SOME PROBLEMS OF SENSORY INTEGRATION[1].

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A. Demonstrations of uniocular stereoscopy by means of
(1) interruptedly disparate contours in alternation,
(2) progressively disparate contours in succession.

B. The independence and probable primacy of uniocular or progressive stereoscopy.—Binocular or static stereoscopy an adaptation to the needs of static vision.

C. Depth-effect is a secondary attribute of visual sensation, derived from the integration of differences in the order aspects of its uniocular components.

D. Theory of stereoscopic vision from interrupted stimulation.—Presumption that the mechanisms of uniocular and binocular stereoscopy are similar.

E. Further theory of A.—The psychical determinateness of the object of regard determines the ambiguous uniocular stimulation.—Experiments with the stroboscope and various ambiguous stimulations.

F. Size as the special determinant in E.—General treatment of the result.—Ambiguous stimuli and their determinants.—Inadequate stimuli have a meaning only in relation to integrative processes.—Central and peripheral determinants.—Presumption that the latter are, for sensory integrations at least, consensuous with the ambiguous stimuli.—Parallelism of physiological and psychological investigation.

THE presence of a multiplicity of sense-organs of the same and of different kinds presents a number of interesting problems to the psychologist and to the physiologist.

An intimacy of connexion between *nerve-paths* or impulses emanating from different sense-organs is, of course, recognized in many forms.

[1] The following paper was read in a somewhat modified form before the British Psychological Society in London, on March 12th, 1910.

But this connexion has been somewhat exclusively considered to consist in a mere *coordination* or association of afferent or efferent impulses with one another. Sufficient attention has hardly been paid to the possibility that upon these afferent impulses an afferent structure might be raised which is dependent upon but essentially an addition to these. To distinguish it from mere coordination, such a structure might well be called *integration*.

The *psychical* elaboration of sensations is also generally recognized by psychologists. But here again there has been a strong tendency to emphasize the process of coordination of sensations with one another and to ignore the presence of any features of the elaborated state which were not original to the primary sensation from a single sense-organ. Any apparently new product of elaboration has been generally attributed to the action of a central unifying power, the mind. Reasons for this are not far to seek. It is the aim of science to free the individual from the primitive nomadic view of the world and to create a knowledge of things as they are independent of all particularities of cosmical position and psychophysical distortion. The nearest psychical correlate of a real thing is the sensation from a single sense-organ. If, then, the sensory effect of coordination of sense-organs is markedly different from such simple sensation, it is not surprising that the activity of the mind should be made responsible for the change; the more so, since the first attempts to establish a mental chemistry or the features of mental elaboration intended in that notion failed to find sufficient factual or speculative support to establish them truly. This is commonly expressed by saying that a particular effect, not obtained from a single sense-organ, is due to judgment, or is perceptive in character. Much ingenuity has often been required to overcome this conclusion in particular cases, for example in that of Helmholtz's theory of colour-contrast. When the change of view has been obtained, however, proof to the affirmative or contrary is found to be almost superfluous. The mind is then released from the power of its judgments and the observation takes on the character of self-evidence, because it becomes a matter of pure introspection. In fact, to call for an introspective observation from a mind that is carefully prevented from obtaining a knowledge of the real character of the contrasting surface in the example given, is the best means of refuting the judgment theory. The incognitive procedure now demanded in psychology is merely a generalisation of this.

But the thought of the bare realities of analysis and induction is still strong enough in many psychologists to blind the eye to the actualities of experience. A sensationalistic theory of experience is well able to hide many incompatible forms of experience completely from view or thoroughly distort their actual character. The fatigue of inventing forms of judgment and their more obvious futility may even lead to the statement that the muscular response to simultaneous stimulation of individual sense-organs is responsible for the apparent integration of experience resulting therefrom.

It will therefore be the aim of the following pages to emphasize the purely sensory character of some forms of integration involving a multiplicity of sense-organs.

Towards this end, however, a renewed examination of these forms must be the first contribution.

A. Complete and stable depth-vision can be obtained uniocularly in a variety of ways. These may be classed in two groups. In the first the single eye is stimulated in alternation by such disparate contours as suffice to produce ordinary stereoscopic vision binocularly. In the second, the eye is stimulated by contours which change by gradual and progressive disparity, whether this be produced by the continuous displacement of the eye over against the field of visual objects or by suitable displacement of the field of objects relatively to the eye. It seems better to begin with the first because of its greater resemblance to stereoscopic vision in its familiar binocular form. It will, however, become apparent that the second method represents the normal form of uniocular depth-vision. It may even be that this is the primitive form of stereoscopic vision in general.

1. Uniocular depth-vision can be easily obtained and demonstrated, if the right- and left-eye pictures of a stereoscopic view representing a good landscape or other group of natural objects are projected in alternating succession so that their far points and their coordinates exactly coincide. This can be done by using two simple projecting lanterns set side by side or above one another. Where Ives' apparatus for demonstrating printing by the three-colour process is available, good results can be got very easily, by taking out the front plain glass reflector and the coloured filters, so that the middle and right hand fields of projection are alone in use and colourless. The stereoscopic diapositives ($\frac{1}{4}$ plate) are then inserted in the apparatus in the place in which the Ives special triple plates are usually inserted. Then the two views will be projected upon the same field of the screen. Fine adjustments are present in the Ives apparatus for obtaining complete

overlapping of the far points of the two pictures which should give clear images when both pictures are projected upon the screen simultaneously. This fine adjustment can be best carried out when the rotating disc standing in front of the two paths of light emerging from the apparatus is slipped down into place and set in rotation. The disc should have alternate segments of 45° cut out, leaving a steady carrying centre and a continuous rim. A radius of 14 cm. gives a good size and allows of easy adjustment of the projecting light-pencils on equivalent points of open and close segments. Any circular deviation of the two diapositives from common coordinate axes is very hard to deal with, but it can be rendered negligible, if the diapositives are carefully made. Slight errors of adjustment in the horizontal plane also detract from the stereoscopic effect, because they induce an apparent oscillation of the landscape round the virtual fixation-point, i.e. round the objects whose images in the projection exactly overlap. This apparent oscillation is rather disturbing and does not allow the depth-effect to develop clearly. The alternating disc should rotate so that there are some two or three cycles, i.e. successive projections of right- and left-eye pictures, per second, each picture thus lasting about 0·2 sec.

It is obviously immaterial whether the right- or left-eye views stand so in the apparatus or reversed; for the two series *r*, *l*, *r*, *l*, *r*, *l*... and *l*, *r*, *l*, *r*, *l*, *r*... are identical as soon as they have started.

Under these conditions a brilliant stereoscopic effect is obtained with uniocular vision. It is so clear that it could easily be demonstrated to a large audience. In the first few seconds, the effect is not quite so marked as afterwards, when, if the observer be at the proper distance from the projection, it is quite startling. The average time spent in the full development of the uniocular depth-effect might be some 10–14 seconds. But it must not be thought that the depth-effect as such is weak or absent at the beginning; it is brilliant at the very first change of view after the rotation of the interrupting disc is begun. Continuous fixation of far points of the landscape does not reduce the effect, but rather to enhance it, especially if a number of points unequally distant surround the far point fixated in the projection. The unavoidable flickering of the field of projection is rather unpleasant, but it is not so marked when the rate of rotation is as slow as possible. It is surprising how slightly it disturbs the observer, if the adjustments are good and when the depth-effect is fully developed. The rocking of the foreground is of course very curious, but it does not hinder full appreciation of depth-effects.

The depth-effects got in this way were compared with those got from the same views (natural water-cuttings in rock) in the stereoscope in the ordinary way and were found to be quite as good, if not superior to these. The much larger size of the projected view may be responsible for any superiority of the projection. It may be remarked in passing that the well-known stagey appearance of stereoscope pictures can be removed, if the two pictures are set further apart, and are seen under higher divergence than is usual[1]. When the field of projection is viewed with two eyes instead of one, the depth-effect is not nearly so good, although it is undoubtedly present, while the flicker and the oscillation of the foreground are much more pronounced and disturbing. Nor is the depth-effect obtained from the single resting projection in any way to be compared with that obtained uniocularly from alternate projection. The stereoscopic effect is also got uniocularly with inverted head, although the strangeness of the picture does not allow of full scenic interpretation.

It is also possible to get uniocular depth-effects from real as distinct from projected objects. If an observer, looking with one eye upon a natural scene containing marked depth-differences shakes his head from side to side, so that the eye moves from right to left and receives successively at the point of change of motion of the head disparate images similar to those received by the two eyes normally, a very pronounced stereoscopic effect is obtained. An instrument may also easily be devised whereby stereoscopic vision of a natural scene is made possible to uniocular observation. The principle of construction is that of the demonstration described above. A mirror at an angle of 45° to the line of vision reflects its light upon a transparent mirror set in front of the observing eye at an angle of 45°. The latter reflects this light into the eye and at the same time transmits light from a natural scene directly. Stereoscopic effects will be got if transmission and reflection are made to alternate by the rotation of a suitable disc set up in the paths of light entering the silvered mirror and the transparent mirror. I have not made any such instrument, but I have satisfied myself by rough trial that it is possible.

2. In the second of the two main methods, marked depth-effect is obtained when the eye is in motion over against a field of natural objects. The view from a moving train or steamer provides an excellent opportunity for observing this in all its degrees and variations. The depth-effects of the landscape can then be observed to be identical

[1] Of this, more later.

in all essentials, with those presented to binocular vision. Even a single line, group or pair of light-points on a dark background, such as is often seen from the train on approaching a town from a slight elevation, is present in perfect depth to the eye. Fixation of relatively distant points does not lead to any decrease or deterioration of depth-effect, but rather enhances it. I have seen these effects beautifully reproduced by the cinematograph. The pictures had evidently been taken from the deck of a vessel sailing on rapids in a well-wooded country. Stereoscopic effects are of course always seen with uniocular vision, when views of persons or animals in motion are projected. Quite a number of interesting demonstrations on vision are given in any cinematographic exhibition. These are also obtained in a much rougher form with the help of the stroboscope, as described by Straub and Brown (cp. below, p. 340). They, indeed, lay stress upon the degree of stereoscopic effect obtained, although the novelty of it and probably various theoretical views, incline them to urge that it is illusive or at least of another mental order than is binocular stereoscopy. But it must be clear that the psychical identity of uniocular and binocular stereoscopy, while it can be emphasized by theory or quantitative treatment of judgments, cannot be refuted by these. It must, anyhow, first be established by observation for itself. A report of experiments in the uniocular observation of moving objects will follow.

B. Uniocular depth-vision must be quite a normal process and must be habitual with all those animals whose usual state of activity involves more or less rapid motion and whose eyes project laterally. Overlapping of the fields of vision is either entirely absent or it is very limited in extent amongst these animals, while the increase allowed by convergence of the eyes is often very small and seldom employed, if indeed it be present at all.

Tschermak[1] is inclined to believe that some slight amount of binocular vision, however limited, is possible through overlapping of fields of vision in all the vertebrates. Harris, on the other hand, maintains that "in graminivorous and fruit-eating birds, as the parrots, pigeons, fowls, ducks, swans, many finches and others, the eyes are set laterally on the head, no attempt at binocular vision being possible[2]."

[1] A. Tschermak, "Studien über das Binokularsehen der Wirbelthiere," *Pflüger's Archiv*, XCI. p. 13.

[2] Wilfred Harris, "Binocular and stereoscopic vision in man and other vertebrates, etc." *Brain*, XXVII. p. 115.

I have, however, frequently observed momentary convergence of the eyes of no mean extent upon a piece of food held in the claw-fist in a grey-rose cockatoo. In attaining convergence the bird seemed each time to make a sudden effort. Similar movements, perhaps much smaller, have been observed by A. Tschermak[1] in fishes and by Th. Beer in birds[1].

Birds are undoubtedly well accustomed to uniocular observation, for they adopt it regularly during near vision in a state of rest. Everyone is familiar with the peculiar position of a bird's head when it is looking from a cage downwards at some object. There can therefore be no doubt but many birds and other animals in rapid motion can have and observe depth-effects on either side of the head at will. It would also follow that their whole field of uniocular vision can be filled with depth-effects, no matter what the direction of parallactic displacement may be. Whether in these animals there is not also some further integration of vision involving the impressions or the depth-effects of both eyes at once is another matter, but they evidently do not need both eyes at once for the appreciation of relative distance as such. A suggestion of such further integration of vision is found if we ask why a bird on the wing should not be able to appreciate the relative distances of entirely different objects on each side of the head, on the basis of the different rates at which the depth-effects of the two visual fields would change, if the objects in each were at different distances from the head. The coordination or integration of relative speed of displacement and relative depth-effect would be possible in entire independence of any relative or apparent size of the objects of vision. Such correlation of visual fields should be a comparatively simple matter. It should, for example, be simpler than the coordination of tactual direction with visual direction or than the commonly postulated coordination or integration of movement of eye or hand with visual order. Unless some such integration as this is present, it is hard to see how a bird can fly securely between two trees or other obstacles.

One might indeed well go so far as to maintain that stereoscopic vision, far from being dependent upon coordinated use of two eyes for its first occurrence, is primarily uniocular[2]. That it is only obtained

[1] *loc. cit.* p. 13.

[2] Cf. A. Kirschmann, "Die Parallaxe des indirecten Sehens," *Philos. Studien*, IX. p. 492. "Die Parallaxe des indirecten Sehens, d.h. die Incongruenz zwischen Gesichts- und Drehungswinkel des Auges, ist von erheblicher Grösse und bewirkt bei Accomodations-änderungen und Bewegungen des Auges (bezw. der Objecte) Veränderungen in den relativen

uniocularly when the eye or the objects of regard are in motion, is no serious objection to this view, because it is well known that very many animals notice well defined near objects when these are motionless, important or dangerous though they be, just as little as we notice motionless objects situated in the periphery of our uniocular field of vision. Binocular stereoscopic vision would then be an adaptation of vision to the demands of a life of comparative or frequent bodily repose. The life of a beast of prey would also seem to bring many moments which demand long-continued observation of objects towards which it must turn its head with little or no progressive or regressive motion. Herbivorous animals and birds on the other hand, however swiftly they may move, seldom need to observe near objects in front of the head for any length of time, and are more dependent upon a wide field of vision for secure motion and feeding. Simultaneous use of both fields of vision would therefore seem to be necessary if motionless depth is to be obtained. Binocular depth-vision might, accordingly, be called static in distinction to uniocular or progressive depth-vision.

Comparative study of the vision of animals lead Harris to recognize the influence of the carnivorous habit upon the position of the eyes. "Binocular vision is originally associated with carnivorous habits, and is found to a moderate degree amongst carnivorous fishes in a few of the sharks and rays, in some amphibia, as the toad, which lives on flies and insects and in many carnivorous birds, especially the larger gulls some penguins, hawks, owls and vultures. Amongst mammals binocular vision is especially developed in the carnivora and in the primates[1]." Many animals besides the chameleon[2], may make a momentary convergent movement of the eyes at the moment of striking their prey, especially if their mode of pursuit happens to be that of rapid flight or chase, without long fixation or combat. "Though many of these animals have fair binocular vision, yet in all vertebrates below mammals there is total decussation of the optic nerves at the chiasma[3]." It is obvious then, that if the presence of total decussation is no barrier to the occurrence of static stereoscopic vision in the chameleon and owl, it can also be no argument against the presence of progressive stereoscopic vision in the birds and in all animals with fixed or laterally projecting

Lageverhältnissen der Netzhautprojectionen. (Diese) stehen in eindeutiger und ganz gesetzmässiger Beziehung zur Tiefendimension und werden wahrscheinlich vom Gesichtssinne als Hilfsmittel zur Gewinnung einer monocularen Tiefenwahrnehmung verwandt." Cf. also the same author, *Philos. Studien*, XI. 1895, p. 188.

[1] *loc. cit.* p. 108.

[2] *loc. cit.* pp. 113, 114.

[3] *loc. cit.* p. 108.

eyes. Decrease in decussation would seem to involve very radical neural rearrangements, so that the easier means of obtaining static stereoscopic vision by connexions between the hemispheres is adopted when a sudden need for it arises.

I have observed that stimulation of a portion of one retina to the right or left of the macula by alternating disparate contours suffices to produce depth-effects. Depth-effect can therefore be produced by one-sided uniocular stimulation.

C. The stereoscopic effect of the double Ives' projection is still quite as clear to an eye paralysed with atropine, although the picture is not so sharply defined. It has also been noted that uniocular stereoscopy is present in full degree when a far point is fixated if only there is sufficient alternately interrupted or continuously progressive disparation of contour. It is therefore clear at least that uniocular depth-vision is not dependent on convergence, eye-movement, or accommodation or on any judgments based upon the presence of these.

Besides, no judgment or inference can be observed to intervene between the vision of the oscillating field of projection and the subsequent depth-effects. I have demonstrated uniocular depth-vision to a number of different observers and none of these gave utterance to anything which would show that inference or judgment was responsible for the depth-effects they observed. The usual exclamation of the unprepared observer was "Oh! it seems quite solid" or the like. In any case, argument seems quite irrelevant, because it needs no knowledge of psychology or any experimental inference to observe that depth-effects are presented directly to uniocular vision just as much as colour- or breadth-effects are. This is surely a matter of introspective comparison, not of the quantitative analysis of judgments. Nor does depth-vision involve any sort of judgment or consciousness of meaning, signifying that point A is nearer than point B, as its classification under Perception would suggest.

Depth-vision does not occur without a complex of sensational data. In what relation, then, does it stand to these? Primitive sensation may be defined as the simplest change in experience which is immediately and regularly dependent upon the stimulation of a sense-organ. Depth-vision, however, is not a simple, but a rather complex change in experience, involving more than one sensation as defined and more than one sense-organ in the strict sense, according to which the eye consists of a vast number of juxtaposed visual sense-organs. If it is not a perception or a process of judgment, it is certainly sensational in character, in so far as it is regularly and immediately dependent upon the stimulation of sense-organs. Yet depth-effect clearly cannot itself be thought to be even an elaborate sensation. For where are its attributes or aspects—its quality, its intensity, its extent or its position? Amount of depth could of course be called the extensity or the intensity of depth-effect, according to inclination; and the localisation of depth-effect might be found to be particularised, if imagination invented other forms of depth-effect peculiar to ultra-geometrical worlds.

Besides, depth-effect can obviously not itself be a sensation, because it cannot occur alone. It must be carried by more than one colour-sensation. Its nearest relative is the plane local character of every visual sensation, of which it forms a kind of continuation, and from the diversities of which it is evolved. Is depth-effect itself perhaps an attribute of visual sensation? It is certainly attributive in its general character, but it shares only one—the less strict—of the two peculiarities of the usual features of sensation, viz. independent variability. It might therefore well be called an occasional, additional, secondary or derived attribute of sensation[1]. Its separability would, however, not be demonstrated by the effect of flatness evoked by exactly similar stimulation of both retinas. That is, of course, itself a case of depth-effect, for the effect of flatness is much more compelling when both retinas are stimulated than when only one is affected. If we argue by analogy from the fact that cutaneous space is practically devoid of any clear element of solidity, it might be maintained that primitive normal and resting uniocular vision gives no direct or sensational sense of flatness. Besides, the loss of depth-effect, which may be observed in the transition from uniocular or binocular stereoscopic vision to motionless uniocular vision, is so enormous, that it may fairly be argued, that any primitive form of the latter is quite devoid of depth-differences. Any semblance of stereoscopic vision in resting uniocular vision may be properly put to the account of indirect or (in respect of stereoscopic vision, based on disparity of impressions) heterogeneous indications of depth. The presence and action of the latter naturally form an important problem for investigation.

D. What theory can be offered to account for the occurrence of

[1] This view seems to be in no way opposed by the fact that a certain amount of depth-effect may be evoked by double images of an object that is too far or too near for proper binocular stereoscopic fusion, v. Tschermak u. Hoefer, *Pflüger's Archiv*, XCVIII. pp. 299—321. Such a fact indicates, however, that the basis of the integration of depth is broader than that of stereoscopic fusion. We, too, found distinct depth-effect even in the case of the oscillating, unfused objects in the foreground of the landscape-projection.

depth-effect under the circumstances of uniocular observation described in section A.

A reason must first be sought for the presence of stereoscopic vision under the conditions of alternation of disparate contours, when each stimulation lasts about 0·2 sec. We have shown that uniocular stereoscopic vision, in so far as it is evoked by gradual disparation of contours, for example when the eye is moved over against a group of objects, is quite a normal occurrence; it is perhaps even the commonest and primary form of stereoscopic vision. It is, however, not quite clear how sudden and considerable disparation of contours in alternation should evoke depth-effect.

Certain observations of Guilloz[1] are of considerable interest in this connection. He found that "the sensation of relief is easily evoked through successive vision of the two eyes, by very slow alternation, without vision being at any moment binocular." A disc was rotated before an ordinary stereoscope or before real objects, so that only alternate uniocular and never binocular vision was possible. The duration of total eclipse was very short however. Under these circumstances perfect stereoscopic vision demanded at the most ten successive stimulations of each eye per second, on an average six per second, and at least two per second. I obtain the full effect myself with some four or five successive stimulations. As M. Guilloz noted, parallactic displacements of the various objects seen become rather pronounced with the slower rate of vibration, as in the case of the Ives projection also. That is as it should be; for if the integrated effect is just at or below its threshold for any given circumstances, the order-aspects of the two integrating sensations should then force themselves separately upon our notice. When the integration is complete, they disappear psychically in the integrated or derivative aspect of depth. Even in normal forms of stereoscopic vision, however, a slight effort of attention will easily discover the order-differences of the component sensations[2].

Guilloz's observations point to a feature common to both binocular and uniocular stereoscopic vision. Both of these are possible in the absence of synchronous disparate stimulations[3] and the rates of alterna-

[1] *Comptes rendus de la soc. d. biologie*, 1904, I. 1053–4. The same observation was made by Lohmann, *Ztsch. für Psych.* XL. p. 191, by alternately closing each eye before the stereoscope.

[2] Cf. W. Lohmann, "Ueber den Wettstreit der Sehfelder und seine Bedeutung, etc." *Ztsch. für Psych.* XL. p. 191.

[3] Cf. Stevenson and Sandford, "A preliminary report of experiments on time-relations in binocular vision," *Amer. Journ. of Psych.* XIX. pp. 129—137, 1908. The matter needs further investigation.

tion of stimulations are in both cases similar. Now Sherrington has shown "that only after the sensations initiated from right and left 'corresponding points' have been elaborated, and have reached a dignity and definiteness well amenable to introspection, does interference between the reactions of the two (right and left) eye-systems occur. The binocular sensation seems combined from right and left uniocular sensations elaborated independently[1]." It has also been shown by Sherrington for flicker in relation to brightness value that the state of the latter is relatively independent of the laws of the former so far as they are valid for identical tracts (uniocular). Guilloz's and our observations show that the continuity of stereoscopic effect is also to some extent independent of the continuity of its integrating stimulations. If the physiological bases of binocular stereoscopy are separate and distinct for each eye, it would seem to follow that in uniocular stereoscopy produced by alternate disparate stimulation two separate and distinct physiological bases, one for each of the disparate stimulations, may be presumed to exist. Further it may be presumed, that if binocular stereoscopy involves a special apparatus for the integration of its separate bases, so also should uniocular stereoscopy. It would therefore seem that binocular and uniocular stereoscopy are in no essential way different from each other. The physiological and psychological devices of both mechanisms are essentially the same. Hereby we feel confirmed in our view that binocular stereoscopy is an adaptation to a life of comparative repose (cf. p. 330) of a mechanism which was primarily developed to suit a life of rapid progressive motion. Binocular vision does not add anything essentially new to the physiological or psychological equipment. It only does in a slightly different manner what uniocular stereoscopy did before it.

There is furthermore a clear parallelism between the integrative process of stereoscopy and that of motion. In so far as vision is impossible during rapid and extensive movements of the eye, which are of the commonest occurrence, the effect of motion must be elaborated out of successive, interruptedly different visual impressions, in which any changes which might be brought about by movement of the eye or of the objects of regard, are reduced to a minimum. The stroboscopic representation of motion is the experimental statement of this fact. But although there is an obvious parallelism between the two integrative processes, their differences are also patent. For motion is just not depth-effect and the one can be present without the

[1] "The integrative action of the nervous system," p. 381.

other. Besides there is no special binocular form of the integration of motion.

It is of interest to make further comparisons between the mechanisms of uniocular and of binocular vision. Binocular vision is accompanied in the mammals by semi-decussation at the chiasma, so that the left halves of each retina are connected with the left hemisphere, and the right halves with the right hemisphere. These double left and right halves must therefore be associated with one another by connexions between the hemispheres. In birds and many other animals, on the other hand, there is total decussation at the chiasma, each nerve passing over completely to the opposite hemisphere. The cerebral connexions between the two fields of vision will, of course, not produce overlapping or rivalry of these fields, but will tack the one on to the other in the way most compatible with the distance between the front edges of the fields of vision or with the overlapping of the fields and with the other peculiarities of the animal's vision. One can imagine an animal with eyes so set that the edges of the two fields of vision should just meet or just overlap all the way round. There would then be no confusion or rivalry of vision but a visual panorama in all directions. Nothing would prevent the animal from being aware of the whole of this steady continuous panorama at one time or of attending to points in it on both sides of itself, i.e. in both fields of vision. It is very hard for us to accustom ourselves to this obvious arrangement. We always feel there should be some rivalry between the two fields of vision and find it curious that the chameleon should direct one eye forwards and the other backwards. That is not more curious than it is that we should hold one arm forward and the other behind and feel with both at once without confusion. We ourselves also enjoy this panorama to some slight extent; for in so far as our two fields of vision do not overlap they extend the total field of vision and we can attend to objects lying in the uniocular left portion of the left field of vision and to others lying in the uniocular right part of the right field of vision simultaneously without confusion or rivalry. Let our two fields be stretched out to the side till they meet behind and till they hardly overlap at all in front and the bird's vision is realised.

Thus it is possible to picture all stages between pure uniocular vision and almost pure binocular vision by supposing one field which just touches another field slid over on to it progressively until they overlap. We must remember, however, that the bird is surely just as unconscious of two eyes, of two fields of vision as we are usually. It sees, just as we feel, continuously, and better in some parts of the field of visual sensation than in others. Birds' vision is therefore also cyclopean, as, after all, all experience is. Vision therefore has to remain cyclopean however much overlapping of fields there may be. That could only be done by virtually eliminating this overlapping. Two ways are possible. In one, such connexions are made between the hemispheres as will eliminate the order-differences of the overlapping parts by the excitation of certain afferent impulses, e.g. sensations of eye-movement. One may compare this form of integration to that which we find in ourselves in touch, when distances are discriminated at one time with the fingers placed together, at another time with the fingers apart. There can, however, be no doubt but the visual impressions of the chameleon are modified in some apparent way—depth-effect—when the two eyes are directed upon one object amongst others. There are many other kinds of these modifications or derived attributes, which I shall treat by themselves. In the other of the two ways, such connexions are made between the retinal elements and the hemispheres as will procure visual identity of the overlapping parts. This can be done only if the relations between the eyes are of a fixed and unfluctuating nature or if certain points in the two overlapping parts are always used and stimulated identically. This we find realised in our own vision, for if the two foveas are not directed upon one object, allowing for very slight deviations within the fovea, and stimulated almost identically, we see double. Such a fixed relationship within binocular vision is, of course, a corollary of the very function of binocular vision, namely to give static depth-vision. Now, as a jointure has to be effected between the two fields of vision somewhere, it is quite the most natural and economical arrangement to split each of the overlapping areas into two halves, and to splice the two left halves by the shortest neural paths, as also the two right halves, the rest of the two retinas remaining in *status quo*. The split must obviously be in the vertical direction, since the two binocularly used eyes are upon a horizontal plane and the method of decussation is economical because thereby the neural paths between the hemispheres are dispensed with.

We need a large range of eye-movement in order to follow the motion of the objects we fixate binocularly and to bring our identical (or "corresponding") points of vision always to bear on the object of binocular regard. This fact suggests two extremes, between which all actual forms of vision may find a definite place. An ideal progressive vision, on the one hand, would show practically no overlapping or distance between the two fields of vision at any point of their whole circumference, equally clear vision at all points and therefore a complete visual panorama and consequently no need for any eye-movements whatsoever. The possessor of this form of vision would fly in a spherical panorama, hardly conscious of his own body visually. The vision of some of the birds may approach this, if we neglect for a moment the obstruction of the outstretched wings. And even these may be just as transparent as are our eyelids. The more an animal, on the other hand, becomes binocular and static, the more it must need eye-movement. The highest conceivable degree of eye-movement would be needed by an animal which could not move and had only the tiniest fields of vision completely overlapping one another. If it wished to view its whole visual environment, it would have to have universal eye-movement. The fingers of the blind are eyes of this kind.

Since the one retina in binocular vision is practically converted into a part of the other, it is quite evident that there should be a slight amount of difference of localisation to distinguish confused stimulations of identical points of the two retinas from one another. For in so far as the localisations of the two eyes are not specially identified, that of the left should be somewhat to the right, that of the right somewhat to the left, just as they are for disparate points in one eye, whereby uniocular progressive stereoscopy is accompanied by apparent motion[1]. For if we presuppose the left field of vision, the view of the object obtained in the right field would uniocularly only be got by a relative motion of the object towards the left, i.e. the presupposed left-eye view is to the right of the right-eye view. All these things argue still more strongly, that the integration of stereoscopy is achieved uniocularly and binocularly by similar mechanisms. The connexions of disparate points should be much the same whether some of them are in one eye and some in the other, or all of them in one eye.

Stereoscopic vision may therefore be defined as the integration of the order aspects of successive stimulations of one or of simultaneous stimulations of both retinas, under the familiar conditions regarding disparation, of which integration a new attribute or modification of visual experience—depth-aspect—is the psychical equivalent.

E. It has already been noted that it is a matter of indifference which of the two stereo-diapositives stands right or left, above or below in the methods of stereoscopy by projection ; for the series of expositions given in both cases is identical, as soon as the series has been started.

[1] Cf. Witasek, *Ztsch. für Psych.* Abt. I. Vol. XL. p. 217.

But binocular depth-effect is essentially dependent on the projection of the right-eye image into the right eye and the left into the left. If the projection is reversed, the depth-effect is usually reversed as well. How then can the one ambiguous series of the Ives projection give a perfectly unambiguous depth-effect to monocular observation? Does it always do this?

To test this, one naturally turns to the simplest case of stereoscopic vision, that in which one unsuspended point is seen in front of another. The two images consist each of two dots at unequal distance from one another, thus: . . and . . . But if these are projected successively upon a screen as above described and observed unioculalry, no proper depth-effect is obtained. Either one point is seen to oscillate laterally or both do so, according to the manner in which they are adjusted in projection. Either can be *thought* to be behind the other, but neither is *seen* to stand in front of the other. There is nothing present which could give rise to depth-effect.

Nor is the matter essentially altered by the projection of a large number of points in two successive pictures corresponding to the left- and right-eye views of a number of points (walnuts) suspended on fine invisible threads before a white background. Several interpretations of such a projection are, however, possible. If the adjustment is so arranged that all the points except a few which do not move, oscillate simultaneously in one direction, the oscillating points can be interpreted or more or less clearly seen as in front or behind the steady points. If some points oscillate in opposite directions, while others remain steady, they must be interpreted by one of two opposite systems, which are defined by the interpretation of any one oscillating point as being in front or behind, while the steady points are at half-depth. Therefore it should be possible that different observers should chance upon each of these opposite systems of interpretation of the same projected views.

Such differences of interpretation do actually occur. They can be obtained in greatest variety when successive views of a schematic object are exposed in a stroboscope in periodic series, in which a circle A moves within a circle B from the point of concentricity along the horizontal diameter of B towards L and back again to concentricity in some 12 steps (cf. Fig. 1). The horizontal tangential points of the two circles are joined by lines in each case[1].

[1] Cf. Straub, *Ztsch. für Psych.* 20 Juli, 1904, Bd. xxxvi. p. 435, upon one of whose figures the series indicated in the text was modelled.

When the stroboscope is rotated, successive pictures falling on one eye are seen momentarily and induce thereby the perception of a single object in which a certain spatial change is taking place. For the above series, the only one I have examined by Straub's method, the following different interpretations were the first given by different observers: (1) The circle *A* seems to move on the plane of the paper laterally towards *L* and back to the middle position periodically; (2) The circle *A* stands nearer than the circle *B* and suggests the figure of a truncated cone which is making a periodic oscillation towards *L* and back to middle position, as if the body were moving on a vertical axis lying half way between the plane of *A* and the plane of *B*. These two are the forms in which the figure appears first to most observers; (3) The figure can be seen with the depth relations of (2) reversed, i.e. surface *A* lying farther away than surface *B*, and forming the figure of a hollow truncated cone; (4) It may appear that the surface *A* rises from the plane of *B* periodically towards the

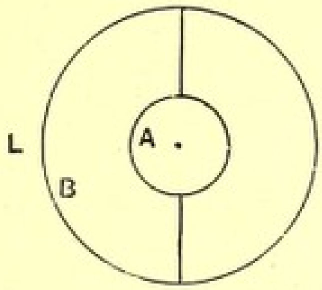

FIG. 1.

observer and back to the plane of *B*; or (5) the reverse, the surface *A* may appear to sink periodically away from and back to the plane of *B*. The latter two forms are those which appeared to the writer first, who made the figure series and owing to the suggestion exerted upon him by Straub's paper expected to see these forms. Straub notes[1] all these forms of interpretation and they can be readily seen by all observers. These interpretations are, of course, not usually steady or permanent in any one form. When all of them are familiar to the observer, they displace each other continuously. They can even be combined together to larger periods, as when forms (4) and (5) alternate rhythmically and give the appearance of a body collapsing from above to the level and then out behind and back again. There can be no doubt about the depth-effect presented to uniocular observation by any of the forms except the first (1).

[1] *loc. cit.* pp. 435–6.

This method of demonstrating uniocular stereoscopy was, it seems, devised independently and simultaneously by Straub and Brown[1]. The pictures used by the latter consisted of series of photographs of a group of small objects upon a table, which was turned through a small angle before each view was taken. Elschnig remarks in his discussion of these stroboscopic observations that because of the persistence of visual perceptions the single phases fuse to a unitary and therefore solid visual perception[2] and otherwise emphasizes the stereoscopic effect of uniocular change of parallax. He maintains however in general that "monocular stereoscopic vision with Straub's stroboscope is as little real stereoscopy, as is the apparent plasticity which a photograph viewed through a convex lens or two identical photogrammes seen binocularly in a stereoscope or any perspectival drawing or a well shaded photograph shows." He cites in evidence of this the fact that the depths in the stroboscope are so often reversed quite suddenly even when they seem clearest. In real stereoscopic vision, he says, only one interpretation of what is seen is possible. Straub goes so far as to maintain that there is no difference between uniocular and binocular stereoscopy in respect of the depth-effects in each[3]. He concludes, that both of these processes are inferential (in bieden Fällen ist die Tiefenvorstellung ein Schluss). Elschnig gives a further instance of illusory (vorgetäuschte) depth-effect; it is obtained very often in cinematographic projections especially in respect of the apparent approach or retreat of men, horses, waggons and the like. Finally he speaks of the "radical (himmelhoher) difference between apparent and real stereoscopic vision."

Evidently it is hard to see the facts clearly, so great is the reluctance to let uniocular stereoscopy pass. The stroboscope presents to us several different and very unstable forms of depth-effect from the same stimulus and there must be some reason for their presence. To call them illusory is no explanation and to compare them to a less degree of their own appearance, is not to discredit that appearance, but to emphasize the need for an explanation of the presence of any degree of stereoscopic effect. On the other hand, processes which might be called inferential may certainly often be involved in am-

[1] Theod. Brown, "Direct Stereoscopic projection," *Photography*, 23 July, 1904. The title and the description of the experiments I take from Prof. A. Elschnig's "Ueber monokulare Stereoscopie und direkte stereoskopische Projektion," *Jahrb. für Photographie*, 1905, pp. 103—108. I have not seen Brown's paper.

[2] *loc. cit.* pp. 104, 105.

[3] *loc. cit.* p. 432.

biguous presentation of depth, as will become more apparent in the experiment next to be described. But no reason has yet been given why inferential or any other hetereogeneous processes should be able to create or induce an actual presentational depth-effect, such as is observed in these experiments. This applies also to all "experience" theories of stereoscopic vision, which are not essentially nativistic or physiological. These theories do not call for discussion here, for the burden of proof lies upon them. They must show how their "experience" is capable of producing what careful introspective comparison shows to be a distinctly presentational state.

Further light is thrown upon uniocular stereoscopy by a form of experiment similar to that of Straub but of a much less regular and unitary nature. This consists in projecting through Ives' apparatus two pictures of a group of words set up and printed twice over as nearly as possible alike, cf. Fig. 2[1].

STEREOSKOPI-
SCHE UNTER-
SCHEIDUNG EI-
NES DRUCKES
VON SEINEM
NACHDRUCK.

FIG. 2.

In the single still projection of such a plate, there is of course hardly even a suggestion of depth-effect. The printing seems in no way to differ from the usual form of letters printed on a plane surface. Even if all the letters do not seem to be of the same height and at the same distance from one another, it is not easy to detect any difference between the right- and left-eye pictures, as these are found, when prepared specially for stereoscopic demonstration; and in this experiment no differences *can* be detected, because these plates are not projected at once, but successively.

When the projections are given successively in the way described, the depth-effect is found to be good, especially if the maximal oscillation is kept small. The letters are seen to stand well forward and behind. Too large a degree of oscillation spoils the depth-effect. But

[1] This stereoscopic slide is one of a set accompanying a small book, *Das Stereoskop und seine Anwendungen*, by Th. Hartwig-Teubner, Leipzig, Stereogramm v.

although all observers see depth-effects throughout the field of projections, they differ in their reading of these; they do not even each maintain one system of interpretation, as in the case of the experiment with the stroboscope. The variation in the observations of different observers may be exemplified by the following table in which the signs > and < stand for the expression "in front of" and "behind" in the direction in which the table is read. Three lines of the slide are given and, amongst the letters of these, signs are to be found indicating the depth-effect got from the slide in the stereoscope. It will be noticed

TABLE I.

Stereoscope	S > T E R < E O S K O > P I
O_1	< > <
O_2	> <
O_3	< > < or <
O_4	< > < > > > = > <
O_5	< < <
Stereoscope	S · C H E > · U > N < T < E R
O_1	> = = <
O_2	> >
O_3	> < >
O_4	< >
O_5	> < <
Stereoscope	S C H E I D < U N G > E I ·
O_1	> < >
O_2	> <
O_3	> <
O_4	> <
O_5	> <

The table indicates by the signs >, "in front of," and <, "behind" in the direction in which the table is read, the relative depths at which the letters opposite "Stereoscope" are seen when the right and left halves of this familiar stereoscopic slide (*v.* Fig. 2) are presented alternately to uniocular vision. The signs between the printed letters indicate the depth-effects seen through the stereoscope. A long sign > means "much in front of" a small one >, "slightly in front of."

that though there is much agreement amongst the five observers, no one of them remains consistently either in the system of depth-relations of the stereoscope or its reverse. A number of observations made by two observers seem to suggest that for the most part the positive or negative character of the depth-effect seems, as in the case of Straub's pictures, to follow Wundt's rule for plane optical illusions that the point fixated appears the nearer. An exception to this is found in the case of the three lines given in the table in the letters U N T E R.

These can be seen in various ways. If the observer looks at the letters S C H E, the letters U N stand well behind these and the T. There is a large space between these sets of letters and this it is, probably, which gives the impression that one is looking through between two different layers of letters of which U N forms the more distant. If the observer, on the other hand, fixates the E of U N T E R, the T stands forward, it may be, in front of both E and N. If the letters U N T E R are held visually in reference to the line above or the line below, they may be seen in front of or behind the latter, according as the position of the observer gives him the impression of looking down or up through the space between the lines. Curiously enough the depth-effects in this picture are also changed when the head from being allowed to hang down over the left shoulder is moved to hang down over the right shoulder. Finally, it may occur in this experiment that, if the observer in doubtful cases is pressed to decide upon depth-relations, inferential processes proper may make their appearance.

There are therefore a number of indirect factors which help to determine whether the depth-effects shall be positive or negative in the case of successive views which if reversed in the stereoscope would give an equally coherent object. These factors are presumably identical with those operative in the case of the ordinary visual illusions and in the reading of plane pictures. I have observed whether a number of points (walnuts) suspended on invisible threads were capable of giving systematic and unitary depth-effects, when the points were surrounded by a well-defined room-picture, as against the depth-effect produced by their projection alone. But while the depth-effect of the latter followed that just described and was best when the points at middle distance are made stationary in the projection, the scene did not seem to help, because such suspended points were, normally, separated by the attention demanded by close observation from the room-picture which surrounded them. But it is to be emphasized that in spite of this, the depth-effect, wherever it occurs, is direct and proper, and not essentially different from that first described. There can then be no doubt but the reason why the immediate depth-effect got in the projection of the landscape is permanent, unitary and unambiguous, is that a landscape is not capable of the double interpretation, positive and negative, which the projection of the series of views *r*, *l*, *r*, *l*, *r*, *l*, *r*, *l*, *r* makes possible. The landscape cannot be inverted in regard to its depths mentally. Even when the retinal images are reversed in the pseudoscope, or other similar appliances, the depth-effect is not coherent or unitary. Much of the usual effect is lost, what remains is awkward and puzzling; but there is certainly no extensive reversal of effect in a natural landscape.

F. What is there, then, in the landscape that excludes the double interpretation of its depth-aspects which is theoretically possible? After the treatment of stereoscopy in the foregoing pages, it would, of course, be absurd to suggest that the irreversibility of the landscape makes up the depth-effect derived from the successive projection of its disparate views. Stereoscopy is a sensory integration which is realisable in independence of all other visual integrations or integrative influences.

There is obviously one feature of the landscape that is not present in the ambiguous figures—the relation between the size of projected objects and their distance as indicated by their disparity of retinal position. This is the only afferent element which could account for the stability of the depth-aspects of the landscape. There is a perfectly unambiguous relation between apparent size and distances, as soon as any one apparent size and its psychical distance are given or are known by associative coordination. We have therefore to consider it probable that this unambiguous relation between size and distance acts as a determinant upon the ambiguity of the system of depth-aspects presented to uniocular vision by the successive projection of disparate views. Other factors might be suggested to account for the determination of the ambiguity, e.g. the psychical unity of or familiarity with the system of things in a landscape; and factors like these may very well act sometimes as determinants, as in the case of the stroboscopic stereoscopy where expectation kept the ambiguous figure determinate for some little time. In the case of pseudoscopic observation we find however that the relations of retinal disparity artificially reversed are in general unable to integrate the depth-effects for which they form the adequate stimuli, when the given relations between size and distance are familiar. For the latter, not having been altered, of course, run against the former and are able to disintegrate or suppress their effects. If relations of size to psychical unity and familiarity are able to disintegrate a complete process, it is not surprising that they are also able to determine the ambiguity of integrative stimuli. Psychical unity and familiarity and relations of size must usually accompany one another, as in the above two cases; so that it is, so far, impossible to exclude the one or the other. It must be left for other cases or general treatment to indicate which of the two is the actual determinant. It is only important to notice that a determinant, be it peripheral or central in origin, may support or encounter an integrative process, ambiguous or fully determinate.

A new interest attaches itself immediately to all forms of sensory integration which can be rendered ambiguous and their discovery is a matter of importance. We must also know what circumstances can determine their ambiguity and why.

Many of the familiar visual illusions show marked ambiguity quite apart from their use in the stroboscope or in double projection. If the outline of the cube-figure is drawn even quite roughly on a sheet of paper sufficiently large to fill a considerable part of the field of vision and is regarded uniocularly, the stereoscopic effect so obtained is, for moments, almost as good, as that of a cube in the stereoscope or elsewhere[1]. It can also be observed, as is well known, that with change of fixation all the depth-effects of the figure change consistently and almost instantaneously to their opposites. The stereoscopic effect is so pronounced that, on moving the head or the figure, the cube seems to shift to keep its near and far points in a line with the line of vision, just as has been observed with Rollmann's colour-stereoscope, although no two systems of disparate points are stimulated. Whence this effect?

The visually presented set of lines would naturally remain mere lines psychically, if some determination were given to the mind concomitantly to take them as such. But as we have seen stereoscopy and probably many other processes are integrated upon various primitive visual presentational complexes. Now the stimulus to a primitive sensation can not be inadequate, as no psychical change less than the primitive sensation is possible. *Only in respect of sensory integrative processes can a stimulus be said to be inadequate,* if the word is to convey any useful meaning. But if such an inadequate stimulus be moderately vigorous, we must not be surprised if it exert some stimulative effect upon the integrative mechanisms attached to the incoming paths of primitive sensations, unless we can show that the latter have certain main thoroughfares provided for them, from which they have to be specially deflected to reach these integrative mechanisms. This is, for vision at least very unlikely, in face of the facts. One may of course assert with confidence, that inadequate stimuli will not stimulate integrative processes, if they cannot, nor are they likely to do so, if the latter have not yet been roused by the corresponding adequate stimuli. In the latter case even the cube-figure might appear as a mere group of "insignificant" lines, although this seems rarely to occur for that figure. With many other figures it will occur readily at times with everyone. But the cube-figure may also arouse those integrations

[1] Except, perhaps, where the lines of the figure cross each other, especially if attention is not generally, but specially directed.

immediately coincident upon the presentation of lines of whose adequate stimulus the latter can form and have often formed a part. These integrations are the two cube-forms and the truncated many-sided pyramid, although everyone finds that even the help of attention is seldom able to integrate the latter. All these forms are possible, if the given stimulus suffices to evoke them. If they are found to have any tendency to arise, they can, of course, only be excluded, if one particular integration is so adequately determined that it will suffice to maintain itself steadily, besides excluding the others. Such a limitation, say to flatness, is often provided by binocular identity of stimulation. This might not however necessarily be a sufficient limitation, because it is conceivable that the attractive power of one of the solid forms and the chance support given to it by various circumstances might be great enough to break down the limitation to flatness.

What are these circumstances which act as *determinants* upon ambiguous stimuli, whether these be inadequate or under normal circumstances adequate? The investigation of the illusions of reversible perspective attempts to give an answer. Fixation of certain points and the movement of fixation along certain lines, e.g. are well established as peripheral determinants; but there are also central determinants which may support it or suppress it, for a reversal of perspectival illusion will take place even during fixation. Here we have a case in which probably a central determinant may act with or against a peripheral determinant[1]. The natural form which a theory of these determinants will take is that such and such an one determines an ambiguity, say of depth, because it is always or very usually found that fixation of a certain point involves a better view of farther points surrounding it, than of nearer points, perhaps because there is naturally and usually nothing opaque between us and our object of regard. Or it might be said that a determinant acts because it itself actually integrates partially or wholly one of the forms which the ambiguous stimulus integrates, or that it acts because it arouses centrally by memory-image or associative recall or the like one of these forms and therefore facilitates the passage of the inadequate stimulus by that way. In regard to *peripheral determinants* there is a presumption in favour of their being *consensuous* with the original ambiguous or inadequate stimulus, for it does not readily appear how a stimulus through

[1] Cf. Meumann, "Ueber einige optische Täuschungen," *Archiv f. d. ges. Psych.* Bd. xv. p. 405. In these illusions irradiation acts as a determinant within the details of a depth-integration. It strains the facts however to talk about "conflict" in this case, between irradiation and perspective.

another sense, e.g. the afferent products of muscular activity should produce a change in an integrative effect in a given sense. This is borne out by the results of the examination of the eye-movements accompanying visual illusions by means of cinematographic photography[1]. Central determinants are intelligible already in so far as they act as facilitants to the course of the original stimulation.

The psychological aspect of these problems is perfectly parallel to the physiological basis indicated. What relation is there between the sensations which form the basis of integration, be this basis perfectly or imperfectly determinate and the psychical state which represents the integration? It may be that the systematic integration of order-aspects in uniocular stereoscopy by alternate projection is made determinate by the order-relations which apparent sizes of familiar objects have developed, because the latter is parallel or psychically identical with one of the former. Similarly in the case of the illusions, the order-aspects inherent in the reversible figure might be determined psychically by the progress of a psychical action of examination from one point common to the order-aspects onwards in a certain progression, whether this progression be determined by habituation or by choice of a certain sequence. There is of course no reason why this psychical action should not be called a process of apperception or assimilation or production provided one does not imagine that these processes manufacture or create the psychical appearance which results upon them, whether a special process be supposed to intervene or not. Such terms as these can surely only indicate that a variety of distinguishable primitive presentational complexes have merged into one unitary and in some aspect at least, unique state. Neither for physiological nor for psychological consideration can it be well maintained that central determinants complete presentational complexes by creation of the missing parts. It must be shown that the given and the determining parts together provide a sufficient integrative basis for the final result. We suggest therefore that the order-aspects of component parts, both in a physiological and in a purely psychological sense, provide a sufficient basis for the determination we find.

[1] Judd and others, *Psychol. Rev. Monogr. Suppl.* Vol. VII. No. 1. Neither a certain amount of correspondence between eye-movement and illusion, as shown to be present by Judd, nor a complete correspondence would suffice to establish the influence of impulses towards or of afferent effects of movements of the eye upon visual complexes, unless the latter were themselves visual. For there would always remain the greater probability that the illusions produced the eye-movements.