VISUAL PERCEPTION DURING EYE MOVEMENT.

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SECTION I. TWO SOURCES OF ERROR IN INVESTIGATING THE PROBLEM.

The problem of determining the character of visual perception during the movement of the eye from one point of fixation to another presents some exceptional difficulties to a psychological investigation.

During the visual examination of an object of any considerable size, say 5°, we are commonly conscious of a series of eye movements 'following the contour lines,' etc. On the other hand, the careful examination of a minute part of such an object certainly demands more than a continuous movement of the point of regard across it. We fixate it directly for an appreciable length of time.

If one endeavors to distinguish by mere introspection between the visual data acquired during the eye movements and those of the fixation pauses, an insurmountable difficulty will be discovered, viz: All self-observation of the eye movements and fixation pauses is utterly unreliable.

Attention has recently been called to this difficulty in a number of ways. It is now well known, for instance, that the eyes make a very regular series of full stops in reading; but even the trained psychologist is unable to give a reliable account of the points fixated at these stops, or even of their number, from mere self-observation.

A less experienced observer is quite unable to tell whether a given eye movement was broken by a stop or not; and even after more than five years' study of the eye movements, I have no confidence in my own judgment in the matter, if it is unverified either by the direct observation of an assistant or by some form of registration.

Direct observation by an assistant is by far the simplest and least questionable control. It has been used throughout the following experiments. Only one precaution is worth mentioning; and that is so obvious from general principles that it needs no elaboration. The assistant must not attempt to follow any point of the moving eyeball in its excursions; but must rather fixate some point of the lid or eyelash, which is relatively at rest. In some cases it may even be necessary to construct an artificial fixation point, independent of the eye.

While this fundamental difficulty is so easily overcome by the simplest experimental conditions, it is obviously not impossible that, without these, it may have led even trained investigators into believing they saw during eye movement that which was really seen during an unnoticed fixation pause.

A second source of error in the investigation of our problem is the familiar difficulty of distinguishing the centrally conditioned elements of a percept from those which are peripherally conditioned. It is perhaps most widely known as the proof-reader's fallacy. A striking example is a phenomenon, well known to all who have worked with the tachistoscope. When a long word or phrase is grasped, even those parts seem to stand out clear and distinct, which a continuous exposure shows to have been so far out of the field of direct vision as to present a hopelessly indistinct blur.

We have no subjective criterion by which to distinguish the perceptive from the apperceptive elements in any given percept. Hence it follows that when we clearly recognize parts of a field of vision which a careful test shows to have been peripherally indistinct during all of the fixation pauses of the eye, the conclusion is almost inevitable that the clear perception was due to clearer vision during eye movement.

This second source of error is not as easily verified and controlled as the first; nevertheless it is the first thesis of this paper that the apparent clear perception of an object during eye movement is an *illusion*, due to these two fallacies of self-observation.

Section II. Clear Perception of a Complex Field of Vision During Eye Movement is Impossible.

The first attempt to determine how much of a complex field of vision could be apprehended during the uninterrupted movement of the eyes was made, so far as I am aware, by Professor Benno Erdmann and the author,[1] in an attempt to explain the meaning of those strangely rhythmic pauses of the eye in reading every page of printed matter.

It was then we chanced on the observation that when the head was held perfectly still we could never catch our own eyes moving in a mirror. One may watch one's eyes as closely as possible, even with the aid of a concave reflector, whether one looks from one eye to the other, or from some more distant object to one's own eyes, the eyes may be seen now in one position and now in another, but never in motion.

This seemed to me and still seems explicable in only one way.

The simple experiment is singularly precise. Since the phenomenon to be observed only occurs while the eye is moving, a pause in the movement, even if unnoticed, can do no harm. Even the apperceptive illusion has no chance, since it would tend, not to constructive imagination of a movement, but rather towards a greater clearness of the peripheral parts of the field of vision. There are two new sources of error, however, which demand experimental precautions. Slight, involuntary movements of the head produce conditions in which the eyes seem to move. They are best prevented by a Helmholtz head rest. Again, any abnormality in the movement of either eye, which causes it to move slower than the other, will make the end of its movement visible to the eye already at rest. This makes it advisable to confine the experiment to a single eye, shutting out the other by a screen.

The same lack of clear perception during eye movement may be discovered when the object is stationary, provided one takes the necessary precautions against the ever-threatening illusions.

If one fixates the beginning of a line on this page, for ex-

[1] Psychologische Untersuchungen über das Lesen, von Benno Erdmann und Raymond Dodge, page 69 et fol.

ample, the words in the middle of the line will be altogether illegible. The same will be true when the right end of the line is fixated, though the general character of the line is seen from both fixation points. If we look quickly from one end of the line to the other, it will seem as though we saw the letters and words during the movement, but an analysis of what was seen will show that we have not seen a particle more than we saw from one fixation point or the other.

This was the experiment by which Professor Erdmann and the author demonstrated the fact that the rhythmic pauses in reading are the moments of significant stimulation. Doubtless most who try it carefully will fall victims to the first difficulty. It will be clear that when the eye moves as rapidly as possible from one fixation point to the other nothing new is seen; but it will seem that, when the eye moves more slowly, the entire line is seen very distinctly. If the observer takes the precaution to have some one watch his eyes, as recommended, he will find that what in self-observation passes for a slow movement of the eyes is in reality broken by one or more clearly defined full stops. An assistant watching the observer's eyes will be able to predict with absolute correctness when the middle of the line was clearly seen, and when not, by the presence or absence of these full stops.

The rapid alternation of black and white stimulation by a line of letters is not the only condition of eye movement blindness. If a simple letter or figure is placed between two fixation points so as to be irrecognizable from both, no eye movement is found to make it clear, which does not show a full stop between them. Four or five lines, close enough together to prevent counting, may be substituted for the letter with the same result. This is more easily explicable when the lines are perpendicular to the line of movement, but the same result also obtains when they are parallel.

Any attempt to explain these phenomena by reference to the known laws of the action of a rapid succession of stimuli is met by the problem, which Professor Cattell emphasized in a recent significant article;[1] viz, why we get no characteristic lines

[1] On Relations of Time and Space in Vision, by Professor J. McKeen Cattell. PSYCHOLOGICAL REVIEW, vol. 4, 325 et fol.

of fusion. It is true that I believe I can detect such faint gray lines of fusion; for example, during long eye movements across a page of print; but the great majority of those I have tested discover nothing of the sort.

SECTION III. THE HYPOTHESIS OF ANÆSTHESIA DURING EYE MOVEMENT.

The possibility early occurred to me that the movement of the eye might condition a momentary visual anæsthesia. This seemed to be supported by the fading of after images during eye movement and similar phenomena. This hypothesis is, however, false. It is rendered improbable by the perception of long streaks of light seen when the retina moves across the image of a bright point of light on a dark ground. It is disproved by the following experiment:

A disk of black cardboard thirteen inches in diameter, in which a circle of one-eighth inch round holes, one-half inch apart, had been punched close to the periphery all around, was made to revolve at such a velocity that, while the light from the holes fused to a bright circle when the eye was at rest, when the eye moved in the direction of the disk's rotation from one fixation point, seen through the fused circle of light, to another one inch distant, three clear-cut round holes were seen much brighter than the band of light out of which they seemed to emerge. This was only possible when the velocity of the holes was sufficient to keep their images at exactly the same spot on the retina during the movement of the eye. The significant thing is that the individual round spots of light thus seen, were much more intense than the fused line of light seen while the eyes were at rest. Neither my assistant nor I was able to detect any difference in brightness between them and the background when altogether unobstructed.

In passing, it may be worth mentioning that the required result was reached when the holes had a velocity of one inch in 22σ, and the arc of eye movements was 4.7°

The lack of suitable regulation for my disk prevents my following out the experiment; but it is certainly striking that this result is much closer in accord with my measurements of the eyes' velocity by the Lamanski method, than with the measurements obtained by the eye cup and pointer method by Huey. The experiment seems well worth while carrying further by some one who has access to suitable apparatus.

Section IV. Perception of a Simple Field of Vision Exposed Only During Eye Movement.

In all the direct experiments thus far published, except the self observation in a mirror, the influence of the vague peripheral image of the object seen during the full stops at the first and second fixation points unquestionably interferes with any attempt to determine just what is seen during the eye movement. The tendency is towards a belief that the same amount is seen during the eye movement as at the more favorable fixation point.

Adequate experimental conditions for the investigation of the positive side of our problem demand a complete separation of the fields of vision during the movement and during the periods of fixation. An exposure apparatus is required, depending for its action on the movement of the eyes, so that objects will be exposed during movement and covered when the eye is at rest.

The conditions for such an arrangement are furnished by the movement of the eye itself. Since the axis of rotation is within the eyeball, in every eye movement the pupil travels through an arc equal to the arc of movement of the point of regard. If the arc of movement is large enough, the pupil may be made to travel the entire width of an open slit in a screen, through which objects behind the screen will be exposed as the eye is passing the slit, while they will be completely hidden by the screen at both termini of the movement. Taking 24 mm. as the diameter of the eyeball and 5 mm. as the ordinary maximum diameter of the pupil in daylight, it will be seen that the arc of movement which would carry the pupil entirely across a slit 5 mm. wide would be 72°. In practice, however, it is better to have the slit somewhat smaller and the arc of movement about 80°.

The necessary apparatus may be easily built up from material in every laboratory. As used in the first part of the following experiments it was essentially a simple perimeter, fixed in the horizontal plane, to which was attached a firm head rest and a special eye-piece. This latter was composed of two screens of black cardboard, set at an angle of about 30°, converging immediately before the eye, and so adjusted that when the eye looked at the center of the perimeter it looked between the screens through a slit 4 mm. wide, standing about 4 mm. from the cornea. The length of the exposed surfaces may be 15° or even more. The best results were obtained when they were not longer than 10°. All reflection from the black cardboard should be carefully shut out of the eye by secondary screens. For fixation points small bright steel rods were used. They effect a minimum retinal area and are very distinct. Whatever the fixation point used, each should be visible from the other.

The first experiments with this apparatus were altogether negative. White cardboard filling the whole ten degrees of the field of exposure was wholly unseen. The result was the same when colored surfaces were substituted for the white.

Fearing the unusually long movement might be an unfavorable condition, a modification of the apparatus was devised to shorten the arc of movement to 50°. The plan of this modification was to substitute the insensibility of the blind spot for the opacity of one of the screens of the eye-piece. It was effected by reducing the field of exposure to 3.5°, removing the screen *a*, and placing the primary fixation point in such a position for each observer that the field to be exposed fell completely within the blind spot.

For convenience of comparison the two pieces of apparatus were made entirely separate; the second form being built up on an ordinary perimeter.

This apparatus has an especial experimental value besides shortening the arc of movement; viz, the exposure is made during the first part of the movement instead of in the middle. It is, however, not without its disadvantages. For some eyes the primary fixation point must be 1°–2° higher than the field of exposure, if the latter is to fall comfortably within the blind spot. This renders the observations in so far questionable as the field of clearest vision is not stimulated by the exposure. Moreover, the movement can be made to advantage with each eye in only one direction; since it is impossible to look from the second fixation point to the first with sufficient accuracy to insure the complete disappearance of the field of exposure within the blind spot, in a single uninterrupted movement.

The results of the first experiments with the new form of apparatus were also entirely negative. Five different colors and white were exposed in the field five times each for both my assistant and myself, with the result that, when the eye movement was unbroken, the observer was unable to tell what had been exposed or even that anything at all had broken the black of the perimeter. My own primary fixation point was directly in line with the upper edge of the field of exposure. My assistant's was $1°30'$ above.

Subsequent experiments under exactly the same objective conditions have given quite different results. But I believe these first experiments are important as showing the difficulty of perceiving the simplest possible change in the field of vision, during eye movement, without special training. It is certainly suggestive of a central explanation for the absence of bands of fusion under ordinary conditions.

These failures suggested an increase of the illumination of the field of exposure. A ground glass plate, illuminated from behind by a bright, sunlit landscape, was substituted for the white cardboard in the first form of apparatus. Under these conditions a long band of light was immediately evident at each movement of the eye. This band uniformly appeared longer than $10°$ even when the length was known. There were no sharp boundary lines; particularly was this true in the direction of movement. This is probably due to a peculiarity of the apparatus, which is of great service in experiments on fusion. Each screen bounding the open slit is really an opaque body, intervening between the eye and the object, and exposing first one part and then the rest as the edge of the pupil moves across its edge. If the slit is near the eye, however, this function is entirely overshadowed by another, viz: that of a diaphragm, increasing and decreasing the brightness of the image on the retina. Thus, when the pupil moves into the pencil of rays which has passed the slit, a point may be found at which a very faint image of part of the 10° field of exposure can be seen before the other part comes into view. This first faint stimulation, as well as the corresponding stimulation as the pupil passes out of the pencil of light, affects a portion of the retina not further stimulated, giving rise to the very faint ends of the band of light as it passes off into black. In experiments with a complex color field these ends are too faint and too far from the field of clear vision to cause any inconvenience.

Except for the indefinite edges, the band of light appeared homogeneous, but very much less intense than the ground glass during direct fixation.

If colored gelatin plates were placed in front of the ground glass, the colors, though dull, were always distinguished from gray and from the other primary colors.

Under the influence of these experiments, a return to the previous conditions showed a decided difference in ability to see the bands of light. At best, however, they had a vague cloud-like appearance, and the colors were mere tintings of this cloud.

Section V. Perception of a Complex Field of Vision Exposed only During Eye Movement.

The experiments have thus far dealt only with the simplest possible fields of light or color; but the qualitative modification of these fields by the movement of the eye clearly indicates the influence of their background. The problem of this influence is of the highest theoretical importance. Professor Cattell holds that the differences in the field of vision do not fuse during eye movement; but that, on the contrary, its various elements may be distinguished with extraordinary ease.

It is certain that we do not ordinarily find in consciousness any sign of a fused field of vision during eye movement. The long failure of physiological optics to correct the illusion of clear vision during eye movement is undoubtedly due in large measure to this lack of a fusion consciousness. In spite of it, however, it is now possible to show experimentally that when a complex field of vision is perceived during eye movement it is seen fused.

A part of a page of print exposed in place of the white cardboard in the original apparatus gave a perfect though shadowy series of gray bands on a lighter gray background, in which individual letters or words were absolutely irrecognizable. The gray bands seemed homogeneous, without sharp boundary lines and of uncertain length.

Two white surfaces separated by a vertical black stripe, 2° 30′ in width, gave a homogeneous gray band, again without sharp boundaries and of uncertain length. There was no trace of an independent black stripe.

The last form of apparatus described was by far the most satisfactory arrangement for the study of color fusions. In front of the ground glass plate, illuminated as before by a bright landscape, was brought a black screen, perforated by four vertical slits which could be filled with colored films at pleasure. Each slit was 1° in width and four times as long as it was wide. They were separated from each other by equally large sections of the opaque screen. In front of this color screen was placed a movable screen, with teeth rising to the middle of the slits in the first screen, so arranged as to cover at will the lower half of either set of alternate slits. Since the same color always filled the alternate slits of the color screen this gave a valuable basis for the comparison of the dull band of apparent fusion of colors, with a juxtaposed band, first of one color and then of the other, as the sliding screen was adjusted.

The resulting fusions were thoroughly normal.

Colorless bands resulted from filling the alternate slits with complementary colors. Red and yellow gave an orange band; red and blue a purple one.

Although the difference between the upper and lower half of the field, *i. e.*, between the mixed and the simple colors, was always clear, the bands had throughout the characteristics previously mentioned. They were elongated, dull in color, and had uncertain boundaries. In no case of unbroken eye movement were the contents of the different slits distinguishable.

Section VI. The General Failure to See a Fused Field of Vision During Ordinary Eye Movement.

The question naturally arises why we fail to notice the fusion which the experiments clearly show must occur with almost every movement of the eye from one point of regard to another. Their persistent absence is, I am convinced, centrally as well as peripherally conditioned. It is my opinion that the difference between the results of the first and second series of experiments, with the first apparatus, under the same objective conditions, was due chiefly to a difference of apperceptive predisposition and attention; clearly indicating a most important factor in any explanation of the non-perception of the faint stimuli during ordinary eye movement. If our attention were habitually attracted by them, it must seriously disturb our clear vision at each new fixation. We should, consequently, rather expect them, like the entoptic phenomena, to be systematically ignored and even to require experimental conditions to demonstrate their existence.

In respect to the peripheral conditions, we must remember that it is only in complex fields of vision that the problem has any meaning. If the field of vision is simple or homogeneous in the planes perpendicular to the axis of rotation of the eye, stimulation during eye movement could not be differentiated in any way from that during the fixation pauses.

In any complex field of vision, the successive stimulation of each point of the retina by its various parts must tend to even up the total stimulation of those parts affected, and to break down the sharper contrasts of the fixation pauses. This is essentially a process of equalizing retinal excitation and of preparing for a new fixation.

Moreover, it must be remembered that the duration of the eye movements is very short, for movements of 10° certainly not more than 60 σ, and possibly less than half that. It will be seen at once that the equalizing stimulation during the movement of the eyes scarcely covers the duration of the most pronounced after-effect of the intense stimulation at the preceding fixation pause; while the interference of the intenser stimulation of the succeeding fixation would make the faint stimulation hardly perceptible, even if it had no after-effect of the previous fixation, and no central inhibition to overcome in establishing itself.

There is strong evidence, with the details of which this article may not be burdened, that the equalization of the stimulation of each reading pause by the fusion during eye movement to the next fixation point is a very essential condition in the elimination of fatigue in reading, and as well in the prevention of error.