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ART. XXXIX.—*On some Phenomena of Binocular Vision;* by JOSEPH LECONTE, Prof. Geol. and Nat. Hist., University of California.*

VI. *So-called "images of illusion;" and the theory of binocular relief.*

IN a very elaborate paper on binocular vision published in the Archives des Sciences† for Feb., 1871, which is itself but a succinct resumé of a much more extended memoir soon to be published, M. Pictet undertakes to establish on a firm basis the "*nativistic*" theory which regards *corresponding points* as *congenital* and the result of *anatomical structure*, as opposed to the "*empiristic*" theory which regards them as the *result of experience.* After summing up the usual arguments and objections on each side, he proceeds, as he thinks, to prove the truth of the former theory by showing, first, *a priori*, the consequences which must flow from the admission of this theory; second, that the visual results of certain experiments are precisely what *a priori* reasoning leads us to expect; and third, that this theory, in the form in which he maintains it, explains all the more obvious phenomena of binocular vision.

The one strikingly new thought in M. Pictet's memoir is the supposed existence of "*images of illusion*" in every act of vision. *This* it is which follows, he thinks, from the admission of the nativistic theory; it is *this* which he attempts to prove by all his experiments; it is by means of *this* that he solves all the

* For previous papers on this subject see II, vol. xlvii, pp. 68, 153; III, vol. i, p. 33, and vol. ii, p. 1.

† Arch. des Scien., nouv. per tome xl, p. 105.

vexed questions of binocular vision. Now while I believe the evidence is overwhelmingly in favor of the nativistic theory, i. e., the *congenital* existence of corresponding points, yet I feel perfectly confident that the existence of M. Pictet's images of illusion, from their very nature, cannot be proved; and that all the phenomena which he adduces as proof may be easily explained by the known laws of binocular vision. Passing over, therefore, the many interesting questions touched upon in M. Pictet's very suggestive paper, I will confine myself wholly to M. Pictet's *illusive images;* my sole object being to rescue the theory of binocular vision from the confusion into which it has been thrown by the introduction of this new idea.

In order to account for single vision with two eyes, Müller supposed that the nerve fibers which terminate *peripherally* in identical points of the retinæ (*corresponding fibers*) are *centrally* fused into *one fiber*, or *terminate centrally in one brain cell.* M. Pictet admits that the nativistic theory is by no means dependent on this assumption—the existence of corresponding or identical points as a congenital fact, by whatsoever structural contrivance effected, being all that is contemplated by this theory—yet all his reasonings are based upon, and all his experiments are intended to prove, *an alliance* between corresponding fibers *equivalent to* the *fusion* of Müller. For M. Pictet, corresponding fibers under all conceivable circumstances behave *like*, and therefore *are* substantially, a *single bifurcating fiber.* Assuming, then, an anatomical structure equivalent to fusion of corresponding fibers into one in the brain, M. Pictet proceeds to show that, by the well-known physiological law which refers all impressions on the nerve *centers* to the *peripheral extremities of the nerve fibers*, an impression made upon any point of *one retina*, being carried to the brain, would thence be necessarily referred back to *both extremities* of the bifurcating fiber, i. e., *to corresponding points of both retinæ.* Therefore, if luminous rays from an object impress the *retina of one eye*, the impression transmitted to the brain must be referred back *equally to both eyes*, producing *two identical external images* in the field of view; the one a *true image* produced by the luminous impression on the retina of one eye, the other an "*image of illusion*"—a subjective or spectral image—*reflected* from the *point of alliance* within the brain to the *retina of the other eye.* According to M. Pictet, therefore, even *when we shut one eye* we still, in a certain sense, *see objects with both eyes;* for there is a true image belonging to the open eye and an illusive image to the closed eye. These two images are *identical* and seen at the *same place.* Stereoscopic effects are not observable in monocular vision only because these two images are *perfectly identical* and *perfectly united.*

It is easy to see, from the perfect identity and the inseparable union of the true and illusive images, how difficult, nay, even *impossible* and therefore futile, to attempt to prove the existence of the latter. Nevertheless, M. Pictet details several experiments which, he thinks, prove beyond doubt the existence of such illusive images in every act of vision. I wish to show that the phenomena of M. Pictet's experiments may be explained without resorting to illusive images. Before doing so, however, I find it necessary to state very concisely certain general principles of binocular vision which I shall use in their explanation, referring the reader to my previous papers for a fuller statement and proof. Throughout this paper I shall refer back to these principles by means of the numerals affixed.

1. The impressions produced by *luminous retinal images* are transmitted to the brain and, by a psychological law, are projected outward into the external world and seen there as *external images.* Each eye has its *own field of view* crowded with *its own images.* As these images are usually seen *double*, it will often be convenient to regard them not as *objects* but as external *images*, the signs of objects. Only when the two images formed by the same object are superposed do we see the object *single* and *in its true position.* This takes place when the *luminous* images fall on *corresponding points.* The two retinal images on corresponding points are *seen* externally as a *single* image or object. It is true this may be regarded as *really a single image —the sign of the fusion of the nerve fibers.* But since we can move about the *two* images of the *same* object, bring them near together, unite them partly or unite them wholly, as we please; and since, moreover, we can even take images of *different* objects and superpose them, and if they be similar, unite them so as to appear as *one* object, it is better, because it more easily explains visual phenomena, to regard single binocular vision as the result of the *superposition of two images.*

2. In binocular vision with the optic axis parallel, as in gazing at a distant object, the whole field of view and all objects in the field, including the visible parts of the face, are shifted by the *right* eye a half interocular space to the *left*, and by the left eye the same distance to the right, without altering the relative position of parts; so that the two eyes and their visual lines seem to unite to form a *single binocular eye*, and a *single middle visual line* along which the eye seems to look. Any line, rod or plane in the median line, as also the nose itself, is *doubled heteronymously*, and becomes two lines, rods or planes, parallel to each other, and separated by a space exactly equal to the interocular space. Between the two noses and between the two parallel lines, rods or planes, the combined eyes seem to look out along the combined visual lines upon the distant object.

Of course, by this shifting of the two fields all objects are similarly doubled.

Thus in binocular vision the two eyes *seem* actually to be superposed and corresponding points to coincide. This apparent combination of the eyes and their visual lines is the necessary result of the existence of corresponding points. Images on corresponding points are seen single; all objects in the two visual lines must impress corresponding points; therefore the visual lines themselves, if they were visible lines, would be seen single. This can take place only by combining to form a single *middle* visual line.

3. In turning the eyes in any direction *without altering their convergence* objects seem stationary, and the visual lines seem to move and sweep over them. But when we turn the two eyes in *opposite directions*, as in strong convergence, then the *visual lines seem stationary* (i. e., we seem to look in the same direction), and *all objects or rather images seem to move in a direction contrary to the actual motion of the eye;* the whole field of view of each eye with all its images rotates about the optic center in a direction contrary to the rotation of the eye. This is plainly seen by voluntarily and strongly converging the eyes upon an imaginary point near at hand, and at the same time watching the movements of the more distant images. The whole field of view of the right eye with all its images will be seen to rotate to the right and of the left eye to the left, i. e., *homonymously.* The images of all objects as they are swept successively by the visual lines of the two eyes are brought successively in front and superposed. If we could turn our eyes outward, the fields and their images would move heteronymously. This is seen to a limited extent in the act of falling to sleep.* Even with the two eyes *turned outward*, therefore, the two visual lines are united *in front*, and objects on the visual lines are brought in front and superposed. This is the necessary result of the properties of corresponding points; but I have also proved it by observations made upon persons whose eyes in a perfectly passive state turned slightly outward.*

Thus, there are two *apparent* movements of the visual fields accomplished by the eyes in binocular vision: 1st, a *shifting* of each field *heteronymously* a half interocular space; this is involuntary and habitual, and would of itself double all objects heteronymously; 2d, in ocular convergence, a *rotation* of each field about the optic center *homonymously.* The necessary consequences of these movements are: (a) that the two images of *an object at the point of sight* are superposed and the object is seen single; objects on *this side* the point of sight are doubled heteronymously, while objects beyond the point of sight are doubled

* The proof of this statement I hope to give shortly in a separate article.

homonymously; (b) that all objects (*different objects*) lying in the visual lines, whether on this side or beyond the point of sight, have two of their images (one of each) superposed; so that the two visual lines *under all circumstances* are combined to form a binocular visual line passing from the combined eyes, through the point of sight, and onward to infinite distance.

Let us now, in the light of these facts, examine M. Pictet's experiments. I will pass over for the present what he seems to regard as his crucial experiments, and take up first the general phenomena of double images, as a proper understanding of the nature of these will make all that follows clear.

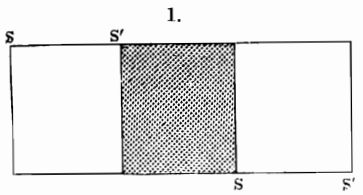
If we hold up a finger before the eyes, and gaze at the wall on the opposite side of the room, two heteronymous images of the finger will be seen separated by a space nearly equal to the interocular space. As a question of geometry this is sufficiently explained by the different parallactic position of the finger as seen by the two eyes; as a question of binocular vision, by the shifting of the fields of view of the two eyes heteronymously as already explained (2).

But the images are *transparent*. M. Pictet lays much stress on this. It is, he says, "an essential point which we have not found in works on optical physiology" (p. 105). He explains it as follows: There is a part of the wall which sends no luminous rays to the right eye (viz: that covered by the right-eye image); but this part impresses the left eye, and this impression is *propagated* to the right eye, and perceived by it at the same place as an *illusive image*. The finger, therefore, will appear transparent to the right eye because by means of an illusive image the wall is seen behind it. The same explanation of course applies to the left-eye image of the finger, which is transparent, according to M. Pictet, because the left eye sees the wall behind it by means of an illusive image propagated from the right eye. Now *our* explanation is entirely different; and we cannot but think that the transparency of double images have been so little noticed by writers only because their explanation seemed so obvious. Our explanation is as follows: We see *every* part of the wall because *no* part is concealed from *both* eyes. The images must seem transparent since they conceal nothing from *the observer*. M. Pictet would say the right-eye image conceals nothing from the right eye, and the left-eye image nothing from the left eye, and therefore the parts covered by these images must be seen, by the corresponding eye, by means of illusive images; but *we* say, a part of the wall *is* concealed from the right eye (viz: that upon which the right-eye image falls), but this part is visible to the left eye; similarly, a part of the wall *is* concealed from the left eye, but this part is visible to the right. M. Pictet says, every part of the wall is

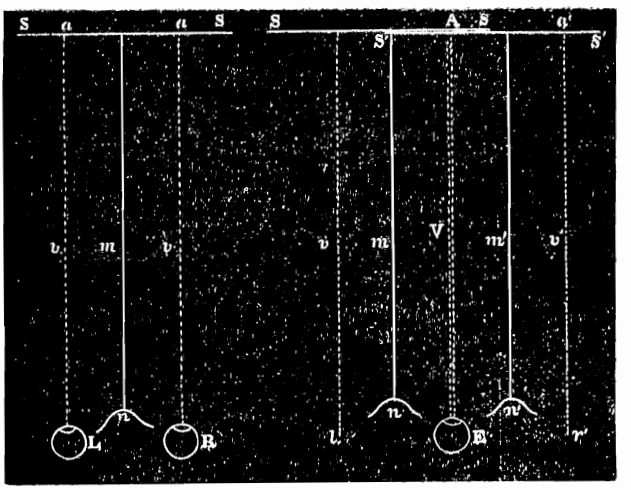
seen by *each* eye, either by true or by illusive images; we say, every part of the wall is seen, not by each eye, but by the *binocular observer;* not some parts by true and some by illusive images, but only by *true images.*

If instead of a finger we use a screen several inches wide (wider than the interocular space), then the double images will not entirely separate. They will slide over each other heteronymously through a space equal to the interocular space (2). The overlapping area will be opaque because it covers a portion of the wall concealed from both eyes; the rest will be transparent. The visual result is represented by fig. 1, in which S S is the right-eye image of the screen, S′S′ the left-eye image, and S′S the overlapping area. These facts are more completely represented by my method in figs. 2 and 3, of which fig. 2 represents the actual relation of parts, and fig. 3 the visual result. In fig. 2, R and L are the right and left eye respectively, *n* the nose,

1.



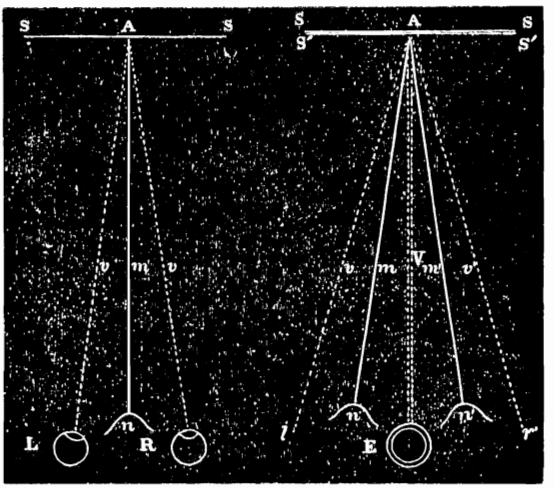
2. 3.



m the median line, *v v* the visual lines, S S the screen. Fig. 3 will readily explain itself if the reader will call to mind that in all my figures representing visual results capitals represent combined images, small italics right-eye images, and dashed italics left-eye images. If now the optic axes be gradually converged, as already explained (3), these heteronymous images will slide over each other homonymously, making the opaque area larger and larger, and the transparent margins smaller and

smaller, until when the point of sight is at the screen, fig. 4, then the images will *completely unite*, and the screen become *entirely opaque*. This is shown in the visual result, fig. 5.

4. 5.



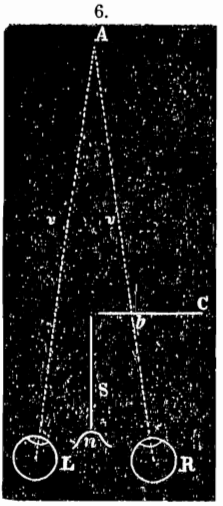
If next we use *two* fingers, one of each hand, and gaze again at the wall, we will see four images all transparent. Now approximate or separate the two fingers until the two middle images unite; we will have three images, the middle one *opaque*, the other two transparent. The reason is obvious. The middle one is opaque because a portion of the wall is concealed by it from *both eyes*. This portion of the wall is concealed from the right eye by the right finger, and from the left eye by the left finger; but it is the right-eye image of the right finger and the left-eye image of the left finger which unite to form the middle opaque image, while the right-eye image of the left finger is seen to the left, and the left-eye image of the right finger to the right, both *transparent*. In binocular vision, *superposed images* of opaque objects are *always opaque*, while *single images* are *always transparent*.

The principles (1, 2, 3) laid down in the early part of this paper, together with the explanation of transparent double images just given, furnish, we believe, the key to all M. Pictet's experiments. We will make the application only to those which he thinks most conclusive of the existence of illusive images. We will first give his experiments and his conclusions as fairly as we can, and then will proceed to give our own explanation. The following experiments M. Pictet thinks conclusive:

Place an opaque screen S (fig. 6) against the nose *n* in the *median plane of sight*, in such wise that the object A may be

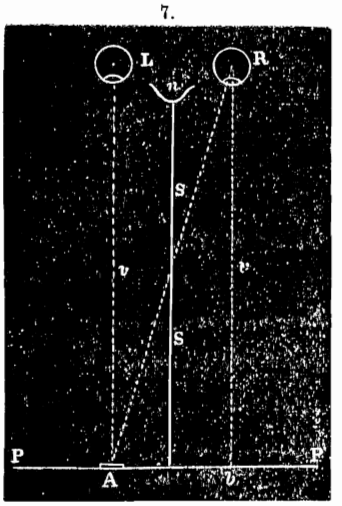
seen by both eyes. Now place a second screen C across the visual line A R of the right eye, so as to intercept rays from the object A to the right eye. Nevertheless, the object A will be seen *apparently* through the opaque screen C, which will therefore appear *transparent*, and may even be drawn in outline with accuracy on the screen at *b exactly where the visual line of the right eye pierces the screen*—exactly where, if the screen were transparent ground glass, we would see it with the right eye, and might trace its outline. M. Pictet thinks this absolutely inexplicable, except on the assumption that an illusive image is actually seen at A by the right eye; and that it is this that we draw in outline on the screen at *b*, the screen being transparent because the illusive image is seen beyond.

6.



But M. Pictet gives another experiment which he thinks still more conclusive. On a sheet of paper lying on the table place a piece of money; then place a screen upright on the right side of the money, and let the face of the observer be brought down upon the screen, so that the latter being in the median line *shall intercept the view of the right eye.* Nevertheless, says M. Pictet, "on directing the regard upon the piece of money, we see that the vertical screen appears transparent throughout, and that *it permits the right eye to distinguish the piece*, as if through a very diaphanous surface." "If now we give to the optic axes a direction more parallel, we see the image of illusion of the right eye move gradually toward the right, traverse the line of intersection of the screen and the table, and come to project itself on the other side upon the paper, where we may trace its outline correctly." To represent these facts more clearly I give the diagram, fig. 7. In this figure R and L are the two eyes, *p p* the sheet of paper, A the money in the direction of the visual line of the left eye, S S the median screen, A R the visual line of the right eye when we look at the piece of money A and seem to see it through the screen, R *b* the visual line of

7.



the right eye when the optic axes become parallel, and *b*, *exactly where the visual line of the right eye pierces the paper*, the place where the outline of the piece may be traced. The image moves to the right or left according to the position of the optic axes, being always where the visual line pierces the paper. But "the most advantageous position of the optic axes," says M. Pictet, "is parallelism, for it is that which *removes the farthest the image of illusion from the real image.*" I wonder that M. Pictet did not reflect that, being on corresponding points, by his own principle *the image of illusion*, if any, *cannot be separated from the real image;* and that *there is in fact but one image seen.*

But furthermore, if a convex lens be placed across the visual line of the right eye R *b*, the image at *b* will not be affected, but the *tracing* we make of the image will be found as much smaller than the money as the lens magnifies; showing that the image is not magnified but the drawing is magnified, and therefore, M. Pictet thinks, that the *image of the money is illusive or subjective, while the image of the paper and of the tracing is real.* If, however, the lens be placed before the *left eye*, the image is magnified because, thinks M. Pictet, this image is the *illusive right-eye fac-simile of the magnified real image of the left eye.*

One more step of M. Pictet's proof. By keeping both eyes open, objects in the microscopic field may actually be drawn with accuracy on a sheet of paper placed on one side of the microscopic tube. Or, still better, if a stereoscopic card, having a picture on one half and the other half blank, be placed in the stereoscope, we may trace the picture on the blank half. According to M. Pictet's view, the light impresses one eye, and this impression is propagated as an illusive image to the other eye, and thrown on the paper just where the visual line pierces it.

Such are the most important experiments upon which M. Pictet bases his belief in the existence of illusive images. I have been familiar with all these phenomena for many years; I have also often used the method of tracing microscopic objects recommended by him; but my explanation is wholly different. If M. Pictet's view be correct; and if in the experiments detailed we actually trace the outline of an *illusive image* belonging to the right eye, then where is the *true image* belonging to the left eye? We see but *one image.* M. Pictet, in accordance with his principles (although he forgets them in the passage quoted above), ought to answer, that being on corresponding points the two images are perfectly *united.* Then why call the image we outline an image of illusion? The truth is, in every case, we *trace the outline of the true image seen by the left eye;* although by the principles laid down in the early portion of this paper, or by the properties of corresponding points, we draw the outline at *a different place* from the object.

[To be concluded.]