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Lettvin asks you to perform a few experiments to learn exactly what you can and cannot see "through the corner of your eye." To do the exercises, you needn't be a psychologist or a physiologist. What you may discover from doing these eye games may have enormous implications.

On Seeing Sidelong

by Jerome Y. Lettvin

When I look at something it is as if a pointer extends from my eye to an object. The "pointer" is my gaze, and what it touches I see most clearly. Things are less distinct as they lie farther from my gaze. It is not as if these things go out of focus — but rather it's as if somehow they lose the quality of "form." Oddly, even when form is lost I can still notice movement even though I may not be able to distinguish exactly what is moving.

Like most others, what I usually mean when I talk of vision is gazing during daylight. Our gaze passes through an anatomical feature of the eye called the *fovea*, a patch of retina which is at most two degrees wide (an angle that corresponds to about the width of a half dollar at arm's length). Sidelong seeing — or what I call *eccentric vision* and what is usually called "peripheral vision" — deals with what we see through the whole hemisphere of the retina outside the fovea.

To learn what this is all about, I will ask you to perform some experiments. This is necessary for two reasons. First, conventional language used to describe perception cannot easily be used in understanding sidelong vision. It is important for the reader to have direct experience of eccentric vision so that I can refer to it without too much ambiguity. Second, the laws of perception do not refer to public measures or data but to private processes or phenomena.

There is enough evidence, I think, from these and other eye games to ask whether the usual explanations of illusions are proper. Illusions are like paradoxes: they must be explained or else the fundamentals have to be reworked. Most explanations of illusions do not explain anything at all, even granting the mechanisms claimed. For example, in a classic demonstration, people are asked to look at two lines and usually they find one to be longer. There is no reason I can imagine for accepting the notion that I *should* have seen them the same length because they *are* the same length. To assume so constricted a map of the world and the things in it is to subvert the study of perception by prejudice. It supposes that the purpose of vision is to serve as a handmaiden to elementary geometry. The proper question is not why I can't see what some precisionist thinks I ought — but rather why I see what I do. And that means that I must attend to what I see and not take a hearsay account for granted.

The Blind Spot

First, consider your "blind spot." You may never have looked for it, but every eye has one. You will discover yours if you do what is suggested in the accompanying box. Now, draw an imaginary line or horizontal axis across the bridge of your nose from one pupil to the other. There are two eye movements perpendicular to this axis, either *up* or *down*. The two directions along the line are *nasal* — meaning "nose-ward" — and *temporal* — meaning "temple-ward."

In Exercise 1, I have given a fixation point for the eye and the approximate location of the blind spot in terms of a black disc when the page is 15 inches away from your eye. As you shorten the distance between the page and your eye, the "temporal" edge of the disc comes into view. As you move the page away from your eye the "nasal" edge of the disc appears. As you rotate the page clockwise away from the horizontal axis, the lower part of the disc appears — counter-clockwise, the upper part. Thus you learn how to center your blind spot.

With the page on a table in front of you, your eye fixated on the mark and the black disc obscured in your blind spot, lay a pencil horizontally on the page temporal to the spot and move it so that the eraser end just goes into the blind spot from the temporal side. For me, that end of the pencil disappears in a curious way. The pencil does not end at the boundary as if it were cut off but, instead, becomes nonexistent. There is no boundary — in the sense that I ordinarily use the term — that marks the apparent end of the pencil. The transition is as if all visual properties vanish. The pencil end becomes nondescript in a nondescript way. As I continue to push the pencil through the blind spot the eraser suddenly appears at the nasal margin, and, when it does, there appears to be no gap in the pencil; I can't quite say how the eraser and pencil are joined. When I retract the pencil the eraser quite sharply disappears. But, curiously, there is no sharp corresponding jump of the vanished end of the pencil body. Now I introduce the pencil end into the blind spot from below and note the same kind of disappearance. When the eraser suddenly appears at the upper end of the blind spot there is again the odd completion. But there is a slight difference in the way I perceive it as compared with what occurred when I introduced the

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pencil horizontally. I will return to this difference shortly. I introduce the pencil into the blind spot in a slanting direction. Now when the eraser appears and begins to move out, the part emerging, while still short, either looks as if it is coming out at an angle to the shaft or as if it is sheared and comes out staggered.

There are a few more simple experiments with Exercise 1. Slip a sheet of colored paper over the blind spot, pushing it in from any direction until finally it overlaps the spot everywhere. I note that I cannot observe the blind spot at all when it is bounded by a single color and that the uniform color is not changed or attenuated by the blind spot. Next, rip out a large patch of text from a newspaper and move it in over the locus of the blind spot. I note again that I cannot see my blind spot. Now draw a set of black polka dots — each about one quarter inch in diameter. Randomly distribute them over a sheet of white paper and move the paper over your blind spot. Once again I find that my blind spot disappears.

Finally, take a sheet of dark or colored paper with a smooth straight edge and move the edge into but not all the way through the blind spot. I discover a murky region corresponding to the spot. But strangely the straight edge appears continuous through the region, particularly if it is horizontal. If you do this experiment with a large smooth disc of dark paper with its edge in the blind spot you may experience the same phenomenon. Contrast this with the appearance of the regular sawtooth or interrupted stripe shown in Exercise 2 where I find the feeling of blindness in the blind spot region is quite strong.

The impressions from Exercise 1 form the basis on which Hermann von Helmholtz (the nineteenth century polymath physicist and physiologist) and later the gestalt psychologists proposed the "filling in" hypothesis. According to them, what we do is recognize those features required to complete a figure that traverses our blind spot; then we supply those features apperceptively — or from our memory of what should be there. These mini-delusions occur, they tell us, in order to see figures and backgrounds in a complete way. But is "filling in" really plausible? I suppose one can make a case for it with the colored patch. But how can we reconstruct a texture, say, of newsprint or polka dots? In Exercise 2, when the dotted row or sawtooth stripe goes vertically into the blind spot it is even more recognizable and predictable than the polka dot array. It is certainly more regular. Why is its regularity so blatantly interrupted, frustrating our apperceptive housekeeping?

Nineteenth century physicians learned that when their patients' retinas were studded with defects, they did not complain of seeing a lacunated image of the world as if looking through an intricate barrier. Rather, patients complained of seeing the world poorly and believed that they needed glasses. Curiously, except when defects occurred close to or at the fovea, their visual world was not so much obscured as unresolved and the visual field was always a plenum — without gaps or bounds. However, there were patients who reported that when an image of an object fell on a defect close to the fovea, occasionally it

The Blind Spot *How to find and use yours.*

On the following pages are four sets of visual exercises, three of which are composed of large, rather odd looking objects and small circles enclosing crosses. The small circles are fixation marks that serve as guides in performing the exercises.

In each exercise, the procedure is to close one eye, stare at a fixation mark, and try to observe the object off to the side of the mark without looking at it directly. Whether you hold the page vertically or horizontally, the object to be observed (but not looked at directly) is always off to one side of the fixation mark, not above or below it, and the letter on top of the fixation mark tells you both which eye should be open, and on which side the object is (R for right, L for left).

Start with Exercise 1. Cover your less favored eye with a patch or your hand, or if you wear spectacles, simply put a cover over one lens. Do whatever allows you to look at the page monocularly, without squinting or other effort.

Use the fixation mark in the upper left. The object is the single black disk. To make things simple, lay the page on a table before you, right side up for your right eye, upside down for your left eye. Or, hold the page directly in front of you, perpendicular to your gaze. Fix your gaze on the fixation mark. You may vary the distance of the paper from you and rotate it slightly one way or the other to compensate for any head tilt you may have taken unconsciously.

You'll discover that as you fix your gaze your first feelings are not comfortable. You will want to look at the object. Do so, but then return your gaze to the fixation mark. It takes some practice to gaze at the mark. You will find that you rapidly learn to shift attention without shifting gaze if you don't squint or peer in a strained way.

Don't fatigue your eyes. If you tire, simply look at something else and then come back to the page or switch from one eye to the other.

The only perceptions that count are those that occur while you gaze at the fixation mark. It's important to remember that these are not tests designed to identify things or for which there are right answers. The only question is: what do you see while you gaze at the mark?

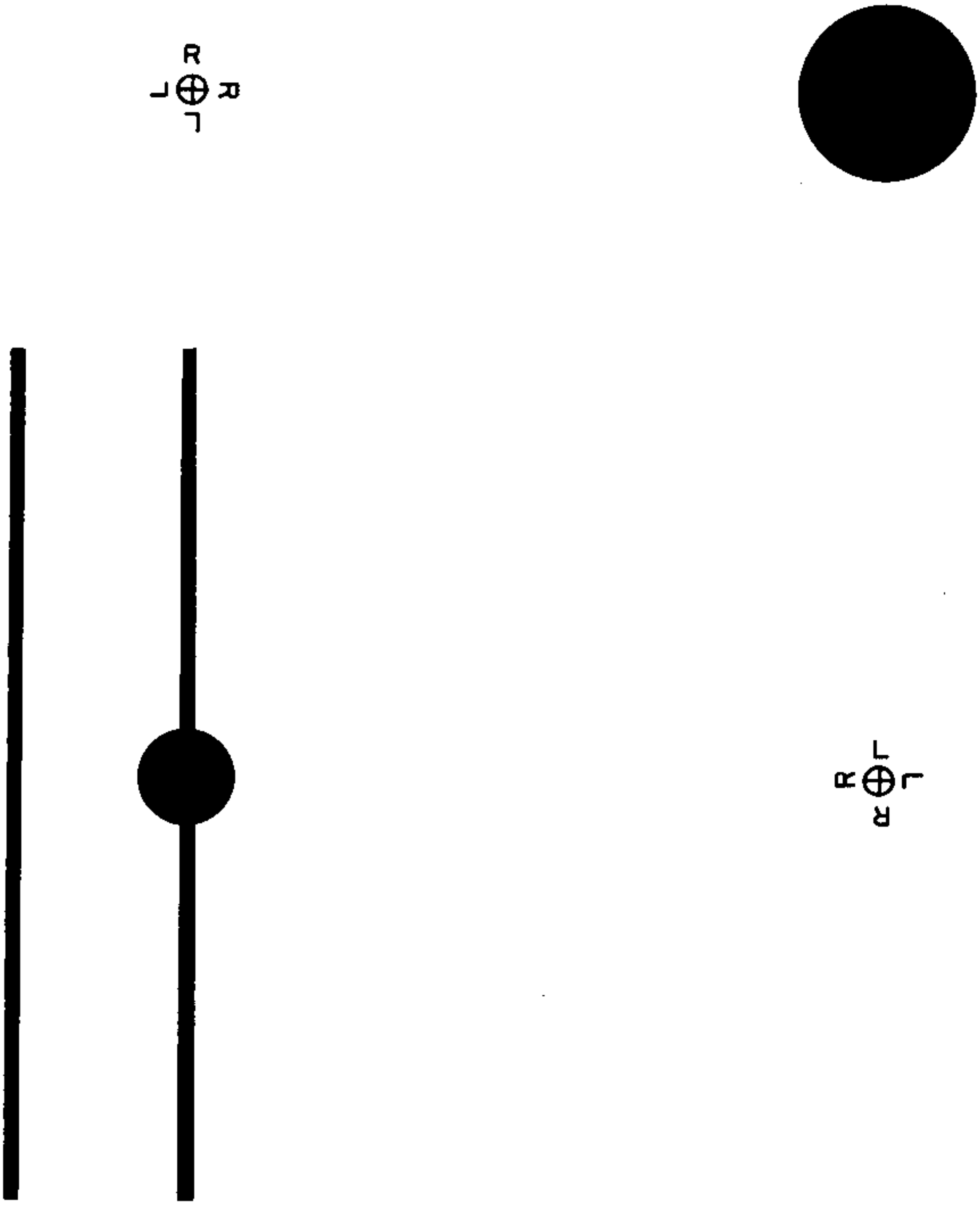
Your eyes move incessantly in jerks called *saccades* as your gaze hops from one thing to another. When you fix your gaze, the hopping about continues at a rate of four to five hops per second but within a limited region around the fixation point. This mini-hopping does not adversely effect the results that I want to show. Since you are probably not a hunter, animal handler, or old-fashioned navigator, you will no doubt need to practice the sidelong view with the first exercise.

To find your "blind spot" vary the distance of the paper until the disc disappears. If you're like most people, your blind spot (for the right eye) is four inches to the right of the fixated gaze at about 15 inches in front of your eye. (For the left eye it is the same distance away, four inches to the left.) For me it is about one and a quarter inches to one and a half inches in diameter at that distance. It is not regular but has bulges above and below it that represent where the large blood vessels enter and leave the retina with the optic nerve.

Once you've found your blind spot, have fun. Bring various objects through the blind spot as suggested in the article. Try your own experiments. Go on to the other exercises.

Exercise 4 is a drawing done by the anatomist S. L. Polyak of the retina of a macaque, a short-tailed rhesus monkey. The fovea—the little black ring of dots to one side of the center of the picture—corresponds to a fixation mark. The circle (optic disc) from which the thick black trunks of the vessels spring, corresponds to your blind spot.

—*Jerome Y. Lettvin*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looked as if the middle had been removed and the ends had been tied together. These clinical reports are puzzling if we fill in space apperceptively. For in order to account for what the tattered retina patients saw, for every hole there should have been a fill-in.

Now return to your blind spot and try Exercise 3. For each object there are two fixation marks. Remember that the test object must always be temporal to the fixation mark along the horizontal axis. When I do this I note that when the staggered stripe is vertical and the center lies on the blind spot, a blank space interrupts the stripe – it is not "filled in" but, surprisingly, it is not staggered. The effect is more pronounced if the straight stripe is covered with the edge of a white sheet of paper.

When the staggered stripe is horizontal and its center lies on the blind spot, there is some nameless discontinuity in the object, but no marked gap. In the first instance, when the staggered stripe is vertical and I see the gap, then, when I shift my gaze to the center of the stripe, there is no change in height, but the center is now visible. In the second instance, when the staggered stripe is horizontal and I note the hard-to-describe discontinuity, then, when I shift my gaze to the center of the stripe it suddenly lengthens and the center is clearly visible. This observation is even more distinct in Exercise 2.

And now an astounding surprise. In Exercise 3, I observe that when the single staggered stripe lies in the blind spot, and is vertical, and the straight stripe not covered, I see two continuous parallel stripes, the unbroken stripe and the staggered stripe.

The four-armed object in Exercise 3 shows a difference in percept between identical vertical and horizontal disparities at the blind spot. If this device is copied on a disc of paper and pinned through its center to the center of a blind spot it can be rotated slowly while the gaze is fixed. Then the vertical disparity between parallel stripes changes violently with the angle while the horizontal disparity does not, and, in some positions parallel stripes will even seem to have a shallow but definite angle between them. The important thing about all this is the different spatial treatment of horizontal and vertical distances in the region of the blind spot.

Now return to the stripe pair in Exercise 3. The staggered stripe was shown vertically simply because the impression that I have of it is that which others have almost always. Now turn it horizontally and gaze at the fixation point that is given on the page for horizontal view. Adjust the distance and angle of the page so that the center disc of the staggered stripe lies in the blind spot. Sometimes you may see it as a continuous stripe but with an indefinable transition in the blind spot. Sometimes you may see it staggered rather strongly. If you make your own drawings, you quickly discover a few simple rules: long staggered stripes promote the perception of a continuous stripe through the blind spot, short ones promote the impression of vertical staggering. If the wide distance between stripes is toward the fovea this promotes the notion of a continuous stripe. But the fluctuation of impression is disturbing.

When I first gaze at the fixation mark for the stripe pair horizontally there is no doubt about the impression of staggering across the blind spot. In a short while this feeling can fade and be replaced by a feeling of continuity and straightness on the stripe and a kind of perspective feeling so that the narrow temporal interstripe distance does not conflict either with the wider separation closer to gaze or with a feeling of parallelism between the straight and the staggered stripe. Now, using a white piece of paper, mask the outer two-thirds of the stripe pair temporal to the blind spot. When I do this, instantly the part of the staggered stripe that remains in view leaps into a profound visible stagger. When I remove the paper, it lapses back the way I saw it before.

Texture

Experience with the blind spot raises the question of how we judge distances. Suppose I have a graph paper made of lines that I can just tell apart. I use the distance between the lines as my unit of measure or my "distance element." Between any two points I can count the number of distance elements and know, within the error of a distance element, how far apart are the points. But now consider the double stripe in Exercise 3 viewed vertically. When the black disc is in the blind spot the staggered stripe appears unbroken and parallel with the unbroken one although there is clearly a big difference in actual distance between the stripes above and below the blind spot. I note that despite their eccentricity from gaze, the small protrusions on the limbs of the staggered stripe are clearly visible. Thus resolution in this region is far better than I would have guessed from my distance judgment and so the height of the small bump and the larger separation of the stripes are not simply related. It seems as if irregularities in an object and space between objects may not be measured in the same way.

Taking a new tack, I introduce some different experiments. Below, when I fix my eye on the star, I can see the isolated N very well but surprisingly not the N in MOANED.

M⊙ANED ✪ N

The N is there – must be there – for I can look at the word and see it. Yet when I fix my gaze on the star, I simply can't see it. The question is not whether I have the moral certainty that the N is there – it is only whether I can actually see it while looking at the star. It makes no difference, incidentally, if the N and MOANED are interchanged.

N ✪ MOANED

It can't be a matter of resolution, for I can see that dot in the O at a greater distance from the fovea than the N, and the dot is closer to the O rim than the N is to the A or to the E. Curiously, I have a more distinct impression of what the dot is than where it is.

If I stop the letters at N as below, I can barely see the terminal N.

Thus, the N, being in the same position with respect to the star as before, and now readable, must have been "masked" by the E and the D in the initial presentation. I check this by lifting the N out of the line as is done above, and it seems visible. If the N is only partly lifted out I have some trouble seeing it clearly, as below.

I choose another word, as above, where the position of the N is now taken by an O and I find the O quite visible as in ZEROED. Closed forms like O and D are always more readable than open forms such as X or T when given in the same context, as shown here:

I choose two words which provide a different context for T as below, and I find that I can almost make out the T in MOTOR but not that in METER.

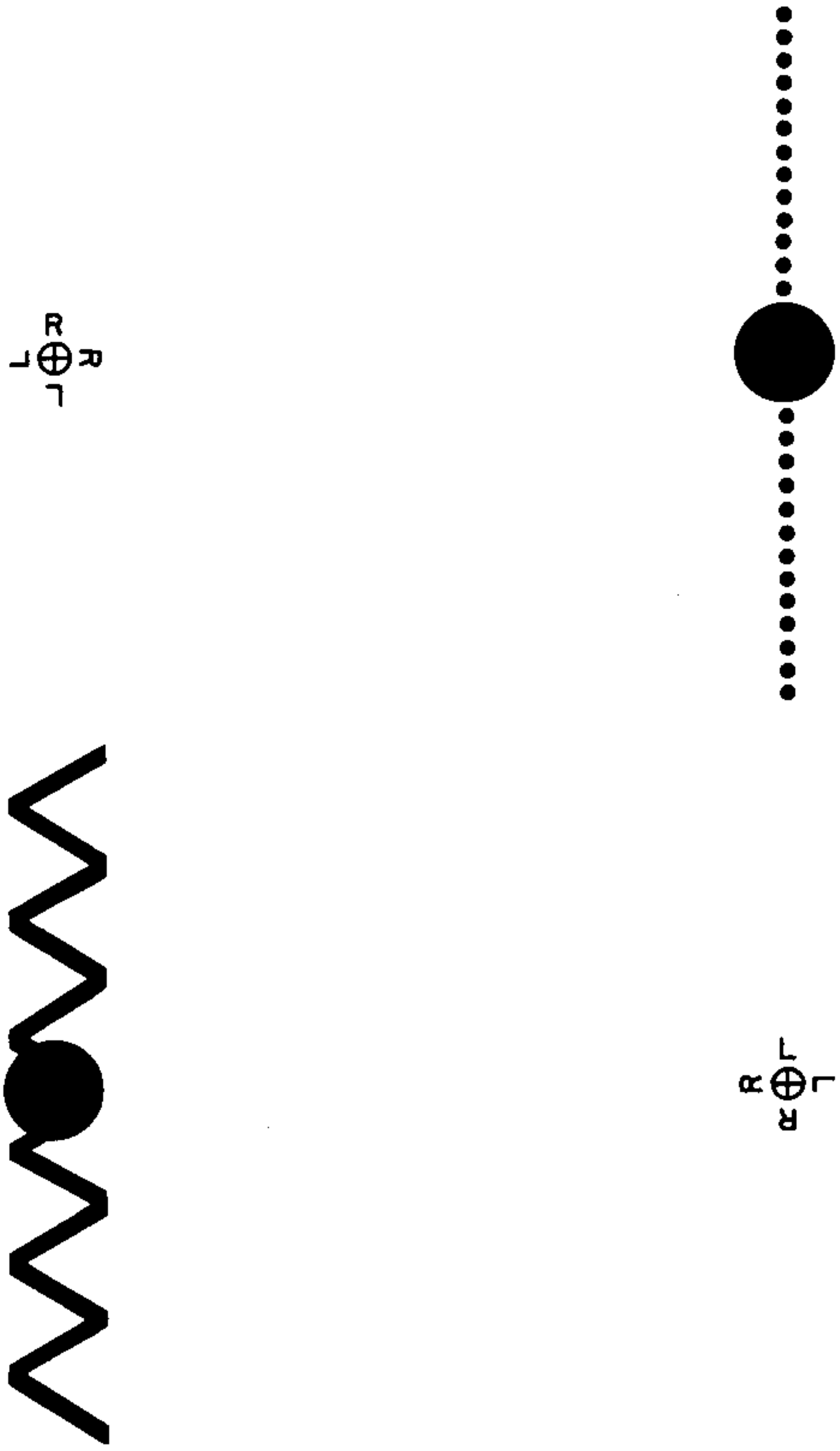
Finally, there are two images that carry an amusing lesson. The first is illustrated by the O composed of small o's as below. It is a quite clearly circular array, not as vivid as the continuous O, but certainly definite.

Compare this with the same large O surrounded by only two letters to make the word HOE. I note that the small O's are completely visible still, but that the large O cannot be told at all well. It simply looks like an aggregate of small o's.

It is hard to find exact words for what these studies show. If you doodle similar illustrations you'll discover certain interesting relations. You'll also find these relations hard to put into words.

By now you must have noticed an important omission. I have not given you the distance the page should be from your eye. The point is, it doesn't matter. The physiologists H. Aubert and R. Förster during the latter part of the nineteenth century showed that if you took the visual angle of a letter that was just recognizable, and the angle away from your gaze on which the letter rested, the ratio of the two angles remained constant over a wide range. That is to say, an A, just recognizable at three degrees away from your gaze, would have to double its size to be recognizable at six degrees away. Since the letters get angularly smaller as the distance of the page from your eye increases — and so too does the angle that they make with your gaze — in our demonstrations it doesn't matter whether you hold the page five inches from your eye, or at arm's length.

I am now driven to abstract some meaning from what has just been shown. First, as the text moves away from my gaze, my acuity — the ability to resolve two points — changes, but yet it doesn't change so drastically that I cannot read a single letter isolated as in the first study. The single letter — in this case an N — is somewhat strange in the eccentric view. True, I can read it, but it somehow seems to have lost form without losing crispness. An O looks more formed in a way. It seems more clearly and definitely an O although the line doesn't seem clearer. A letter combined of a closed loop and one or two lines — such as a P or an R — shows that in eccentric view the ring form seems to have greater peripheral strength than open line segments. In any case, while I can resolve those thin doubly bounded areas — the lines that make up the letter — I can't compose them as easily into a form eccentrically as I can foveally. Furthermore the parts of the form can interfere with each other as I see with eccentric capital letters of an "Old English" font. The isolated N in the first study has eccentrically-seen shape, the imbedded N in MOANED does not, or at any rate, not so distinctly as to be readable at the same eccentricity. The same lesson is poignantly learned in the last study wherein the O in HOE is only a heap of small O's but without the spatial relations that would give the heap a shape. It would appear that the isolated N has something that the imbedded N doesn't, and the imbedded N — as the imbedded circles of O's — only seems to have a "statistical" existence. It is as if the isolated letter were allowed to preserve every property save that of the spatial order that would confer shape. But this loss of spatial order does not involve loss of continuity or boundary — witness the N and the individual o's. Indeed discontinuities and dots are quite visible in a single line, as below, but a single gap or dot is hard to see as the array of similar things gets larger as we see in the successive rows. The loss of spatial order does not involve angles or any other property that we commonly discuss, only the vague property of shape by which parts are related to each other.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Bela Julesz of Bell Labs, in a marvelous essay in *Scientific American* (April 1975), showed that two black-and-white images which are distinct from one another on a detailed examination are indistinguishable to the casual glance if they have certain statistical properties in common. He called these common properties texture.

In the spirit of Julesz' work, let us say that to the extent that visible objects are different and far apart, they are *forms*. To the extent that they are similar and congregated they are a *texture*. A man has form; a crowd has man-texture. A leaf has form; an arbor has leaf texture, and so on. The texture of an isolated N specifies an N; the texture of an imbedded N specifies much less about the N as a form.

Two comments emerge. The first concerns painting. Both the Academicians and the Impressionists during the nineteenth century had mastered ways of painting texture — each method fundamentally opposed to the other. The Impressionists held that texture comes first and form arises from it, while the Academicians believed that shape is prior to texture. The same controversy holds for eccentric vision. One can imagine shapes spatially interfering with each other to comprise texture; or else suppose that texture is primitive and that textures combine to produce forms — just as letters combine to make words. I am on the side of the Impressionists.

The second comment is about how we read. If you look at a middle letter of any medium-long word, say

`emanations`

and see it also in upper case as in

`EMANATIONS`

you will note that despite the fact that the whole word fits well below a dime at 15 inches from the eye—and so lies completely in the fovea—even so you can't read all the letters and are even more disabled in the less textured upper case than in the lower case. What remains to be said is that eye movements determine how we see texture as well as the forms. But Helmholtz made this point more than one hundred years ago.

Eye movements and object movements determine the seen texture as well as the forms. Let's see how this works. Print the word MOANED freehand on a rectangular card near the right hand edge. Cut a hole in the card where the N is, making the hole as large in width as you can without intruding on the A or E. On another card, at right angles to the first, print the missing N near the right hand edge. On a white sheet of paper draw a fixation mark, then lay the N card down to the left of the mark so that the N is about an inch from the mark, and then lay the MOA-ED card over the N card so that the word MOANED appears. When I gaze at the fixation mark, I do not see the N. But, if the MOA-ED card is held stationary and the N card is jiggled slightly, the N becomes as visible in the fixed eccentric view as if it were isolated. Here, the letters around the N are less clear. However, if I hold the N card stationary and jiggle the MOA-ED card, the N does not become clearer except with large vertical excursions, but the end letters of MOA-ED stand out.

Eye movements are a different matter. I believe with Helmholtz that they are a most important but little understood factor in form vision.

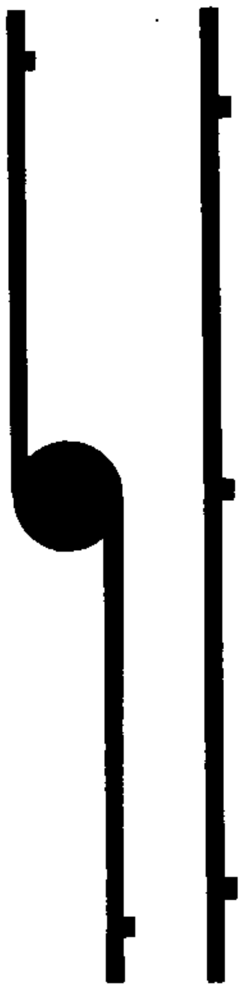
Motion

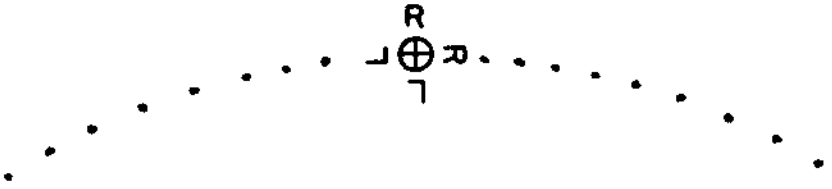
Without constant motion of the eye in small and large jerks, the visual world vanishes. First found to occur in the 1820's for vision in dim light, it is called the Troxler effect. If the light is dim enough — as in moonlight — so that I cannot see any colors even when I have adapted to the light, then, if I steadily regard a scene — moving my eyes as little as possible — details begin to vanish and eventually the whole scene fades only to be restored when I shift my view. I cannot speak of "gaze" in moonlight because below the illumination level at which I can see colors, the fovea is a blind spot — in most respects like the anatomical blind spot I discussed first. This is easily checked: Put a half dollar size disc of gray paper at arm's length against some interesting background and try to gaze at it in moonlight. It vanishes and only reappears when you look slightly away.

Helmholtz found that an image that does not move on the retina vanishes even in bright light. Indeed he devised a most elegant way of showing this without much apparatus. I have modified his method slightly for these experiments. Light passes all the way through the retina before hitting the receptors which face away from the lens. Over the surface of the retina runs a net of blood vessels that come in with the optic nerve through the anatomical blind spot. It is as if cameras were built with a net over the film surface facing the lens.

Ordinarily we don't see these vessels. But now we shall try. The vessel network looks much like the drawing in Exercise 4 and you can see it best by using a pencil flashlight (the smaller the bulb the better). First, close your eyes. Looking moderately downward behind closed lids, rest the bulb on the upper lid of one eye just at the upper margin of the bone socket so that when the light is switched on it shines very locally on the lid and doesn't spread widely. Now gently move the light right and left about three to four times per second. The net stands out as a black silhouette against an orange background. This branching pattern is called the Purkinje tree after the great Romanian biologist who first observed it in about 1820. After a few seconds the net and background turn dim. If you shift your gaze under your eyelids, or if you simply turn off the light for about five or ten seconds and then turn it on again, you'll restore the picture. Note that if you turn the light on and don't jiggle the flashlight the tree vanishes in a second or two.

Now we do a most revealing experiment. Place the light at the bony margin as before, and wait for the image to disappear. Then move it right and left or up and down. If you move it right and left in a small excursion, you'll see only the horizontally arrayed vessels clearly. It

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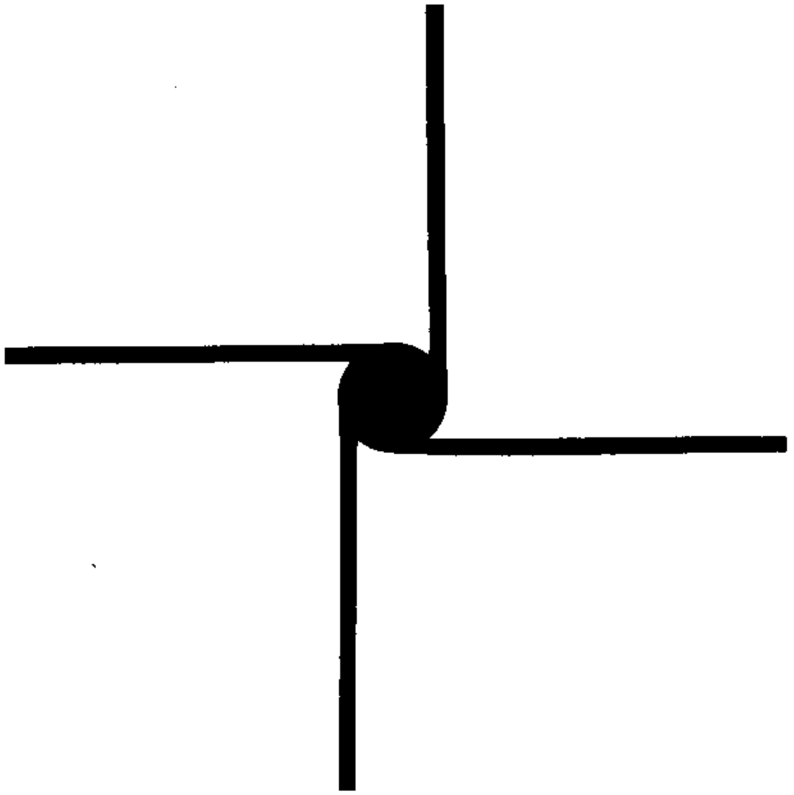


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EXERCISE 4

seems that only those vessels whose shadows move can be seen — those vessels that run transverse to the movement of the light. You can program what boundaries you will see by how you move your eyes, for if you keep the light fixed and move your eyes up and down or side to side you get much the same effect.

Now consider the modern work of that heroic Russian scientist, A.L. Yarbus, whose experiments enlarge upon the earlier studies of Loren Riggs of Brown University and R.W. Ditchburne of Cambridge. (I believe Yarbus' experiments completely without repeating them for I am nervous about attaching suction cups to my eyeball.) Let me present his findings in terms of that favored object of British empiricists wherewith they repel all attempts to bring natural science to epistemology — a reddish orange spot on a cream colored wall. The wall and the spot are flat, smooth and uniformly colored. I gaze at the fixation mark. "What seest thou, brother?" I am asked and I reply, "A reddish orange spot on a cream colored wall." Minute after minute, unblinkingly I keep my gaze as fixed as I can and the spot and wall stay there, colored properly, although the spot may desaturate in color somewhat, and a faint bluish border may flicker along its boundary.

Now imagine that I attach an optical device to my eye with a suction cup. An image of the same reddish orange spot on the same cream colored wall is turned on. There are no fixation points because the image has been coupled to my eyeball so that no matter how I move my eye the scene stays fixed on the same part of the retina. Within a second or two the image begins to fade and is gone completely in about four seconds. It is replaced by absolutely nothing. E. Hering, the great nineteenth century psychologist, coined the term *eigengrau*, or intrinsic gray, a field that has no color and has no visual properties at all—neither of brightness nor of darkness. It is the *tohubohu* of vision, the visual field of a blind man, a void. We experience the *eigengrau* when the entire visual image is stabilized.

But what if only a part of the visual field were to be stabilized? This is just what Yarbus did in his remarkable experiments. On a small pedestal attached to his eyeball he mounted a device that obscured only a small solid angle of the visual field with a stabilized patch that moved with the eye. Yarbus experimented with a number of patches of different colors and of different forms. When a patch was placed so as to be surrounded by a non-stabilized colored spot, the patch disappeared in a few seconds and he could only see the colored spot as if complete. Then Yarbus moved a patch across the boundary that marked the edge of the large colored spot. He experienced "completion" through the patch but he also saw a fuzzy, indescribable area, much as if he were using his anatomical blind spot. Yarbus concludes that since any patch stabilized within the boundary of the colored spot becomes a blind spot, why so does the interior of the spot itself. That is, of course, the greatest possible joke, that the color of the spot is taken at the boundary, and all the interior that is never encroached on by a small movement of a boundary is a blind spot. It may seem a bizarre result, but it is also the most economical procedure for image processing as the color TV people know. Why waste informational channels to report no change? Thus with blind spots, textures, and the sensitivity only to change I may now begin thinking of how my perceptions are possible.

Conversation Piece

When I look at the world what I see are objects moving about in relation to each other. I do not see the image on my retina. Seeing is constructing a model of the world that accounts for the image on my retina. The retinal image is two-dimensional; the model I create is three-dimensional. But the two must be related somehow.

If I receive the image as an array of points of light on the array of my retinal receptors, I have as many sense data as there are receptors. The sense data are then processed — subjected to rules that relate the points to each other. Since the rules cannot be in the points, they must be built into me. Leibnitz calls such rules "innate ideas," and in a more restricted way they are Kant's "synthetic *a priori*." This is the set of rules that gives the space of perception or the order of objects seen at the same time. It is not obvious that the rules for constructing objects must be the same as those that relate them to each other. Nonetheless, Kant felt that intuited space was unitary. This space is certainly absolute since it seems to exist independent of the objects in it, just as I experience it in a totally dark room. Emerging from the exercises I asked you to perform is evidence that, whether or not Kant's intuited space is like Newton's space in mechanics, perceptual space itself is not governed by a simple geometry.

Now as for our blind spot, the longer one plays with it, the more varied are the effects. At first, when I note the anisotropy of the space around the spot — the space has different properties in different directions — I think I can characterize the visual space in a definite way. But increasing experience shows that none of the appearances is immutable. Indeed, they can shift violently. At first, since I do not seem to control the appearance, I feel that I may be driven to the notion of unconscious fill-in. When I return to Exercise 3, I find that as I continue to play with the image of the staggered stripe, I discover that there are times when the apparent stagger disappears and is replaced by a "filled-in" straight stripe. The stripe becomes vague but filled-in around the blind spot, and, when presented again, or shortened a bit, becomes staggered and crisp. It is then that I note a curious thing about the vertical staggered stripe that I saw as filled-in. If the presented stripe is not actually staggered it is quite clear up to the blind spot and has a limited region of uncertainty about it. As the stripe gets more and more staggered through the blind spot, the uncertain region extends up and down away from the blind spot to a greater and greater distance. I exchange one perceptual property for another — uncertainty about the stripe in exchange for continuity and straightness. I look at it horizontally and discover that when the staggered stripe is long at both sides of the blind spot, its horizontal vagueness extends out from the blind spot depending on whether it seems straight, and it is much less vague when it appears staggered. So definite is the trade-off that when I rotate the page slightly with the staggered stripe staying in the blind spot, if it has seemed continuous I will actually get an impression of a double image at one side or the other. The vague continuous straight stripe and an apparently staggered and more crisply seen one sometimes appear at a definite angle to each other. It seems that in the region of the blind spot I can trade resolution for geometric form. What's more, the trade is a switch — I simply cannot force myself to perceive a continuous grading of trade-off. What I can determine is that my eye movements change in making the trade-off. Problem: how can this be tested easily? For this is how apperception in part controls perception.

When I played with a pencil in Exercise I and I introduced it into the blind spot, I saw how it disappeared locally, but had no boundary in the usual visual sense. It appeared as if the pencil was bounded at its sides by what was distinctly not the pencil but something else—the sheet of paper. However, where its tip vanished into the blind spot there was no "something else," but pure negation — "not pencil" and "not anything else." That is why when the pencil tip just began showing across the blind spot there could be no interruption of the pencil, for it has neither ended one place nor begun in the other in the conventional perceptual sense. Since it didn't end here and begin there it is continuous apperceptively—for what would I have to separate the two?

These considerations about the blind spot led me, as other things lead other physiologists, to a queer idea of myself. The "I," who perceives, receives reports from a great many observers whose fields of view overlap considerably. This is in vague accord with anatomy and physiology. My job as perceiver is to construct a model of what is "out there" from the reports. What I don't know is how many collators and processors and censors lie between the point-to-point image reporters and myself. I have a private map showing positions of reports. In this map, one report can be to the left and above another report. Each reporter says only what he sees and uses terms such as *to the left* and *up*. But the terms used by the reporters do not refer to the map.

I have two spaces to deal with: that spoken of by the individual reports and that which I use for arranging the reports. I am obliged to remember that what I am receiving are reports—not images in the optical sense—so that putting together reports is not like patching together NASA photographs of the moon, but rather like taking evidence from witnesses and patching together what they witnessed as a unitary thing. Accordingly, my view of the world—the model I make of it—is not easily imagined in terms of a three-dimensional fixed scaffold. I may have high resolution for the form of something and yet not know quite where it is with the same kind of spatial precision. That is why in Exercise 3 I have put the little spikes on the limbs of the staggered stripes. I see them clearly enough, but if I use them as guides, I find that I can't judge the distance between the stripes. Thus I conclude that there are no fixed distance elements in visual space. As I have described it, perceptual space is a discrete manifold as opposed to the graph paper version or three-dimensional scaffold that marks off a continuous manifold. The rules for the discrete manifold version of space could have been made up by the early Wittgenstein: "The world is all that is the case." Or, the world consists only of reports; therefore it is always complete. That is why the visual space is a plenum. "Whereof one can't speak, thereof must one be silent." In other words, there is no world of perception except for what is given by reports. The visual world is not a continuous and unified geometry but a set of rules whereby patches are somehow fitted to each other in a lawful way—a topology.

To this view, there are at least two major questions that one can pose. First, what is the nature of the reports? Second, what are the rules for assembling reports? I have no carefully grounded scientific opinion by which to answer either query. But with respect to both I have strong tentative suspicions.

I believe the reports are those of a visual texture. In the late fifties, Humberto Maturana and I found several types of optic nerve fibers in the frog. By far the most common and most interesting was what we called the "bug detector." In 1961, we published an essay in which we suggested that these fibers worked by taking a combination of boundary length and the brightness changes across the boundaries. The bug detectors could easily be mistaken for what physiologists call "center-surround" cells. Such a cell can report a darkening in the center of the retinal patch at which it looks, and can diminish that report by how much darkening occurs around the center. Bug detectors, however, are more sensitive to how sharp a boundary is than to how much the light changes across the boundary. They are also more sensitive to changes in the shape and relative positions of boundaries than to the change in lighting. These characteristics have not been carefully enough qualified or even much tested in mammals because it is hard to control a visual field in which spots vary in size and shape and collect or disperse. This is the substance of my present research, for I suspect that texture somewhat redefined is the primitive stuff out of which form is constructed.

I also think that the rules for assembling reports in large measure come from eye movements and their concomitants in the brain. This belief originates with Helmholtz. I have partially satisfied myself that the change in the spatial properties of figures that traverse the blind spot is consequent to changes in eye movement. Again, this is the subject of current research and I cannot predict the outcome.

What emerges from all this is that visual space is a discrete manifold, that texture may be primitive to form—just as the Impressionists thought—and that texture is in part determined by how I move my eyes in order to see. And these three points are of vast importance in understanding the reports made by patients with visual disorders. ■