THE RELATION BETWEEN VISUAL AND POSTURAL DETERMINANTS OF THE PHENOMENAL VERTICAL[1]

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Fifteen years ago Koffka pointed out that perceived space could be characterized as constituting what he called a "framework" (6). Implicit in every visual perception were reference-axes of vertical and horizontal, somewhat analogous to the coordinate axes of abstract geometrical space. Objects in phenomenal space, he said, are seen to be upright or tilted or inverted only by virtue of this frame of reference. It is as if the air surrounding the objects and surfaces in our visual environment contained an invisible coordinate system with respect to which their orientation is visible.[2] Not only the perception of the position of objects but also the perception of one's own bodily posture depended on this framework. In Koffka's theory the "ego" was a part of the phenomenal field, an entity in perceived space, and consequently the maintaining of bodily equilibrium was for him essentially a perceptual process, of which the postural reflexes were simply an expression.

Koffka reached the conclusion that this phenomenal framework, this sense of the vertical which a man possesses, was determined by visual stimulation. More specifically, it depended on the main contours of the visual field such as are provided by walls, floors, and the horizon. He based this conclusion in part on some rather informal observations by Wertheimer which indicated that a visually tilted room will look upright to an observer if he continues to look at it for a long enough time. What Wertheimer did was to rotate the cone of rays entering the eyes from the room by the use of a large mirror, keeping the edges of the mirror invisible to the observer (11).

In 1938, three years after Koffka's book, I suggested, in collaboration with Hobart Mowrer, that the visual vertical and horizontal are *not* determined by visual cues but by postural stimuli, and ultimately by the force of gravity acting on the body (5). The theory was that posture was the primary capacity of an organism, and the ability to see the directions of up-down and right-left was secondary. This conclusion was based on observations which contradicted those of Wertheimer and indicated that a visually tilted room will *never* look upright to an observer. Instead, my observations suggested that a sense of the physical vertical persisted and that the artificial environment continued to look tilted by reference to it. A fairly clear issue seemed to emerge which was in need of decision or resolution. *Of the two kinds of available cues, the lines on the retinas on the one hand and the vestibular-kinaesthetic stimuli for bodily equilibrium on the other, which are decisive in the event of conflict between them?* The original observations, both Wertheimer's and

[1] This is a revision of a paper read at the Symposium on Psychological Factors in Spatial Orientation under the auspices of the Office of Naval Research at Pensacola on Oct. 31, 1950.

[2] A clockwise or counterclockwise inclination should probably be called *tilt*. The writer has recently been investigating two other types of perceived inclination which he prefers to call *slant*, (a) floorwise or ceilingwise, and (b) right-wallward or left-wallward (4). Both *tilt* and *slant* must eventually be taken into account in any complete theory of space-perception.

my own, were based on a few subjects and no precise measurements were made. The experiment needed to be repeated. Other methods of putting visual and postural cues into conflict, such as modifying the direction of gravity by a centrifugal force, also needed careful investigation.

In the 12 years since 1938 a very considerable body of facts has been accumulated which bears on this issue. Since the relation between orientation to gravity on the one hand and orientation to the visual horizon on the other is one of the classical problems of aviation medicine and aviation psychology, this research has properly been supported by the Office of Naval Research. The evidence comes mainly from a series of experiments begun by Asch and Witkin in 1942 (1, 2, 12, 13, 14, 15) and from another series of experiments carried out jointly by the U. S. Naval School of Aviation Medicine and by Tulane University, under the direction of Graybiel and Mann, respectively (8, 9, 10).[3]

These results appear to be contradictory. The observers at Brooklyn College employed by Witkin made judgments of the vertical axis of space which were much influenced by the direction of the lines in the visual field and little influenced by the direction of the pull of gravity on the body. Individual differences were striking. The observers employed at Pensacola and Tulane made judgments of the vertical which were little influenced by the lines in the visual field and much influenced by the axis which the body must adopt in order to maintain equilibrium. Individual differences were not great. In the face of this disagreement, is there any way in which both sets of results can be accepted as correct?

The purpose of this paper is to suggest that the issue formulated above cannot be decided one way or the other and needs to be resolved instead. In making this suggestion, I admit having made what seems to me now a mistake. The controversy arises only if one is forced to choose between a phenomenological theory of space-perception, such as Koffka advocated, or a motor theory of space-perception such as was implied by Mowrer and me in 1938. Let us follow these opposed theories to their ultimate conclusions.

The Gestalt psychologist would like to demonstrate that perception is prior to action. Hence, he assumes that the maintaining of bodily equilibrium is a matter of perceiving one's body-position. The ego is part of a field and the postural reflexes are to be understood as forces in the field. This says, in effect, that a man must be able to sense the vertical in order to stand up. Hence, the upright posture is nothing but a secondary resultant of the spatial framework.

The behavior-theorist would prefer to believe that action is prior to perception (if it came to a choice). He assumes that equilibrium is maintained by reflex adjustments and that one's sense of the vertical is merely the conscious correlate of this process. A man has to be able to stand up, he argues, in order to sense the vertical. Hence, the spatial framework is nothing but a secondary resultant of the postural vertical.

When the theories are contrasted in this fashion the difference between them begins to sound like a terminological problem, or at most a philosophical question which no amount of evidence will settle. Is it really profitable to debate whether an animal must per-

[3] Many of the studies in this series consist of research reports by various writers distributed by the School of Aviation Medicine under the title *The Perception of the Vertical*, ONR Project Designation 143–455. *Cf.* Joint Report No. 18, *Studies in Space Perception* by C. W. Mann.

ceive the environment before he can orient to it or whether he must orient to the environment before he can perceive it? Psychologists have differed on just such questions for years, but I suspect that the argument is fruitless. Why must we suppose either that perception is prior to posture or posture prior to perception? Why not assume that they develop together, both ontogenetically and phylogenetically? Why not conceive them as reciprocally related?

The evidence indicates clearly that the apparent visual vertical, as judged by an experimental observer, is determined by *both* visual stimulation and postural (gravitational) stimulation acting jointly. The evidence is equally clear that the achieving of a vertical posture (in a tilting chair, for instance) is determined by both visual stimulation and postural stimulation acting jointly. The apparent visual vertical is the standard by which we perceive the upright or tilted quality of objects, the horizon, and the visual world around us. The postural vertical is the norm which an animal achieves by virtue of tonic muscular reactions which keep it in balance. The visual phenomena and the motor ability are closely interrelated. Why assume that one is prior to the other? Both are necessary if an animal is to see effectively and act adaptively. In all likelihood they are correlative, and neither has to be taken as the explanation of the other. We neither have to see in order to stand nor do we have to stand in order to see.

If this theoretical issue is disposed of, the question of visual cues *versus* vestibular and kinaesthetic cues appears in a new light. Spatial behavior and spatial perception depend on both modes of stimulation. The question is no longer which mode is *decisive* when they are set in conflict but simply how do they interact?

In normal upright posture in a normal environment the main lines of the retinal image are physically parallel to the direction of gravity acting on the body. When these directions are *not* physically parallel the situation is one of conflicting or discrepant cues. This latter situation can be produced for an upright experimental subject by rotating his retinal images, either by optical means or by actually tilting the environment which determines his retinal images. The optical method is exemplified by Wertheimer's mirror (11) and by Gibson and Mowrer's prism-glasses (5). The tilted environment method is exemplified by Witkin's tilting room (13). It can also be produced by altering the effective direction of gravity by adding a component of centrifugal force without rotating the retinal images. This method was first employed by Mach (7) and requires a human centrifuge with an *upright* visual environment. In either case the effect is to make the subject try to perceive two incompatible verticals and try to adopt two incompatible postures. In this kind of situation the subject must respond either to the retinal cue or the gravitational cues, or to a compromise between them, or first to one and then to the other.

It is important to note, at this point, that the situation of discrepant cues is *not* produced when the subject's body is tilted by his voluntarily reclining or putting his head to one side. The comparable experimental situation is that of a tilting chair with an upright visual environment. In this case, which is common in the activities of daily life, *the lines of the retinal image remain physically parallel to the direction of the pull of gravity,* at least approximately. On the one hand the environment (together with its projected image) and on the other hand the forces acting on the vestibular organs (and

also the skin, the joints, and the muscles) are consistent with each other, not discrepant. When, for example, a man lies on his side on the beach and looks off at the horizon of sea and sky, his retinal image has been rotated 90° out of the normal, but at the same time the pressure within his inner ear has also been rotated 90° out of the normal in the same direction. Whether he tilts his head 90° or 60° or 30° the stimulation of the retina and that of the statocyst remain consistent and may be assumed to have a sort of angular correspondence.[4]

This latter situation may be called one of co-varying cues or of reciprocal stimulation. To each degree of variation in retinal stimulation there is a corresponding degree of variation in kinaesthetic stimulation; the two are coupled together. In this situation the achieving of an upright posture is natural, easy, and accurate. A subject in control of a tilting chair under these conditions can bring himself into alignment with gravity with great precision. Moreover the tilted subject in an upright environment perceives the environment as upright and discriminates the visual vertical fairly accurately.

The above result is in striking contrast with that of the first situation, the *upright* subject in a *tilted* environment. The subject may or may not perceive the tilt of the environment, and he can discriminate the visual vertical only with a considerable error and with much variability (13). In both situations there has been a rotation of the retinal image out of the normal, but in the second there is no reciprocal change in the accompanying postural stimuli. The two modes are still coupled but the stimulus-variables do not correspond. The rotation of the retinal image is not compensated for by a corresponding angular shift in the proprioceptive complex.

The theory which emerges from these considerations is something like this. In the case of reciprocal visual-proprioceptive stimulation, the coupled variables combine to form an *invariant* resultant which is in correspondence with the objective direction of gravity and which provides the stimulus for a univocal impression of the vertical. This is why the ordinary visual scene continues to look upright when one inclines his head and thereby rotates his retinal image.[5] In the case of discrepant visual-proprioceptive stimulation, or conflicting cues, the coupled variables do not yield an invariant. Their values do not correspond in the regular fashion and the resulting perception is ambiguous or equivocal. The subject is instigated to perceive two different verticals at the same time. The organism is forced to choose between them. Accordingly it is not surprising that the resulting perception is unstable and that it differs from one subject to another, as Witkin has discovered. Determinants of perception other than stimulation are free to function—attitudes, expectations, and habits characteristic of the person observing in the situation.

Here, in truth, is the case where the perception can be said to be determined by cues instead of by stimulus-variables.

[4] This formulation, it is true, neglects the slight counter-rolling of the eyes when the head is tilted. But this adjustment may be conceived as simply a part of the compensatory perceptual-motor mechanism being described, which complicates but does not invalidate the theory.

[5] The hypothesis of an "invariant of stimulation" in a number of perceptual situations was the insight which enabled Koffka to comprehend the problems of perceptual constancy more clearly than any other investigator. This hypothesis may be adopted without accepting his theory of field-forces in perception. The above application of the concept of an invariant is quite different from that of Koffka (6, pp. 215–218), but the conception itself is his.

The observer must search for clues to, or indicators of, the direction of gravity. His perception is objectively correct only to the extent that reliable clues are discovered, and consistently correct only to the extent that they are verified and learned.

The explanation of space-perception in terms of cues is roundabout and requires more hypotheses than an explanation in terms of stimulus-variables (3). Nevertheless when stimuli are contradictory they can only function as cues or clues. Let us apply the language of clues to the case of the subject seated upright in a tilted room. His retinal image of the environment taken by itself "tells him" that his head and body are inclined away from the vertical (this being the ordinary and almost invariable cause of a tilted retinal image). But his inner ear, his muscles, and the seat of his pants "tell him" that his body is *not* inclined from the vertical. Which sense is he to believe? If he believes his eyes, he should attempt to align his head with the room and, when asked to rotate the adjustable stick into a vertical position, he should set it nearly or completely parallel to the side walls. The room would appear nearly or wholly upright. On the other hand, if he believes his body-sense but not his eyes, he should sit askew of the room and he should set the stick in line with the main axis of his body. The room would appear to be strongly tilted relative to a larger space outside the room. If he cannot decide between his senses, he may begin to make inferences—unconscious inferences according to Helmholtz. If he has been told to set the stick to the *true* vertical, for instance, he may reflect upon the probability that gravity and balance are "true" and decide to put trust in the body cues. If he scans the visual evidence, however, the retinal lines argue forcibly that his head must be upright when he holds it aligned with the room.

The reason why Witkin's observers tended to see the vertical in alignment with the room whereas the Pensacola-Tulane observers tended to see the vertical in alignment with gravity may not be hard to find after all. If differences in the attitude of the subjects can affect the judgments, this fact may be sufficient to supply the explanation. The very meaning of the term "vertical" can be ambiguous in the situation described, and one group of subjects may have understood by it the apparent vertical while the other group understood by it the objective or physically correct vertical.

The writer has recently obtained evidence to show that, for a closely allied type of space-perception, subjects can distinguish between the "optical" slant of a surface and the "geographical" slant of the same surface when the line of sight is not horizontal and straight ahead but turned (4). The same distinction may prove to be valid for experiments on tilt. When the head is rotated around the horizontal line of sight, my own observations suggest that subjects will be able to perceive an optical vertical and a gravitational vertical independently and correctly, if asked to do so. Both are determined by stimulation, the former by visual stimulation alone, the latter by a visual-proprioceptive invariant. Both may prove to be stable and consistent in this situation.

According to the theory outlined, ambiguous, equivocal, or unstable perceptions of the gravitational vertical occur when the modes of stimulation conflict. More precisely, they are the result of the absence in stimulation of a visual-proprioceptive invariant. Along with the unstable perception often goes an unstable posture, i.e., some degree of disequilibrium. It is important to study

this situation, but it is even more important to understand the basic stimulus-situation of co-varying modes. The reciprocity of vision and proprioception in everyday spatial behavior may prove to be not only the key to the problem of upright posture in relation to the visual vertical but also the key to the problem of geographical orientation. In the most general sense, the covariation of vision and proprioception is probably at the heart of the problems of locomotor behavior, pursuit tasks, and many other motor skills.

It is important to realize that the individual differences which Witkin found to be so striking in the situation of conflicting stimulus-modes (12) are, in all probability, a function of that situation. He has not demonstrated that individuals differ in the basic ways in which they perceive space, but only that they differ in their choice of alternatives when several possibilities for perception are open, i.e., when the process of spatial perception is ambiguous. When the stimulus conditions are indeterminate, the outcome will be influenced by attitudes, motives, and even by social background, sex, and temperament.

On the other hand, the situation of conflicting cues is not unimportant, nor is it wholly unrepresentative of spatial behavior. Equilibrium and orientation in an airplane, and other complex forms of spatial behavior mediated by instruments, probably involve some degree of conflict or discrepancy among cues. The practical problem here is that of learning to use the reliable cues and to neglect the unreliable and irrelevant ones.

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