VOL. 1. NO. 4. FEBRUARY 18, 1904

THE JOURNAL OF PHILOSOPHY
PSYCHOLOGY AND SCIENTIFIC METHODS

ACCURACY OF PERCEPTION OF VERTICALITY, AND THE FACTORS THAT INFLUENCE IT

A PRELIMINARY SURVEY

1. If an attempt is made to place a movable line in a vertical position, it will be found that a peculiar difficulty attaches to the task. The most delicate correction of a very nearly perfect position almost inevitably throws the line too far, and a vacillation results which is difficult to terminate. This vacillation is an effect not merely of an uncertainty due to the limitations of our ability to identify an actual position of the line with our ideal of verticality, —*i. e.*, to the degree of acuteness of discriminative sensitivity for positions nearly vertical,—but quite as much to an apparent restlessness and constant change of inclination of the line itself. The line seems alive, and baffles one's best endeavors to hold it still and subject it to a steady scrutiny. A momentary satisfaction may be obtained and a record made of the degree of error; but this error will represent not merely the sensitivity for the vertical position, but the operation of a considerable complex of other factors also. This present paper aims to give a cursory survey of the errors recorded under a variety of conditions, and of the attempt to unravel the various factors which exert an influence upon the way in which the line is seen inclined.

2. For the purpose of this investigation a line was used—usually a white thread against a black background—fixed at its lower extremity and so arranged that its upper extremity could be pulled to right and left by means of cords in the hands of the observer. The latter endeavored to place the line in a position which should seem to him vertical, and the degree of angular deviation from the true vertical was recorded. It makes much difference whether the eye is free to roam about within the field, glancing up and down the line, or is fixated on one of its points; and whether, in the latter case, it is the top, middle or bottom part that is fixated. For the better comparison of different cases, however, and analysis of the influ-

encing factors, a uniform method of examining the line was adopted, namely, the fixation of its bottom point, or, in case of indirect vision, of some point on the same horizontal level.

3. *Difference between Right Eye, Left Eye, and Both Eyes.*— The right eye tends to judge a vertical line as being slightly inclined upward to the left, when its bottom point is fixated; the left eye, as slightly inclined to the right. Either eye may, however, see it inclined in either direction, but these are the prevalent tendencies, and even when for each it inclines apparently in the same direction, for the left eye it is almost uniformly more inclined to the right (or less to the left) than for the right eye. The average position, for different persons or for the same person at different times, has varied between 0.5° R. and 1.5° L. for the right eye, and between 1.0° R. and 0.9° L. for the left eye. The difference in position for the two eyes separately has varied between 0.1° and 1.25°. These are average positions, determined sometimes by a large number of single observations. The extreme positions which under any circumstances have seemed vertical have been 10.6° R. and 4.2° L.

When both eyes are used the tendencies vary. The averages have ranged between 0.3° R. and 0.3° L. In the case of seven persons the position for the two eyes together coincided very nearly with the position for the right eye alone; in the case of eight persons, with that for the left eye alone; in four cases it was more nearly vertical than for either eye singly, each seeing it inclined in the same direction; and in one case it was more extreme than for either eye alone. In some of these cases the number of tests was insufficient to establish the certainty of the tendency noted. The thoroughly tested cases, however, are enough to show that there is a preponderant tendency for a person to be either right-eyed or left-eyed, when both eyes are used. Curiously enough, no case was met with of the type that one might naturally expect to occur, where for both eyes together the line assumes a position midway between the positions for either eye singly.

4. *Indirect Vision.*—When a point is fixated in the field to one side of the line and opposite its middle point, the vertical line appears to curve with its concave side toward the fixated point. When the fixated point is opposite the bottom of the line, the line as a whole appears to incline upward to the left if fixation is on the left side, to the right if fixation is toward the right. In one particular series, embracing 1,500 tests, the apparent inclination averaged, for fixation to the right, 1.0° more to the right than when the line itself was fixated, and for fixation to the left 0.5° more to the left. In general, the average values have varied between 0.1° and 1.5° for fixation right, and between 0.5° and 1.2° for fixation left, further than in

fixation of the line. Fixation to the right almost uniformly gave the larger effect, in some cases double that of the other. The maximum effect was found to occur in the case of one person at an angular distance of about one half degree from the line. As the fixation distance increased the effect diminished steadily and finally reversed on some occasions, though in extreme positions there sometimes occurred a secondary increase. A possible explanation of this behavior is discussed later.

5. *Effect of Inclination and Rotation of the Head.*—If the head is tipped sidewise toward the shoulder, it has an effect upon the apparent inclination of the line. Inclination of the head makes the line appear inclined in the same direction as the head. The amount of effect has varied from a very slight value up to about 1.5°. Inclination of the head backward and forward and rotation about a vertical axis also seem to exert some influence, but its nature and degree are far from uniform.

6. *Effect of Effort.*—It is possible to change the apparent inclination of the line by exerting a voluntary effort. If one endeavors to force it to appear inclined to right or left he may succeed, and the line then requires a larger correction to make it appear vertical. The degree of this effect has varied in these tests all the way from zero to 3.0°. In the case of one subject, the efforts to the left are from 50 to 100 per cent. stronger in effect than those to the right. The nature of the effort exerted is variable and difficult to analyze. It usually consists of a combination of factors, among which may enter: a mental representation of the line in the desired inclination; a mental representation as of seizing the line with the eye and twisting it, or of seizing some point of it and pulling it to one side; actual fixation to one side; inclination of head and pressing it against the head-rest, as if pushing the line with it; various strains in muscles of head, neck and eyes. That the effect is not identical with that of side-fixation and of head-inclination, already mentioned, is proved by the fact that these may be made in the opposite direction without destroying the efficiency of the effort.

Still other conditions produce definite measurable effects upon the apparent inclination of the line. Some of them are of large importance, as, for instance, the direction in which the corrective movements of the line are made (after-images of movement), the degree of illumination and the number and nature of distinguishable objects in the field. Consideration of these can be postponed a little with advantage.

7. *Analysis of Factors Influencing the Perception of the Line's Inclination.*—It is evident that these are numerous and complex, but it is not impossible that they may reduce to a few relatively simple

ones. It will be well to enumerate them rather crudely at first, and then attempt a reduction to the more important.

(*a*) *True Limitations of the Discriminative Sensitivity for the Vertical Position.*—This is evidently much finer than is shown by the amount of error in attempting to establish the vertical position, on account of the numerous other factors that influence this endeavor. It is impossible to isolate the one from the others and to determine its exact value. A fairly accurate idea may be gained, however, of the size of the variable error by an examination of those cases where, after acquaintance with the important influences has been secured, a special endeavor is made to hold them unchanging through a long series of tests. Even so, irregularities creep in at intervals; but steady results have been attained many times that show a very delicate ability to discriminate between different positions. One series shows five successive positions exactly the same. A series of 10 judgments contains 9 that are within 0.1° of one another; one of 14 contains 11. In one series of 10, all are contained within extreme limits of 0.2°. In a series of 15 the average error is 0.08°, and the extremes are within 0.18° of the average value. Many other series occurred where the delicacy of recognition of a definite position was but slightly less than that shown by these examples.

(*b*) *Purely Mental (or Central) Factors.*—Every sensory complex must be joined to a complex of central apperceptive elements before it can acquire any spatial significance at all. Preperception, which we found acting consciously sometimes, at least: in the case of effort, and which doubtless is present unconsciously in some other cases, is also of importance. But both apperceptive and preperceptive structures are built up out of closely associated sensory material gained in previous experience, and may reduce, therefore, so far as their visual elements are concerned, to sensory factors yet to be mentioned. Moreover, it is conceivable that they may be unable to operate without involving the actual presence of certain peripheral sensory conditions.

(*c*) *Diffusion Images and Retinal Fatigue.*—Only the portion of the line in the immediate neighborhood of the point actually fixated will cast a clearly defined image on the retina, because this portion only coincides with the horopter. The rest of it will be more or less fan-shaped. Retinal fatigue may lead to an over-emphasis of some parts of the fan-shaped image, and produce, therefore, for the moment an actually inclined image of the line on the retina. Experience shows, however, that this factor is much less influential than most of those yet to be mentioned.

(*d*) *Inclination of the Image on the Retina.*—This by itself means nothing spatially until apperceptively interpreted. When a natural apperceptive interpretation is once established, the relative position of the retinal elements affected is of importance. We have just seen one condition which influences the inclination of the retinal image. Another case occurs when the head is inclined to one side. In the latter case, however, when the head-inclination is conscious we are accustomed to allow for its occurrence and to make a more or less accurate correction for it. An approximately vertical line seems still vertical if the head is inclined toward the shoulder, or is upside down. If the inclination of the head were wholly unallowed for, it would result in an interpretation of the line as inclined in the opposite direction. That the direction of apparent line-inclination and of head-inclination when the latter is conscious is usually the same, seems to show a general tendency to over-allowance, or the operation of some other factor.

Still another case of changed inclination of the retinal image occurs when the line is viewed indirectly, with actual fixation on a point to one side of it. The effect in this case is usually explained as reducible to a simple matter of perspective projection. An after-image of a line coinciding with the vertical meridian of the retina will, if projected to the right and upward (corresponding to our case of fixation to the left of the base), seem inclined to the right upward, following Helmholtz's lines of direction. A truly vertical line in that position will, therefore, seem inclined to the left, in case a line whose image falls on the ordinary vertical meridian of the retina is regarded as vertical. This does not occur if the eyes are themselves turned to the peripheral position, for the effect of perspective is allowed for and interpreted, so that the true vertical still appears vertical. But in indirect vision, it seems, no such allowance is made, and that line is regarded as vertical whose inclination is the same as would be that of a vertical after-image if projected to that part of the field. Whether this accepted explanation is fully adequate is a matter to which further investigation should be devoted.

(*e*) *Constant Unconscious Movements of the Eye about the Fixation Point of Attention.*—Attention may be held concentrated upon a given point of the line, accompanied by the feeling that the fixation of the eye is held steadily upon the same point. Yet the eye will nevertheless be making constant slight movements in all directions about the supposed fixation point. That this dissociation of the fixation point of the eye from the fixation point of attention is constant and normal may be shown by three methods at least. While the subject is conscious of no deviation of his attention (or

of his eye) from the given spot, the constant eye movements may be detected (1) by a direct record of slight eye movements, by means of instruments attached to it; (2) by examination of the eyeball through a microscope; (3) by the projection of after-images. Of all these methods use has been made during this research. This normal failure of the eye direction to coincide with the direction of attention serves a useful purpose, in that constantly fresh retinal surfaces are presented for the unchanging stimulus, and the effects of retinal fatigue are thus prevented or delayed. But it is evident that in this way during the course of the examination of a line the effects of side-fixation are being constantly introduced and are constantly changing. From this fact, to a large extent at least, results the puzzling restlessness or aliveness of the line, of which mention was made at the outset.

(*f*) *Muscular Tension Apart from Actual Movement.*—This is a factor which, so far as the writer is aware, has not been considered in previous expositions of the influences that determine our spatial perceptions. Yet it would seem to exist really and to be of large importance. The evidence for it is partly introspective, partly by exclusion of other factors as a possible explanation of the results when muscular strains are present. It may be briefly summarized as follows:

(1) The line often appears inclined in one direction when fixation is on the opposite side (as shown by microscopic or after-image examination), when head-inclination is in the direction opposed to that which would produce such line-inclination (as shown by delicate records of head position), when there is no conscious preperception and no effort. Changing muscular tensions within the eye muscles could account for this effect; it is not easy to see what else could explain it.

(2) Muscular tension can be shown to be efficacious when a voluntary effort is made to cause the line to assume a given apparent inclination. The effect is much larger than could be accounted for by any other factors known—preperception unattended by muscular effort, side-fixation or head-inclination,—and may be made to work strongly in a direction opposed to and overcoming their influences.

(3) Introspection clearly attributes the efficiency of the endeavor just spoken of to the muscular efforts made.

(4) Although head and neck muscles usually cooperate with eye muscles in case a strong effort is made, yet the former may be excluded and the eye muscles alone shown to be capable of producing the results. We have cases of the apparently exclusive influence of tension in eye muscles (i.) when a voluntary effort is deliberately confined to them; (ii.) in the influence of surrounding objects in the

visual field, which produce tensions in eye muscles tending to turn the gaze upon them, and whose number and relation to interest and attention are of large importance in helping to determine the apparent inclination of the line; (iii.) when resistance to eye movements is introduced by attaching recording instruments directly to the eyeball.

Of course, no muscular tension has spatial significance unless it enters into a fitting sensory and ideational complex which permits it to be so apperceived; and a given tension may or may not be spatially interpreted, according as it is incorporated into one or another apperceiving group. If an object, ideational or external, engages attention and tends to cause an eye movement, and if steady fixation is maintained and the solicitation to movement not yielded to, it is evident that the tension induced in the muscles directly solicited to action is balanced by a corresponding tension in the opposing muscles. The tensions directly solicited, or those most clearly felt, enter into a spatially interpreted complex, as a consciousness of an object or field of objects to one side, or of a line under consideration having a certain direction, etc.; the opposing tensions enter into a different apperceptive complex and appear in consciousness, if at all, as effort of resistance. The same two tensions, however, may receive each the other interpretation, if attention is so transferred as to change their rôles with respect to solicitation and resistance. Thus either or both tensions may receive a spatial interpretation, or an effort interpretation, or may be directly felt as strain in eye muscles, according to the particular apperceptive systems into which, because of the interests of the moment and the direction of attention, they are taken up.

8. *The Most Fundamental Factors* of those above enumerated, to which or to influences on which almost all the others may be reduced, would seem to be: (*a*) the actual inclination of the image on the retina, together with those central associates which give it a spatial meaning. This is influenced by the actual inclination of the line, by the position of its image on central or peripheral portions of the retina, by the direction in which the eye is turned, by the slight unconscious movements which the eye is constantly making, by movements of the head as a whole, by over-emphasis of one or another portion of the diffusion image of non-fixated portions of the line, etc.

(*b*) Tensions in eye muscles and head muscles. Among the influences that induce these may be mentioned: deviations of attention from the actual fixation point; preperception; voluntary effort; a tendency to the persistence of previous tensions; movements of the line; attraction or repulsion of distinguishable objects, etc. There seems to be some evidence for the existence of rhythmical tendencies

to variation in tension. It is probable also that certain combinations of lines, when attended to, arouse tendencies to fixation in definite positions, or to tensions toward those positions.

9. *Reduction of Some Complex Conditions to the Simple Factors.*—(*a*) Preperception, expectant attention, the arousal of a mental representation of the line as having a particular inclination, probably never produces any actual effect upon its appearance unless accompanied by actual muscular effort. (*b*) The after-effects of movement of the line are probably due to tendencies of the eye to stop short of the final position of the line, or to go on beyond it; and to the persistence of particular changes in muscular tension. (*c*) The effects of fatigue are due to changes in the retinal image, and to a diminishing control over eye and head movements and muscular tensions. (*d*) Intensity of illumination acts through increasing or decreasing the number and intensity of distinguishable objects in the field. These in turn produce an influence on the apparent inclination of the line, and on other spatial structures, through affecting the muscular tensions; and similarly they ' steady ' the whole muscular system, and increase the delicacy and strength of its control. In the dark, or in high places where the eye has little to cling to, control of the whole muscular system and often of the mental steadiness and clearness is weakened. A field of distinguishable objects sets up innumerable innervations in the eye muscles, holding them in a state of constant tension. This has at least two important consequences. It reflexly affects the innervation of the whole muscular system, giving its action greater control and steadiness. Secondly, it increases the quickness, delicacy and control of the eye's own reactions; and the presence of particular tensions, or prevalence of general tension in particular directions, in conjunction with the particular sensory and apperceptive complexes with which their sensory effects unite, determines particular spatial perceptions. The effect produced by distinguishable objects on apparent inclination of the line varies according to circumstances. If the peripherally situated objects are not attended to, their greater number, or their greater intensity, or perhaps also their greater natural interest, in a certain direction, produces the opposite effect to side-fixation in that direction. The power of an object or of a group of objects to produce this effect is greatly strengthened in case they force themselves on attention. In the latter case, however, if one distinctly does not wish to yield to their attraction, an effort of resistance may be made which is liable to be over-great, and thus an effect of practical repulsion results and the effect on the line under observation is reversed. (*e*) An interesting complexity of conditions revealed itself in a series of tests on the effect of fixation at different distances away from

the line, to right and left. There was an increase in effect up to a maximum a short distance away from the line; then a steady decrease through a considerable distance, proceeding so far as to reverse the illusion; and often a final increase again. In these tests the head was fixed in position and the eyes alone turned. The first phase seems to reveal the pure effect of side-fixation; this is opposed during the second phase by an increasing nearness and visibility of distinguishable objects in the side field, whose effect finally proves stronger than that of side-fixation; and in the extreme positions strong muscular strains are present and clearly felt, and these come to the support of side-fixation. The problem as to the effect of turning head and eyes together and allowing no distinguishable objects in the field is now under investigation.

10. *Practical Applications.*—It is obvious that our spatial perceptions are influenced to a large degree not only by the actual conformation of the image on the retina, and by the movements actually executed by the eye in following lines and contours, but also by the tensions existing in eye muscles apart from those involved in the actual execution of movements. We have seen how these factors affect a particular spatial perception, that of vertical direction. All the other fundamental spatial elements are similarly influenced. Not only is the vertical direction affected, but also all other directions, whether in the plane perpendicular to the lines of regard, or in the third dimension. The impression of spatial extent is determined also by the same factors. It is well known that esthetic judgments are influenced by the natural points of orientation and the natural methods of exploitation. The same is true of spatial judgments. The eye has a tendency to come to rest most easily in certain positions, determined by the combination of lines within the field, and when not at rest in that position, there exists a muscular tension toward it. Again, the eye has a tendency to follow certain paths most easily, in the exploitation of a figure. The spatial consequences of these facts can be observed most simply in the case of the well-known geometrical-optical illusions. The particular form assumed by the figures with reversible perspective, for example, is determined fully only when account is taken not only of actual fixation-points and of actually executed movements in definite directions, but also of the tensions induced in definite directions, either on the surface of the figure or toward points nearer or farther away. The details of these facts we are now investigating. In the case of the Zöllner illusion, the eye in following the parallels tends to slide unconsciously down the transverse lines a little way and to come back always to the line with an effort. Consequently the line seems further and further away, in a direction opposed to that in which the

unconscious deviations from a straight path take place. The eye does not move with equal ease in both of two opposite directions. Consequently the unconscious deviation will be greater for transversals going in one direction than for the other set, and the recently discovered unequal distortion of the different parallels will be explained. With the eye at rest, the conformation of lines is such as to establish for it certain points of easiest fixation, and their assumption, or the existence of tensions toward them, gives the distorting effect of side-fixations, which associates itself with the experiences gained during movement and supports the illusion. In the case of the Müller-Lyer illusion, the easiest fixation-point for the eye, when attention is on the end of the line, lies within the angle. If the eye actually rests on any other position of the field when the figure is under examination, there exists a muscular tension toward the point of easiest fixation. Accordingly, whether the figure is surveyed with the eye at rest, or with it sweeping over the field in any desired irregular manner, or with it following the line carefully from one point of easiest fixation to the other while attention goes from actual end to actual end, the perceived length is determined by the amount of actual movement involved in the latter case; and thus the apparent difference in length of the two parts of the figure is explained. Angles of different degrees and of different lengths of sides, and end-figures other than angles, involve different positions of the point of easiest fixation, and hence differ in the degree of illusion produced.

The most important result of this whole study is the establishment of the fact that the internal tensions of the muscles of the eyes (and of other bodily parts), apart from those involved in the execution of actual movements, are of the greatest consequence in determining the details of our spatial perceptions.

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RECENT CONTRIBUTIONS TO THE LITERATURE OF SCHOLASTICISM.

GENERAL interest in that phase of philosophic thought which is known as scholasticism may be said to date from the publication of Cousin's 'Ouvrages inédits d'Abélard' (Paris, 1836). Since that time much, indeed, has been done towards the historical presentation of scholasticism; much, however, still remains to be done, especially in the matter of completing our fund of original literature referring to scholastic philosophy. It is the purpose of