray. Red and green peppers, on the other hand, were indistinguishable: both appeared black.

Thus reds were seen (or not seen) as black. Yellows and blues, in contrast, were almost white. Further, there was an excessive tonal contrast, with loss of delicate tonal gradations (especially in direct sunlight or harsh artificial light; he made a comparison here with the effects of sodium lighting, which at once removes color and tonal delicacy, and with certain black-and-white films—"like Tri-X pushed for speed"—which produce a harsh, contrasty effect). Objects stood out, if they stood out at all, with inordinate contrast and clarity, like silhouettes. But if the contrast were normal, or low, they might disappear from sight altogether.

Thus, though his brown dog would stand out almost violently in silhouette against a white road, it might get lost to sight when it moved into soft, dappled undergrowth. People's figures might be visible and recognizable half a mile off—as he himself said in his original letter, and many times later, his vision had become much sharper ("that of an eagle"), but this was the sharpness of extreme contrast or silhouette. Faces, on the other hand, would often be unidentifiable until they were close. This seemed a matter of lost color and tonal contrast, not of a defect in recognition—a visual agnosia—as such.

He found color television especially hard to bear: its images always unpleasant, sometimes unintelligible. For, as he now explained, in distinction to his first letter, his world was not really like black-and-white television or film—it would have been much easier to live with had it been so.

His despair of conveying what the world looked like, and the uselessness of the usual black-and-white analogies, finally drove him, some weeks later, to create an entire "gray room," a gray universe, in his studio, in which tables, chairs, and an elaborate dinner ready for serving were all painted in a range of grays (see illustration on page 25). The effect of this, in three dimensions and in a different tonal scale from the "black and white" we are all accustomed to, was indeed macabre, and wholly unlike that of a black-and-white photograph. As Mr. I. pointed out,

> we accept drawings, films, television—small, flat images in black and white you can look at, or away from, when you want. It is only an image, it is not *supposed* to be real. But imagine black and white all around you, 360 degrees, all solid and three-dimensional, and there all the time—a total black and white world…. You can't imagine it: the only way I can express it is to make a complete gray room, with everything in it gray—and you yourselves would have to be painted gray, so you'd be part of the world, not just observing it.

It was, he once said, like living in a world "molded in lead."

Jonathan I. could no longer bear to go to museums and galleries, or to see colored reproductions of his favorite pictures. This was especially distressing when he knew the artists, when the loss of color was felt as a loss of personal and artistic identity—indeed, this was what he now felt with himself.

Music, curiously, was impaired for him too, because he had previously (like Scriabin and others) had an extremely intense synesthesia, so that different tones had immediately been translated into color, and he experienced all music simultaneously as a rich tumult of inner colors. With the loss of his ability to generate colors, he lost this ability as well—his internal "color-organ" was out of action, and now he heard music with no visual accompaniment; this, for him, was music with its essential chromatic counterpart missing, music now radically impoverished.

He was depressed once by a rainbow, which he saw only as a colorless semicircle in the sky. And he even felt his occasional migraines as "dull"—previously they had involved brilliantly colored geometric hallucinations, but now even these were devoid of all color. He sometimes tried to evoke color by pressing the globes of his eyes, but the flashes and patterns elicited were equally lacking in color. He had often dreamed in vivid color, especially when he dreamed of landscapes and painting; now his dreams were washed-out and pale, or violent and contrasty, lacking both color and delicate tonal gradations.[3]

A certain mild pleasure came from looking at drawings; he had been a fine draftsman in his earlier years. Could he not go back to drawing again? This thought was slow to occur to him, partly because he had for thirty years been a colorist and an abstractionist, and it only took hold after being suggested repeatedly by others.

His own first impulse was to paint in color, even though he himself knew he could no longer see any colors. He decided, as a first exercise, to paint flowers, taking from his palette what tints seemed "tonally right." The pictures he did at this time present to normal eyes a confusing welter of colors, and only reveal their sense when seen in black and white. With this he discovered that he might produce pictures that were reasonable (i.e., tonally reasonable) to himself, but unreasonable to anyone with normal color vision.[4]

"Forget color," his friends said to him, and now he finally said this to himself. In February, then, he put aside all his tints, all his experiments in color; he resolved to start painting in black and white only. The first weeks were a time of agitation, even desperation; he was constantly hoping that he would wake up one fine morning and find the world of color miraculously restored, and constantly fearing that whatever had happened would happen again, this time depriving him of all his sight completely. The fear of blindness haunted him in these first weeks but, creatively transmuted, shaped the first paintings he did, the first "real" paintings, that is, after his color "experiments." But black-and-white paintings he found he could do, and do very well. He now found his only solace working in the studio, and he worked fifteen, even eighteen hours a day. This meant for him a kind of artistic survival: "I felt if I couldn't go on painting," he said later, "I wouldn't want to go on at all."

In his studio, in contrast to the "real" world, he could exercise at least some power. Outside, in daily life, he was a patient, passively enduring an all-pervasive deprivation. Yet there was an obverse even to the deprivation, which hit him about three weeks after the onset of his achromatopsia. This was seeing the sunrise one morning, the blazing reds all turned into black: "The sun rose like a bomb, like some enormous nuclear explosion," he said later. "Had anyone seen a sunrise like this before?"

His first black-and-white paintings, done in February and March, gave a feeling of violent forces—rage, fear, despair, excitement—but these were held in control, attesting to the powers of artistry and sanity that could expose, and yet contain, such intensity of feeling. Thus, in these two months, he produced dozens of powerful paintings, marked by a singular style, a character he had never shown before. In these paintings, done at a time of acute and anguished feeling, when the sense of a shattered world was fierce, there was an extraordinary shattered, kaleidoscopic surface, with many abstract shapes suggestive of faces—averted, shadowed, sorrowing, raging—and dismembered body parts, faceted and held in countless frames and boxes (see illustration this page). They had, compared to his previous work, a labyrinthine complexity, and an obsessed, haunted quality—they seemed to exhibit, in symbolic form, the predicament he was in.

Starting in May—it was fascinating to watch—he moved from these powerful but rather terrifying and alien paintings toward themes, living themes, he had not touched in thirty years, back to representational paintings of dancers and race-horses. These paintings, even though still in black and white, were full of movement, vitality, and sensuousness; and they went with a change in his personal life—a lessening of his withdrawal and the beginnings of a renewed social and sexual life, a lessening of his fears and depression and a turning back to life.

At this time too he turned to sculpture, which he had never done before. One felt he was now turning to all the visual modes that still remained to him—form, contour, movement, depth—and exploring them with an intensity that was, in a sense, new for him. He also started painting portraits, although he found that here he could not work from life, but only from a black-and-white photograph, fortified by his knowledge of and feeling for each subject. Life was tolerable only in the studio, for here he could reconceive the world in powerful, stark forms. But outside, in real life, he found the world alien, empty, dead, and gray.

3.

This was the story we got from Jonathan I.—a story of an abrupt and total breakdown of his color vision, and his attempts to live in a black-and-white world; a story incompatible with any innate or degenerative problem with the eyes, but indicative of a sudden mishap in those parts of the brain needed for the inner representation, the seeing, of colors. Besides this catastrophic breakdown in the cerebral "construction" of color, he had a transient breakdown in the ability to construe letters, and perhaps, in a slight form, and not even known to him, breakdown in other "constructive" functions of "visual" parts of the brain—parts responsible for the perception of movement, depth, contrast, or form. His account pointed to such breakdowns, but to define them precisely we needed tests of various sorts. Some of these tests would be quite informal, making use of everyday objects or pictures, whatever came to hand.

We first asked Jonathan I. about a shelf of notebooks—blue, red, and black—by the desk. He instantly picked out the blue ones (a bright medium blue to normal eyes)—"they're pale"; the red and the black were indistinguishable—both, for him, were "dead black."

Presented with a magazine photograph containing a complex, predominantly red, multiple exposure, showing dozens of figures — some red-lit, some white-lit—he missed all the red-lit figures and faces, and saw only darkness with occasional hands and half-faces. He saw one face, of which half was illuminated crimson and half was white, as a face half blocked by an opaque pillar in front of it. A black-and-white photocopy of this photograph produced a picture very similar to what Mr. I. was apparently seeing.

When we gave him a large mass of yarns, containing thirty-three separate colors, and asked him to sort these, he said he couldn't sort them by color, but only by gray-scale tonal values. He then, with extraordinary rapidity and ease, separated the yarns into four strange, chromatically random piles, which he characterized as 0–25 percent, 25–50 percent, 50–75 percent, and 75–100 percent on the gray-tone scale. (Though nothing looked to him purely white, and even white yarn looked slightly "dingy" or "dirty.")

We ourselves could not confirm the accuracy of this, because our color vision interfered with our ability to visualize the gray scale, as, earlier, normally sighted viewers had been unable to perceive the tonal sense of his confusingly polychromatic flower paintings. But a black-and-white photograph and a black-and-white video camera confirmed that Mr. I. had indeed accurately divided the colored yarns in a pure gray-scale manner. There was, perhaps, a certain crudeness in his categories, but this went with the sense of sharp contrast, the paucity of tonal gradations, that he had complained of. Indeed, when shown an artist's gray scale of perhaps a dozen gradations from black to white, Mr. I. could distinguish only three or four categories of tone.

One anomaly again showed itself in the wool-sorting test: he ranked bright saturated blues as "pale" (as he had complained that the blue sky seemed almost white). But *was* this an anomaly? Could we be sure that the blue wool was not, under its blueness, rather washed-out or pale? We had to have hues that were otherwise identical — identical in brightness, saturation, reflectivity. This is the case with a set of carefully produced color buttons known as the Farnsworth-Munsell test, which we now gave to Mr. I. He was unable to put the buttons in any order, but he did separate out the blue ones as "paler" than the rest.

When we asked Mr. I. to examine and paint a copy of a colored spectrum (we used the printed one in Helmholtz's *Physiological Optics*), he could see only black and white and varying shades of gray, and painted it as such. Intriguingly, his perception of the spectrum bore no resemblance to that of the retinally colorblind (which has a single peak of luminosity in the green around 500 nanometers) but did resemble that of people with normal ("photopic") vision, whose perception of luminosity reaches a peak in the yellow-green (around 560 nanometers). This showed that his cone mechanisms and discrimination of wavelengths were intact, and only color "perception" (or "construction") was deficient. There was, however, a strange, additional anomaly: an additional luminosity in the blue part of the spectrum, similar to the transformation of blue already observed in the Farnsworth-Munsell test.

We now came to the classic color-dot test plates always given as a test for colorblindness—the Ishihara plates, in which configurations or numerals of subtly differentiated colors may stand out clearly for the normally sighted, but not for those with various types of colorblindness. Mr. I. was unable to see any of these figures 9although he had no difficulty with certain "trick" plates, which are designed to catch pretended or hysterical colorblindness).

Though problems arose occasionally when he was shown reproductions of colored paintings, Mr. I. had no difficulty describing black-and-white photographs or reproductions accurately; he had no difficulty recognizing forms. His imagery and memory of objects and pictures shown to him were indeed exceptionally vivid and accurate, almost eidetic, though always colorless. Thus, after being shown a classic test picture of a colored boat, he looked intensely, looked away, and then rapidly reproduced it in black-and-white paint (see illustration on page 32). Vivid positive and negative afterimages occurred after he was shown bright colors, but these were also devoid of color. When asked the colors of familiar objects, he showed no difficulties in color association or color naming. Nor did he (now) have any difficulties reading.

Testing up to this point—other forms of visual testing, and a general neurological examination, were entirely negative—had shown an isolated but total achromatopsia or colorblindness, but one with some atypical features. Clearly his case did not resemble "ordinary" colorblindness, in which the color receptors of the eyes are defective or missing. Mr. I. made distinctions where the retinally colorblind could not—e.g., the blues (although these were seen not as "blue" but as "pale") on the Farnsworth-Munsell and other tests. In some sense, it seemed, he was "seeing" the blue, at least seeing *something* about it, although (to use the current word) he could not, apparently, "process" this internally to create the cerebral or mental construct of "color." Thus we needed more sophisticated tests, designed to explore the brain's mechanisms for generating and perceiving color.

Such cerebral mechanisms may be examined by the active responses of a subject (human or animal), responses that indicate what the subject is perceiving. They may also be examined in a purely anatomical or physiological way, by visualizing or measuring the electrical activity of the brain. The first (or neuropsychological) approach is of particular use for examining color perception, since the areas of the brain involved in this are so minute that they may elude direct visualization. Efforts had indeed been made to delineate the brain damage in Mr. I.'s case (by the use of special scan techniques: CAT scan, NMR scan), and to measure the physiological reactions of the visual cortex (with evoked potential tests), but these tests were all negative. With more sophisticated brain imaging we might well be able to identify the minute brain areas affected; but Mr. I. was getting tired of "all those tests," and for the present it seemed best to return to perceptual testing, but in a more elaborate form.

"Higher" forms of color perception have engaged the interest of Edwin Land in this country and S. Zeki in England, who have both devised a number of experimental and clinical tests. These use complex, subtly juxtaposed blocks of different colors, with a vague resemblance to some paintings of Mondrian (and hence sometimes called "Mondrians"). The colored shapes are projected on a screen through filters that can quickly be changed. In January 1987, with the patient, we met with Professor Zeki, and performed more elaborate testing. A "Mondrian" of great complexity was used as a test object, and this was projected with white light and with extremely narrow-range gel filters allowing the passage of only red, green, and blue light. Strictly speaking, of course, one should refer, as we did during the testing, not to color but to the wavelengths that are associated with each color—to long, medium, and short wavelengths respectively.

Mr. I., it was evident, could distinguish most of the geometric shapes, though only as consisting of differing shades of gray, and he instantly ranked them on a one-to-four gray scale, although he could not distinguish some color boundaries (for example, between red and green, which both appeared to him, in white light, as "black"). With rapid, random switching of the filters, the gray-scale value of all the shapes dramatically changed, some shades previously indistinguishable now becoming very different, and all shades (except actual black) changed, either grossly or subtly, with the wavelength of the illuminating beam. (Thus a green area would be seen by him as "white" in green [medium-wavelength] light, but as "black" in white or red [long-wavelength] light.)

All Mr. I.'s responses were consistent and immediate. (It would have been very difficult, if not impossible, for a normally sighted person to make these instant and invariably "correct" estimations, even with a perfect memory and a profound knowledge of the latest color theory.) Such a response was utterly unlike that which would be made by someone with retinal colorblindness—i.e., an absence of receptors sensitive to wavelengths in the eye. Mr. I., it was clear, could discriminate wavelengths—as no retinally colorblind person could—but he could not *go on* from this to "translate" the discriminated wavelengths into color, could not generate the cerebral or mental construct of color.[5]

This finding not only pinpointed the nature of the problem—the inability to "create" color, to "arrive at" colors on the basis of information about wavelengths, edge-matching, etc.—but also served to pinpoint the location of the trouble. For it has been established, directly, in animal experiments (conducted by Zeki), and the human cases of achromatopsia reported would support this, that the visual cortex deals with "color" (and other percepts) twice. First, it discriminates and categorizes the physical aspects of the stimulus (e.g., wavelength, displacement in time, parallactic displacement, etc., as these have been coded by the retina); this is done in the primary visual cortex. Second, it constructs from these the perceptual qualities required for an image (color itself, movement, depth, etc.); this is done in another region of the brain, the secondary, or associational, visual cortex.

What had been suggested by Mr. I.'s history, and by the other tests, was definitively corroborated by the "Mondrian" test: it was the visual association cortex, and this only, that had been damaged in Mr. I. Hence his inability, despite the intactness of the retinal output and processing in the primary visual cortex, to construct color (and, for a short time, letters) as an element of the visual world.

There is a simple or "naturalistic" way of regarding color, and indeed the whole perceptible world, that has its philosophical exemplar in Locke and its scientific exemplar in Newton. Here sensations are given an "absolute" status corresponding to the "absolute" status of physical stimuli: nothing is added, nothing is removed, in passing from the outer world to the inner world of each person or sentient being. The mental world, according to this philosophy, is a physical world—a little replica of it, perhaps, within the brain. Newton, in his famous prism experiment in 1666, had shown that "white" light was composite—could be decomposed into, and recomposed by, all the colors of the spectrum. The rays that were bent most ("the most refrangible") were seen as violet, the least refrangible as red, with the rest of the spectrum in between. The colors of objects, Newton thought, were determined by the "copiousness" with which they reflected particular rays to the eye.

But it was not necessary to have all the spectral colors; artists had long known that one could obtain most colors by the admixture of as few as three brightly colored pigments. This, and perhaps also John Dalton's description of his own colorblindness a few years before, moved Thomas Young, in 1801, to his "trichromatic" hypothesis, the hypothesis that the eye had just three color receptors, which were "tuned" to resonate to red, green, and blue. Young's hypothesis was confirmed by Helmholtz a half-century later, so that we now speak of the Young–Helmholtz hypothesis.

But for Helmholtz there was something mysterious, nonmechanical, at work too. Objects retain their "color" even in very different illumination: for example, in the evening when they are bathed in long wavelengths. This obvious yet central phenomenon—of color constancy —was seized on by Helmholtz as implying that something active went on, not simply a mechanical translation of wavelength into color. He spoke of color vision as "an act of judgment."

This was, for Helmholtz, a special example of the general act of "perceptual judgment" required to make a stable world from a chaotic sensory flux, a world that would not be possible if our brains merely reflected passively the ever-changing input that bathed our receptors. There is thus, in Helmholtz, even though he is seen as the great successor of the Newton and Young tradition, something that departs radically from the naturalistic tradition, in that it assigns an *active* role to the organism and to the brain.

The neuroanatomy and neurophysiology of Helmholtz's time, and indeed the concept of the nervous system as a static mechanism rather than as an active processor, made it difficult to find out, or imagine, how such "judgment" could be exercised. Indeed, it is only in the last fifteen years or so that new concepts and investigations have made it possible to envisage this, and in a way that must fill us with awe for the brain. The fundamental work of Land and Zeki has been largely responsible for these new concepts. Both use "Mondrians" illuminated with light of different wavelengths. Land's work with human subjects leads him to see the "color" parts of the brain as working like a computer, one that computes color by using three estimates of light intensity ("lightnesses"), each itself computed using intensity information from the entire image. Thus, for Land, the surround is all-important. The seeing eye, or retina-cortex (Land calls his theory "Retinex"), always takes in an entire scene, and makes a judgment of color in any given part from a consideration of color information throughout the scene.[6] Land's model enables him to predict, with some accuracy, how colors will look to human subjects, whatever the changes in illumination. The mystery of color constancy, or color judgment, seems to depend upon an immense inner act of comparison and computation, performed continually and faultlessly, every moment of our lives.[7]

Land proposed a model—an internal color computer. Zeki has actually located this computer by inserting microelectrodes into the brains of rhesus monkeys while they view "Mondrians" in differing lights. He finds that there are cells that respond to different wavelengths in the primary visual cortex, but cells that respond to different *colors* in the visual association cortex (in areas that he labels "V4" and "V4A").[8] These latter cells themselves show color constancy, each cell acting as a Landian computer, or (if you will) a Helmholtzian judge.

What happens if there is damage to Land's color computer, Zeki's color center (and so specialized and tiny a knot of cells may be especially vulnerable)? Land and Zeki do not ask this question, since they work only with healthy subjects—but it is precisely this question that Mr. I.'s case poses, and answers.

The varied symptoms that Mr. I. complained of, and showed, finally led us to test him on a color-Mondrian, with illumination of different wavelengths, in precisely the way that Land's subjects are tested. And this showed us with great clarity how his ability to discriminate different wavelengths was preserved, while his color perception was obliterated, how there was a clear dissociation of the two. Such a dissociation could not occur unless there were separate processes for wavelength discrimination and color construction. Thus, Mr. I.'s situation only becomes intelligible with a theory of multistage processing such as Land's or Zeki's; and such a theory can only be grounded, finally and elegantly, in such a patient.

4.

This is the scientific interest of all such acquired, perceptual, cerebral disorders, that in their breakdowns they can show us how our perceptual world is made up. Patients such as Mr. I. show us that color is not a given but is only perceived through the grace of an extraordinarily complex and specific cerebral process. The same is true for the perception of motion, depth, and form: all of these we take for granted, until we see patients who have lost them, patients who have motion blindness, depth blindness, or form blindness (visual agnosia) on the basis of highly specific cerebral lesions.[9]

The elucidation of perceptual makeup by studying specific cerebral breakdowns was established more than a century ago. Thus several neurologists in the 1880s described cases of people who were colorblind in half the visual field (hemiachromatopsia) or were unable to recognize faces (prosopagnosia), and concluded that there must exist in the brain separate "centers" for light perception, color perception, and the recognition of form. (The centers for recognition of letters, recognition of movement, and, finally, recognition of visual form itself are very close to the color center.) But after this promising early start, there then occurred one of those unfortunate events that can exert a profound negative effect on the growth of knowledge, and indeed on our ability to recognize, or even "see," important syndromes.

In an influential study of World War I gunshot wounds to the head, Gordon Holmes, one of the prominent neurologists of the time, wrongly concluded that colorblindness could not be caused by localized damage to the visual cortex. What he failed to realize was that, by a fluke, most of his patients had damage in areas of the visual cortex that were not concerned with color processing. They showed various other visual defects, but their color perception was intact.[10]

Thus achromatopsia disappeared from the medical literature, and was expunged from medical consciousness for more than sixty years. This strange situation was reversed in 1973, partly through clinical observation, but equally through the fundamental physiological work of Zeki, which established the existence of a specific "color center" in monkeys. Zeki's work had a profound impact in clinical circles, liberating a description and discussion inhibited for sixty years.

The implications of the experimental for the clinical are indeed exemplified in Mr. I., who has suffered very severe, yet singularly circumscribed, damage more or less limited to Zeki's areas for color coding in the brain. These parts of the brain are somewhat vulnerable at best, especially in an elderly patient, who may have had a sudden diminution of blood supply with the jolting of the car accident, or, coincidentally, suffered a small stroke (another patient known to one of us in England suddenly developed both colorblindness and profound visual agnosia, as a result of lack of oxygen in these areas).[11]

At the level of the brain Land and Zeki explore, there is nothing subjective—the physiological and perceptual processes at this level are automatic and impersonal, and are the same in every person (or monkey). The same appears to be true with regard to the "processing" (or computation) of motion, depth, form, and, after these have been separately processed, their integration into an "image." David Marr has described how by such a computation the brain constructs visual patterns and forms of great complexity to elaborate what he calls a "primal sketch" (or three-dimensional image). This sketch can now be envisaged as colored and moving. All this is accomplished, automatically, in the visual association cortex—the formation of an image is not dependent in the least on expectation, memory, association, meaning. Such an image, or initial representation of the visual world, it would seem, can be constructed wholly by computation, without reference to the memories, expectations, or associations that are lodged in the "higher" parts of the cortex.
Marr, in his pioneer study, *Vision*, has given us the general theory of such computations, and it seems likely that they occur in the "lower" portions of the cortex.

It is only at higher levels that integration occurs, that these (computational) images meet with our memory, expectations, associations, desires, to form a world with resonance and meaning for us. There can be disorders at this higher level, too, color association defects, or color agnosias, when colors, though they may be "constructed" correctly, lose their usual associations, feelings, and meanings. In this situation, a patient could see, but would not be surprised by, a blue banana; perhaps dress in inappropriate colors; and remain unmoved by the color of his beloved's eyes. Color would no longer be a carrier of *sense*, no longer a significant part of the patient's visual world. Though one may separate out a small part of the visual cortex as an isolated unit, as is necessary in a physiological approach, the visual cortex is part of the brain, and the brain is part of the organism, and the organism—every organism — has a world of its own, in which perceptions become infinitely more than information carriers, become an integral part of the subjectivity, the feeling, the style of the individual.

Goethe thought (mistakenly) that Newton had reduced color to the purely physical, and reacted by elevating it to the purely mental. But there is something in the language of physics—"rays differently refrangible"—that seems very far from the experience of color. Goethe's fear that science might reduce the richly colored world of living reality to a gray nullity is expressed in the famous lines from *Faust*:

> *Grau, teurer Freund, ist all Theorie*
> *Und grün des Lebens goldner Baum.*
>
> *(Gray, dear friend, is all theory.*
> *And green is the golden tree of life.)*

One has a shadow of this fear when Land and Zeki say, in effect, "color is a computation," and seem to reduce color to something colorless, in the depths of the visual cortex. Color *is* this, but it is infinitely more; it is taken to higher and higher levels, admixed inseparably with all our visual memories, images, desires, expectations, until it becomes an integral part of ourselves, our lifeworld. It is not clear that the experience, the phenomenon, of color can ever be explained (or explained away) by physiology or science: it retains a mystery, a wonder, that seems inaccessible, and that belongs in the sphere of the "given," not the sphere of questions and answers. Something of this sentiment is expressed by Wittgenstein:

> We feel that even if *all possible* scientific questions be answered, the problems of life have still not been touched at all. Of course there is then no question left, and just this is the answer.

The wonder of color vision, and the horror of its loss, are not diminished, are perhaps increased, by our scientific knowledge—and its limits. This was fully appreciated by Newton, who was the first to explore it, and by his friend Robert Boyle, who was the first to describe its complete loss. One can only echo the words with which W.A.H. Rushton closes his essay on color vision:

> Colours are so gay that those with total colour loss cannot but be pitied: and it must be wondered what it is that makes red produce the wonderful red sensation most people perceive. What has been said here explains only what cannot be discriminated, and nothing has been said about how sensations arise from what is seen. Let it be concluded that Newton ended his first paper with these strong words: "But to determine…by what modes or actions light produceth in our minds the phantasms of colours is not so easie. And I shall not mingle conjectures with certainties."

Postscript (October 1987)

It is almost two years since Mr. I. lost his color vision. The intense sorrow that was so characteristic at first, as he sat for hours before his (to him) black lawn, desperately trying to perceive or imagine it as green, has disappeared, as has the revulsion (he no longer sees his wife, or himself, as having "rat-colored" flesh).

There has, we think, been in his case a real "forgetting" of color — a forgetting at once psychological and physiological, at once strategic and structural. Perhaps this has to occur in someone who is no longer able to imagine or remember, or in any physiologically based way generate, a lost mode of perception. It does not, by contrast, happen in those who have become ordinarily blind or deaf, but their cerebral cortices, their powers of inner representation, are unimpaired; it is quite different for the *cortically* blind or deaf, who become not only unseeing or unhearing, but as if they had never been seeing or hearing, as did a patient with cortical blindness described by one of us (see Oliver Sacks, *The Man Who Mistook His Wife For a Hat*, Summit Books, 1985, p. 39).

In the past few months Mr. I. has been changing his habits and behavior—"becoming a night-person," in his own words. He has taken to roving about a great deal, exploring other cities, other places, but only at night. He drives, at random, to Boston, Baltimore, or small towns and villages, arriving at dusk, and then wandering about the streets for half the night, occasionally talking to a fellow walker, occasionally going into little diners: "Everything in diners is different at night, at least if it has windows. The darkness comes into the place, and no amount of light can change it. They are transformed into night places. I love the nighttime," Mr. I. says. "I often wonder about people who work at night. They never see the sunlight. They prefer it…. It's a different world: there's a lot of space—you're not hemmed in by streets, by people…. It's a whole new world. Gradually I am becoming a night person. At one time I felt kindly toward color, very happy about it. In the beginning, I felt very bad, losing it. Now I don't even know it exists—it's not even a phantom." (Mr. I. never had "phantom" colors, as amputees may have phantom limbs, and the deafened "phantasmal" voices and music; for the cerebral cortex is needed even to make a phantom.)

Mr. I., when he is not traveling, gets up earlier and earlier, to work in the night, to relish the night. He feels that in the night world (as he calls it) he is the equal, or the superior, of "normal" people: "I feel better because I know then that I'm not a freak…and I have developed acute night vision, it's amazing what I see—I can read license plates at night from four blocks away. You couldn't see it from a block away." With his revulsion from color and brightness, his fondness of dusk and night, his apparently enhanced vision at dusk and night, Mr. I. sounds like Kaspar Hauser, the boy who was confined in a lightless cellar for fifteen years, as Feuerbach described him in 1832:

> As to his sight, there existed, in respect to him, no twilight, no night, no darkness…. At night he stepped everywhere with the greatest confidence; and in dark places, he always refused a light when it was offered to him. He often looked with astonishment, or laughed, at persons who, in dark places, for instance, when entering a house, or walking on a staircase by night, sought safety in groping their way, or in laying hold on adjacent objects. In twilight, he even

> saw much better than in broad daylight. Thus, after sunset, he once read the number of a house at a distance of one hundred and eighty paces, which, in daylight, he would not have been able to distinguish so far off. Towards the close of twilight, he once pointed out to his instructor a gnat that was hanging in a very distant spider's web.[12]

Richard Gregory, speaking of those who have never had color vision (owing to absence of cones, or normal cone function, in their eyes) said, "They live in a scotopic world, in a world of bright moonlight," and this now seems to be the only world that Mr. I. can bear. Our world—our "photopic" world, dazzlingly bright and colored—must appear discordant and painful to an achromatope (whether he has been born colorblind, like Gregory's subjects, or become colorblind, like Mr. I.); given this, along with an enhanced, compensatory sensitivity to the nocturnal and scotopic, it is not surprising, it is perhaps inevitable, that achromatopes should be drawn to the only world in which they feel at ease and at home—and that they should, like the loris and the potto, the big-eyed primates that only emerge and hunt at night, turn wholly, or as much as they can, to becoming night creatures in a night world.

We owe a great debt to many colleagues whom we have consulted or conversed with in relation to this case, in particular Drs. Richard Blanck, Ivan Bodis-Wollner, Francis Crick, Antonio Damasio, R. L. Gregory, John C. Marshall, and S. Zeki.

Notes

[1] Robert Boyle, *Some Uncommon Observations about Vitiated Sight* (London: J. Taylor, 1688). Boyle described the case of a young woman of twenty-three who lost all color vision following a cerebral fever, probably a meningitis, and thereafter saw only black and white.

[2] Similarly, a patient of Dr. Antonio R. Damasio, with achromatopsia from a tumor, thought everything and everyone looked "dirty," even finding new-fallen snow unpleasant and dirty.

[3] Only one sense could give him any real pleasure at this time, and this was the sense of smell. Mr. I. had always had a most acute, erotically and aesthetically charged sense of smell—indeed, he ran a small perfume business on the side, compounding his own scents. As the pleasures of seeing, and almost everything else, were lost, the pleasures of smell were heightened, or so it seemed to him, and formed the only pleasure—the only intense pleasure—in the first grim weeks after his accident.

[4] An instructive corollary or converse to this phenomenon was made use of by the military in World War II, when those with severe red-green or other forms of colorblindness were pressed into service as bombardiers, etc., in view of their ability to "see through" colored camouflage, and not be distracted by what would be, to the normally sighted, a confusing and deceiving configuration of colors.

[5] When looking at the "Mondrian," Mr. I. consistently saw blues as a sort of brilliant grayish white (as had been the case on all the other occasions on which his color vision had been tested). Professor Zeki was puzzled by this, as we had been, and said that he could offer no explanation.

[6] "What can be shown cannot be said"—thus Land's and Zeki's views are difficult to state, but easy to show. This has been done very vividly in a recent BBC film (*Colourful Notions*) by Land and Zeki themselves, using fascinating simulations to show what would happen if color constancy were *not* preserved. The most recent discussion of Land's theory is given in the account by J.J. McCann and may be found (along with Rushton's general discussion of color vision) in the just published *Oxford Companion to the Mind*, edited by R.L. Gregory (Oxford University Press, 1987).

[7] In particular it must be asked whether the word or concept of "computation," used by both Land and Zeki, is being used in its strict sense—or metaphorically. Does the brain work like a computer — or, to put it more usefully, does the brain use algorithms—for the construction of color? It is certain that it does so in a much simpler form of visual "judgment"—the judgment or perception of depth (stereopsis)—which so fascinated Helmholtz. Stereopsis, it has now been confirmed by David Marr, is based on an algorithm, a relatively simple iterating algorithm. And this is employed now in robots who "judge" or "see" depth with two "eyes." Land has devised a rather more complicated model or algorithm for predicting color by an equation with three axes—a "color cube." And this, in turn, may allow us to give robots not only stereo vision but color vision as well. Land and Zeki, it might be said, are concerned with the "robotics" of color vision; but this does not mean they regard living beings as robots. They regard the robotics as the starting point in exploring a far more mysterious business—the living processes of perception, processes that go beyond any algorithm (for a world, a judgment, cannot be reduced to an algorithm). This too is implied in Helmholtz's use of the term "judgment"—first an algorithm, then a meaning. (This thesis is central in his *On the Sensations of Tone*, 1863; fourth edition 1877, translated, Dover, 1954.)

[8] The loss of fine contrast vision, the "silhouette" vision, which Mr. I. had, also points to damage in the visual association cortex, probably in an area immediately abutting "V4."

[9] A remarkable account and analysis of a patient with a pure "motion blindness" has been provided by Zihl et al. (1983). The patient's problems are described as follows: "The visual disorder complained of by the patient was a loss of movement vision in all three dimensions. She had difficulty, for example, in pouring tea or coffee into a cup because the fluid appeared to be frozen, like a glacier. In addition, she could not stop pouring at the right time since she was unable to perceive the movement in the cup (or a pot) when the fluid rose. Furthermore the patient complained of difficulties in following a dialogue because she could not see the movements of the face and, especially, the mouth of the speaker. In a room where more than two other people were walking she felt very insecure and unwell, and usually left the room immediately, because 'people were suddenly here or there but I have not seen them moving.' The patient experienced the same problem but to an even more marked extent in crowded streets or places, which she therefore avoided as much as possible. She could not cross the street because of her inability to judge the speed of a car, but she could identify the car itself without difficulty. 'When I'm looking at the car first, it seems far away. But then, when I want to cross the road, suddenly the car is very near.' She gradually learned to 'estimate' the distance of moving vehicles by means of the sound becoming louder."

[10] This extraordinary story has been reconstructed by Damasio in his article "Disorders of Complex Visual Processing" (1985).

[11] These areas, indeed, seem to be particularly sensitive to disturbance and impairment, from a

great variety of causes, Transient alterations of color vision are not uncommon in (visual) migraines. They are well-known to users of mescaline and other drugs. They can be a disquieting side effect of ibuprofen (Motrin). Partial or total achromatopsia ("graying-out"), also temporary, is characteristic of fainting, or shock, in which there is a reduction of blood supply to the posterior, and especially the visual parts, of the brain. These vulnerable areas may also be affected in a variety of diseases, from multiple sclerosis to brain tumors and strokes.

[12] The case of Kaspar Hauser was described by Anselm von Feuerbach in 1832 in a document of great importance for those who wish to study the effects of profound sensory, linguistic, or social deprivation in the first years of life.