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EXPERIMENTAL INVESTIGATIONS OF THE GENESIS OF VISUAL SPACE PERCEPTION[1]

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The methodology and findings of 3 categories of experimental studies are reviewed and evaluated: (a) studies of organisms that have been deprived of visual stimulation until the time of testing, (b) studies of newborn organisms that are tested soon after birth, and (c) studies in which E controls the visual stimulation to which O is exposed from birth to the time of testing. The evidence provided by these experiments suggests that conclusions about the genetic basis of space perception will differ depending on the stimulus correlates under consideration.

This article is concerned with the genesis of space perception. It is necessary at the outset to distinguish the question under consideration from two other issues with which it is often confused. The first concerns the role of past experience in determining the current perceptual event. The second is related to the influence of specific practice on perceptual discrimination. Arguments intended to bear on the question of genesis are often derived from experiments dealing with the latter two issues. For example, it is asserted frequently that if perceptual judgments can be modified by certain types of previous experience, then experience must have been required for their original emergence. This argument has persisted since Helmholtz who wrote in 1866 that "whatever, therefore, can be overcome by factors of experience, we must consider as being itself the product of experience and training [Helmholtz, 1925, p. 13]." Despite the long history of this assumption it must be clear that evidence of the malleability of perception cannot entail any conclusion about the origin of the experience. Thus, one would hardly wish to conclude from the observation of the phenomenon of "memory color" (Duncker, 1939) that color perception is learned. Pastore (1960) has called attention to a parallel example in the field of genetics where "evidence of environmental modification of a trait does not preclude its genetic determination [p. 94]." This argument is mentioned at this point only to make clear that the issue under consideration is *not* whether space perception can be modified by experience.

For this reason many investigations which might otherwise be included, for example, studies of adaptation to spatial displacement, were omitted (I. Kohler, 1951, 1962). This rule of omission is followed regarding the adaptation studies despite the fact that Kohler and others seem to feel that these experiments provide data relevant to a determination of the origins of space perception. Kohler has maintained that the conditions of displaced vision produced by the prisms reinstate in the adult an earlier state of perceptual development comparable to that of the infant. And that the processes that lead to adaptation to the experimentally induced displacement are reiterations of the processes of original perceptual development. A thorough review of the adaptation studies conducted by Stratton, Snyder and Pronko, Kohler, and others may be found in Smith and Smith (1962, Ch. 4–6).

The investigations reviewed in this paper were concerned mainly with the

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sufficient conditions for the *initial* occurrence of a response indicating that an organism is capable of spatial discrimination. Can these conditions be specified entirely in terms of the organism's native or congenital constitution or must a complete statement of these conditions include reference to processes of early learning?

THREE METHODS OF INVESTIGATION

Until recently many American psychologists have been content to relegate the genetic question to the realm of philosophical inquiry. However, insofar as the question is concerned with the genesis of space perception and not with its epistemological status, it can only be decided empirically and is not properly a matter for philosophy. Fortunately, not all psychologists have abdicated their prerogatives of investigation and the last decade has witnessed a modest resurgence of interest in the problem. The experimental investigations can be classified usefully into three categories.

One category consists of studies of organisms that have been deprived of visual stimulation until the time of testing. On the first, or on a very early, occasion of stimulation their perception of space has been examined. When animals have been studied they have been reared in total darkness from birth to the time of testing. When human subjects have been studied, these have been (ideally) persons with congenital cataracts whose vision has been restored surgically.

The second category includes the investigations of naive, newborn organisms tested soon after birth. Animals are better suited to this approach than humans since human infants are capable of very few reliable overt behavioral responses soon after birth. Consequently, human infants have usually been studied at a later age (Fantz, 1961; Gibson & Walk, 1960). However, there has been one study by Wertheimer (1961) of the auditory and visual space of a human neonate during the first 10 minutes of life.

The third category of experiments utilizes an entirely different approach. In these studies the experimenter controls the characteristics of the visual stimulation to which the animal is exposed from birth to the time of testing. The aim is to determine whether animals that have been subjected to different conditions of stimulation will respond differently when confronted with a relevant test discrimination. The rationale of this approach will be elaborated when Hess' (1950, 1956b) studies are considered.

STUDIES OF VISUALLY DEPRIVED OBSERVERS

Studies of Animals

The earliest systematic study was performed by Lashley and Russell (1934). The object of the study was to determine whether rats reared in darkness from birth to 100 days of age would perceive variations of distance. The rats were induced to jump from one platform to a second platform whose distance was varied from 20 centimeters to 40 centimeters. An apparatus invented by Russell (1932) in order to study depth discrimination with normally reared rats was used. This apparatus allowed the experimenter to measure the force exerted by a rat in attempting to jump the given distance. Variations in force were interpreted as signifying corresponding variations in perceived distance. The experiment was conducted during a period of 3 days with the rats returned to the dark cage at the conclusion of each day's testing. On the first day the animal was removed from the dark cage and given five trials in *stepping* across a gap of 5 centimeters from the starting platform to the landing platform. Immediately following this practice, the landing platform was moved to 20 centimeters for five trials. On the second day the animal began with five trials at 20 centimeters. This was followed immediately by a sequence of nine jumps in this order: three jumps at 40 centimeters, three jumps at 20 centimeters, three jumps at 40 centimeters. On the third day the rat's difference-threshold for distance was determined. For this purpose, each rat was given one trial at each of nine distances ranging from 24 to 40 centimeters in 2-centimeter intervals. The distances were presented in random order.

The results showed that upon first exposure the rats adjusted the force of their jumps to the variations of distance. Thus a rat that overestimated the 20-centimeter distance on the first test trial would consistently reduce the force of his jump during the next nine trials. However, the first time the 40-centimeter distance was presented (Trial 6 on the second day), the rat immediately reversed the trend and doubled the force. This occurred with every subsequent change of distance. On the tests for difference-thresholds the dark-reared rats were almost as accurate as light-reared rats that had been tested earlier by Russell (1932) in the same situation. Lashley and Russell (1934) concluded

> that the visual perception of distance and gradation of force in jumping to compensate for distance are not acquired by learning, but are the product of some innately organized neural mechanism [p. 143].

Several doubts may be raised concerning the Lashley-Russell study. Greenhut and Young (1953) were unable to repeat Russell's (1932) original findings with 100-day-old and albino rats that had been reared normally. When they presented the initial test distances in random order they failed to find any correlation between the force of the jump and distance. However, it should be observed that Greenhut and Young used electric shock in order to motivate the animals to jump. Despite some evidence to the contrary (Greenhut & Young, 1953, pp. 174–175), it is possible that this aversive stimulus disrupted the animal's spatiomotor coordination in many instances. In fact, Greenhut and Young (1953) reported that "the animals were emotionally disturbed throughout the experiment [p. 160]."

In addition to the results of Greenhut and Young, the Lashley-Russell experiment has been criticized on the grounds that opportunities for learning were not completely eliminated. In particular it has been noted that on every second day the dark box was opened in dim light while food was supplied. Although each interval of light stimulation did not exceed 10 seconds, it is possible that the cumulative exposure was sufficient to produce substantial learning. The five practice trials which preceded the first test jump may have provided an opportunity for rapid learning. This argument gains plausibility from the general observation that organisms which have reached an advanced maturational level require less practice to achieve a specified performance level than organisms that begin their practice at an earlier level of maturation (Munn, 1955).

Lashley and Russell (1934) recognized the problems discussed above and presented counterarguments that are persuasive. However, the only effective way to deal with these objections is to perform new experiments which are more successful in eliminating opportunities for learning. The main flaw in the Lashley-Russell study stemmed from the nature of the response that they studied. The jumping response is a complex motor skill which requires practice. Rats reared in the dark are deficient in this skill. Therefore, it was necessary to introduce the practice trials, thus providing an opportunity for both visual and motor learning. A response indicator which is part of the organism's unlearned response repertoire would eliminate this necessity. Since the performance of the response per se would require no practice, the subject could be tested on the very first occasion of his exposure to the stimulus without prior practice of the response.

Kurke (1955), using a technique similar to that employed in the earlier studies by Spalding (1875) and Thorndike (1899), studied the depth perception of chicks reared under different conditions of visual and motor experience. Kurke's procedure was based on the observation that lone chicks will run to join their fellows. The chick was placed on a platform whose height could be adjusted. From the platform the subject could see a group of six chicks. The assumption was made that if the chicks perceived the height of the platform, then they would be reluctant to leave the platform before it was lowered to a safe level. The platform was set initially at a height of 21 inches, and if the chick did not jump within 30 seconds, the platform was lowered 3 inches. This was repeated until all subjects had jumped or the platform was on ground level. Dark-reared chicks were tested at 1, 2, or 3 days of age. Their performance was compared with a group of 3-day-old control chicks raised in normal lighting. The very young chicks (1 and 2 days) refused to leave the platform regardless of its height. The 3-day-old dark-reared chicks did not differ significantly from the light-reared control chicks. Nor did they differ significantly from 10-day-old light-reared chicks whose opportunities for jumping experience was limited. However, 10-day-old light-reared chicks which were subjected to enforced jumping activity differed from the other goups in that they jumped from the platform at a greater height. Kurke (1955) concluded:

> that the lack of visual experience does not appreciably affect the chick's perception of depth at an early age. However, the further development of depth discrimination apparently depends in some manner on the integration of experientially determined kinesthetic cues [p. 195].

Kurke's experiment is not very convincing. As was the case with the Lashley-Russell study, the difficulty is due mainly to the response measure. The response of jumping is determined by other variables besides perceived height. Among these is the level of muscular coordination and jumping skill which has been achieved. This leads to ambiguities in interpreting the results. Differences in performance may reflect differences in depth discrimination, but it could also be the case that subjects who are equally able to discriminate depth will vary in performance because of different levels of motor achievement.

The resolution of this methodological problem has been accomplished in several studies of color vision (Hess, 1956a), form discrimination (Fantz, 1957), and recently in a study of depth discrimination by dark-hatched chicks (Fantz, 1958a). The chick's discrimination of depth or solidity was examined by observing the distribution of unreinforced pecks in response to the simultaneous presentation of a spherical and plane circular surface. The rationale underlying the test is that if the chick shows a significant preference for one of the stimuli, that is, pecks more frequently at one, then the chick must be making perceptual discriminations between them. If the stimuli differ only on the relevant dimension, for example, solidity, then the subject must be able to discriminate along this dimension. It should be noted that, in addition to providing a resolution of the methodological difficulties described above, the stimulus-preference method also reduces the likelihood of confusing two different achievements: (*a*) learning a discrimination between stimuli to some arbitrarily assigned experimental criterion, and (*b*) discriminating between stimuli. While the former achievement presupposes the latter, it cannot be utilized as an index of the latter achievement except with certain qualifications. Suppose the experimenter confronts the subject with the task of learning a discriminatory positive response to a convexity as opposed to a concavity. As a measure of learning the experimenter uses the criterial level of nine correct responses in a block of 10 successive trials. This accomplishment presupposes that the subject can perceive the depth difference between the two stimuli, although he must learn that this difference is the criterial attribute. Therefore, it would be erroneous to conclude that a subject that fails to achieve the criterial level, for example, correctly selects the convexity in only 8 of 10 trials, cannot discriminate depth. It is equally plausible to infer that depth is discriminated, but has not been selected unequivocally by the subject as the basis for responding. This argument has been made earlier by Zuckerman and Rock (1957) in their analysis of the genesis of form perception.

Fantz (1958a) hatched 94 chicks in complete darkness and tested them at the moment of their initial visual stimulation. The chicks had no experience with food or water prior to or during the experiment. In the first experiment chicks were tested singly, and in the second experiment they were tested in pairs. The test consisted of a 5-minute exposure to a pair of stimuli. The stimuli were two hemispheres, one presented so that the curved surface faced the chicks and the other presented so that only a flat circle was visible. The stimuli were presented either under direct lighting which produced strong shading or under diffuse lighting which reduced the brightness gradients greatly. Under both conditions the curved surfaces received significantly more pecks than the plane surfaces. Apparently these chicks, with no visual experience, discriminated between the solid and plane stimuli. Comparable findings were reported by Fantz (1957, Experiment 5) in his studies of form preference in newly hatched chicks. While these newborn chicks seemed to make no use of light and shade distribution in discriminating depth, Fantz reported that slightly older chicks that had visual experience showed an enhanced preference for spherical surfaces when shading was present. This observation is consistent with Hess' (1950) findings which will be described later.

Walk and Gibson (1961) realized the same methodological objectives by using the visual cliff apparatus. This is a simulated cliff consisting of a board laid across a sheet of heavy glass which is supported at a desired height above the floor. On one side of the board a sheet of patterned material, for example, checkerboard pattern, is placed flush against the undersurface of the glass. On the other side the same patterned material is laid on the floor below the glass. This is the cliff side. If an organism which discriminates depth is placed on the center board it will avoid the cliff side and step on to the shallow side. If the organism cannot distinguish between the shallow side and the cliff side, then no preference should be observed. In these experiments, as was the case in Fantz' study, the discriminatory response required no pretraining in light, and the discrimination did not entail cognitive, problem solving elements. Rats were dark-reared and tested at the age of 90 days. These rats showed the same preference for the shallow side as a group of 90-day-old light-reared rats.

Walk and Gibson's results for the dark-reared rats were confirmed in a modified experiment by Nealey and Edwards (1960). Nealy and Edwards noted that the dark-reared rats in the Walk-Gibson experiment were subjected to a light-adaptation period of 20 minutes prior to testing. This adaptation period may have provided the opportunity for learning to occur. For this reason Nealey and Edwards repeated the Walk-Gibson study with the following modification. During the 20-minute period subjects were kept in a detention box which was so contrived as to permit light adaptation without pattern vision. These rats showed the same preference for the shallow side as rats that received the Walk and Gibson treatment. Nealey and Edwards also tested 24 enucleated rats in order to determine whether a preference could be obtained on other than visual bases. These rats did not show a reliable preference.

In further experiments Walk and Gibson (1961) tested dark-reared rats when the available stimuli for depth discrimination were reduced. When motion parallax was eliminated, leaving only the difference in density of optical texture as a stimulus for depth discrimination, no preference for the shallow side was exhibited. However, when parallax was retained, in the absence of the textural difference, the rats showed a strong avoidance of the cliff side. This is interpreted by Walk and Gibson to indicate that only motion parallax is an innate cue for depth discrimination on the visual cliff. Since visually experienced animals show a preference for the shallow side when cued only by textural density while dark-reared rats show no preference, the cue of textural density must be learned. This conclusion is reasonable, but it is not the only interpretation which can be given to these findings. An alternative stems from the observation that the procedures did *not* in fact isolate motion parallax from textural density. Instead, the two gradients were opposed to each other. One gradient was fixed to produce equidistance while the other was fixed to produce differential distance. In this conflict situation motion parallax was decisive. However, it cannot be concluded that the effectiveness of textural density requires learning. This conclusion can be derived only from the observation of performance in response to textural density in isolation.

Regardless of the above qualification, the general trend of the evidence obtained in the visual cliff experiments is clear. The evidence led Gibson and Walk (1960) in an earlier article "to venture the rather broad conclusion that a seeing animal will be able to discriminate depth when its locomotion is adequate, even when its locomotion begins at birth [p. 71]."

Studies of Humans

The case of the congenitally blind person whose vision is restored surgically would appear to provide an opportunity for gaining decisive evidence concerning the origin of visual perception. Since Molyneux's famous inquiry addressed to Locke, philosophers and psychologists have looked to these cases for evidence. Several reviews have appeared which evaluate the results of the investigations of restored vision (Dennis, 1934; Senden, 1932; Wertheimer, 1951). Prior to evaluating the evidence it will be useful to consider several relevant methodological and definitional questions.

1. The perception of space includes several related, but distinguishable and perhaps functionally independent, experiences. There is the fundamental and relatively undifferentiated experience of the extensity of the visual scene. The scene appears to extend in the third dimension and not merely to be a plane surface like a painting in the frontal-parallel plane. Within the scene, objects have a specific location relative to us (absolute distance) and also a location relative to other objects in the scene

(relative distance). In addition, each object will appear to be some linear size, either absolutely or relative to other objects. Finally, some objects will appear to be solid and others two-dimensional. Every student of perception knows that these aspects of the visual world are closely related. Nevertheless, it does not follow that an observer whose vision is tested immediately after surgical restoration and who is found deficient in one of these experiences is totally lacking in space perception. Therefore, broad conclusions concerning space perception based on performances related to only one aspect of space perception should be considered cautiously.

2. These remarks lead directly to a consideration of the method of testing. It is easier to specify prohibitions than to advance positive proposals. Tasks which demand prior visual learning for successful execution are unacceptable. One illustration of this is the designation of an object by the appropriate verbal label. Thus the subject might be confronted with a number of objects and the question "Which of the objects is a cube?" This question cannot be answered without a prior association of the auditory stimulus, "cube," with the *visual* stimulus produced by a cube. Obviously an observer with no prior visual experience will lack this association. A better procedure would be to confront the subject with equivalent plane and solid objects and then simply ask the subject to report whether he perceives several different objects or several instances of the same object.

Similar reservations exist regarding another testing method which has often been used. Investigators have sought to determine whether apparent size is invariant with changes in distance for the subject whose sight is newly restored. The presence or absence of constancy is used to derive conclusions concerning distance perception. These conclusions are open to question. Size judgment is a complex performance which is regulated by many variables in addition to distance perception. One powerful determinant is the conceptualization of the relationship between size and distance which the subject brings to bear on the experimental task (cf. Carlson, 1960, 1962). Subjects with normal vision will produce results ranging from marked underestimation to marked overestimation of size depending on their attitude of observation. In the absence of knowledge about the subject's attitude of judgment, it is impossible to interpret the results of his performance. Therefore, prior information concerning the preoperative conceptualization of the visual world is a prerequisite for interpreting the performance of the newly-seeing subject.

The question with which this discussion was started remains. How should the subjects be tested? No ordered schedule of tests will be introduced here. However, it seems best that an open-ended question should initiate the inquiry. It should not direct the subject to any specific aspect of the visual world. A simple question such as "What do you see?" would meet this requirement. The response to this question might introduce the experimenter to the subject's preferred language of perceptual experience. Later questions or instructions could then be phrased in the subject's language so that there would be assurance of their meaningfulness to him.

3. Senden (1932), Dennis (1934), and Wertheimer (1951) have described the postoperative visual disabilities which interfere with good vision. For instance many patients suffer from exaggerated and involuntary nystagmus which may continue for several weeks. This interferes with the normal functioning of accommodation and convergence. Two additional postoperative effects which occur frequently are acute dazzle and a narrowing of the visual

field. Obviously, tests which produce negative results are equivocal if the results are obtained prior to the adjustment of the visual mechanisms. On the other hand, if the experimenter elects to postpone the test for several weeks to allow the inhibitory effects to diminish, then there is a possibility that some learning occurred during the delay.

A review of the literature is disappointing. None of the subjects have been tested adequately (for present purposes), and most of the cases have been described only cursorily. The chief source of information is Part III of Senden's (1932) book. Senden reviews the evidence regarding the perception of spatial extension per se, relative distance, and solidity.

The reports concerning spatial extensity are unanimous, leading Senden to the conclusion that the newly-seeing have an immediate impression of depth. The objects in the field appear to be spatially separated from the subject. The patient localizes objects at certain indefinite distances although he cannot estimate their absolute distance. Thus the patient will reach out to grasp an object which is several yards away, or he will overreach an object which is only 1 foot from him. However, he *does* reach out into space and does *not* localize the object at the plane of the eye. This reaching response is qualitatively different from the normal groping that the blind usually execute in order to identify objects tactually.

The evidence concerning relative distance is ambiguous. The most frequently used procedure entailed a crude test of size constancy. Most examiners report that constancy is absent. This observation suggests that differences in distance were not perceived. However, as was noted earlier, this conclusion can be challenged.

Most of the cases reviewed by Senden (1932, pp. 264–271) indicate that the discrimination of solidity is absent. For example one subject was unable to distinguish a ping-pong ball from a comparable plane figure, for example, a white disc of equal diameter. For another subject a table in the center of the room appeared flat against the farther wall.

Recently London (1960) provided a summary of a Russian report on the postoperative newly-seeing which was published originally in 1953. This report is of special interest in that, unlike the Senden report, the writer, Pokrovskii, performed the surgery and the postoperative visual tests. Of the six cases described only two are directly pertinent. These are cases of two children, born with mild cataracts which allowed the patients the experience of light although pattern vision was not possible. London presents only the author's statement of results omitting details of the testing procedure. In the only statement dealing with space perception Pokrovskii reported that

> the children were unable by vision alone to determine distance or, more exactly, the distance of the nearest objects. When walking, they collided with these objects [London, 1960, p. 479].

This review of the investigation of the newly-seeing has revealed the unsatisfactory status of this evidence. The techniques of investigation are crude and the data are incomplete. In fact, there is not a single systematic parametric study of the visual perception of the newly-seeing. In the absence of more acceptable studies, the most prudent course is to refrain from introducing the findings described above as evidence. It is only fair to add that this judgment is not shared by all who have considered these investigations. In his early theoretical statements Hebb (1949) assigned great significance to Senden's findings and he has more recently reaffirmed his evaluation (Hebb, 1963).

STUDIES OF VISUALLY NAIVE OBSERVERS

The study of the newborn organism requires that a reliable unlearned indicator response be available immediately after birth. This requirement can be satisfied for many organisms although not in all testing situations. For example, the human neonate cannot be tested with the visual cliff apparatus. In order to employ the visual cliff, the experimenter must await the development of locomotion at which time the organism is no longer perceptually naive. Nevertheless, the human infant is not entirely excluded from investigation. Fantz (1961) and Wertheimer (1961) have studied the human neonate by observing the systematic changes in orientation of the eyes in response to various stimuli.

Studies of Animals

Walk and Gibson's (1961) work with the visual cliff apparatus did not include testing newborn observers. However, several species (e.g., the chick and the goat) are able to locomote during the first day of life. Gibson and Walk reported that none of their 1-day-old chicks, goats, or lambs ever stepped onto the glass on the cliff side. Gibson and Walk consider it very likely that similar results would be obtained with newborn animals as well. This expectation received support from Tallarico's (1961) study of the choice behavior of 3-hour-old chicks on the visual cliff. Of the 320 chicks observed, 90.6% chose the shallow side. Those chicks that stepped onto the glass on the cliff side seemed to do so inadvertently.

In another study Fishman and Tallarico (1961) also studied visual depth perception in 3-hour-old chicks. As an indicator response Fishman and Tallarico selected the avoidance response made on the first occasion of an approaching object. Six groups of chicks were tested. Three groups consisted of chicks reared in the light. The remaining three groups consisted of chicks reared in the dark. All chicks were tested individually at the age of 3 hours. There were three conditions of testing. In Condition FP (feigned poke) one experimenter held the chick in his fist while the second experimenter feigned a poke at the left eye of the chick. This consisted of moving a black pocketcomb from a distance of 1 foot to within $\frac{1}{2}$ inch from the subject's eye at the rate of 1 foot per second. The experimenter recorded the occurrence of a spontaneous head movement away from the direction of the poke. In Condition EF (extended fan) no poke was feigned. Instead a black fan held about 1 foot from the subject was opened in about a second at a right angle to the subject's line of sight. In Condition C (control) the experimenter held the chick as before and for the same length of time but without introducing any stimulus.

The dark-reared chicks did not differ from the light-reared chicks under any of the three conditions. The control chicks made very few "avoidance" head movements. Of the 73 control chicks only five spontaneous head movements were observed which were similar to the aversive movements of the experimental subjects. For both light-reared and dark-reared chicks the number of avoidance responses under Condition FP were significantly greater than under Condition EF. In fact only 1 of 18 chicks gave an avoidance response to EF, while 44 of 96 chicks responded to FP. These results are evidence that visually naive chicks can discriminate depth.[2] The

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[2] However, Riesen (1947, 1950) reported that dark-reared chimpanzees "did not blink at a threatening motion toward the face [and] when an object was advanced slowly toward the face there was no reaction [1950, p. 17]." Riesen's work has not been described in detail because it did not include any systematic tests of the subject's depth discrimination. In addition his chimps suffered from considerable oculomotor disturbance at the time of testing.

avoidance reaction seems to be a response to the unique stimuli provided by an approaching object. It is not a startle response made to a novel stimulus since it did not occur under Condition EF. Nor does it occur with great frequency in the absence of stimulation (Condition C).

It would be interesting to determine whether the newborn chick can indeed distinguish between the optical stimuli produced by a change in position and the comparable stimuli produced by an equivalent change in the size of a stationary object. Apparently infant rhesus monkeys respond to the isolated presentation of a closed contour undergoing symmetrical expansion as if it were an approaching object (Schiff, Caviness, & Gibson, 1962). On the other hand the chicks in Fishman and Tallarico's study did distinguish between the optical stimuli produced by FP and EF. However, since these two conditions were not exactly comparable no firm conclusion can be drawn concerning our question. The apparatus and stimulus events employed by Schiff et al. would be very appropriate for this purpose.

Studies of Humans

There have been even fewer studies of naive humans. Although the infants studied by Fantz (1961) had a median age of 15 weeks this investigation will be included. The only experiment which investigated newborn humans was reported by Wertheimer (1961).

Fantz (1961) employed the stimulus-preference method using the direction of orientation of the eyes as an indicator of preference. A solid object and a comparable flat object were exhibited for a series of 20-second trials and the subject's direction of gaze was recorded. The criterion of fixation was the superposition of the reflection of the object over the pupil. The subjects were 52 infants with a median age of 15 weeks. The test objects were a sphere and a disc of equal diameter. Each infant was tested under eight conditions: binocular and monocular vision, presence and absence of surface texture, direct and diffuse lighting. A differential response was obtained only in the tests using textured objects under direct lighting. The other six conditions did not yield a differential response. A curious finding emerged from these results. Infants under 3 months did not give a differential response in the binocular test but the same subjects showed a clear preference in the monocular test. This result, together with others, suggested to Fantz (1961)

> that the use of both eyes interferes with vision in the early months before the development of good binocular coordination, while binocular vision improves visual performance later on [pp. 29–30].

The results led Fantz to conclude that young infants discriminate solidity when gradients of texture and brightness are available. Binocular cues did not appear to be essential in the presence of these gradients nor were binocular cues sufficient in the absence of differential gradients. It is interesting to note that whenever a differential response occurred it was a preference for the solid object. It may be that the basis for this preference is the more general visual interest which young infants display in response to complex visual patterns (Berlyne, 1958; Fantz, 1958b). It is immediately evident that the presence of a general tendency of this sort introduces difficulties in interpreting Fantz' (1961) results. It is not possible to know whether the differential responsiveness to the sphere reflects a depth discrimination or a pattern preference.

Wertheimer (1961) studied the psychomotor coordination of auditory and visual space of one human infant before she was 10 minutes old. The subject was born without anesthesia, by natural childbirth. Testing commenced 3 minutes after birth. On each trial a click was sounded next to the right or left ear of the subject who was lying on her back. Two experimenters recorded the infant's eye movements in response to the click. Fifty-two successive trials were undertaken. On 45 of the 52 trials both experimenters were in agreement concerning the eye movement. In 23 of these cases there was no movement. On the remaining 22 trials 18 of the eye-movement responses were in the direction of the click and four in the opposite direction. Thus within 10 minutes after birth auditory localization and a coordinate primitive spatial localization is present in the human infant.

EXPERIMENTAL VARIATION OF THE RELEVANT STIMULATION

The only investigations in this category are those performed by Hess (1950, 1956b, 1961). The earlier study was concerned with the development of depth responses to shading cues. Hess (1950, 1961) reared two groups of 50 chicks under different conditions of illumination. The control chicks were reared in cages illuminated from above. The experimental chicks were reared in cages which were illuminated from below. Thus the two groups experienced different distributions of light and shade. They remained in these cages for a period of 7 weeks after hatching.

The test enclosure was a circular cage illuminated by lights at opposite sides of the enclosure. The test objects were two photographs placed side by side. The photographs showed grains of wheat in their natural coloring but about twice the normal size. One picture was right-side up and the other upside down. In the first experiment chicks were tested at the age of 7 weeks. They were put into the test cage in groups of two to four chicks. First they were permitted to eat a few grains which were fastened vertically on a cardboard. Then the photographic plate was substituted and the chicks' responses to the photographs were recorded for a 10-minute interval. The chicks were then returned to their rearing environments and retested a week later. At that time the illumination in the test cage originated from the direction opposite to that of the light in the rearing cages. Because of the wide range in the number of responses made by individual chicks Hess analyzed the first pecks only. The results were the same for the test and retest. The chicks showed a statistically significant tendency to peck at the photograph representing the distribution of shading consistent with their rearing. For instance, on the retest, 93% of the first pecks made by the control group were made on the photograph showing grain illuminated from above, while only 6.1% of the first pecks of the experimental groups were on that photograph.

The second experiment studied the development of depth responses in the experimental animals. At 1-week intervals beginning at 1 week and continuing to 7 weeks of age, groups of chicks were taken from the rearing cage and tested. The main finding of the experiment was that the establishment of a significant preference for the photograph representing overhead illumination occurred earlier in the control than the establishment of a significant preference for the opposite photograph in the experimental group.

The results of the first experiment show that the chick's responses to light and shade cues can be governed by the direction of lighting in its environment. This does not require the conclusion that no preference would be exhibited in the absence of experience. It may be that an unlearned response to illumination from above exists, but that this innate preference can be extinguished if the environment does not support it. In fact, such may be the implication of the results of the second experiment. If no initial unlearned preference existed then the control and experimental groups should develop a preference with equal rapidity. On the other hand, if the experimental group has an initial preference for illumination from above, then they must unlearn this preference prior to acquiring the new response. This could explain the finding that the experimental group established a significant preference later than the control group.

One incidental finding of this study which warrants notice is that the photographs of grain were responded to as if they were real grains. Apparently, for chicks, pictorial representations yield depth responses in the absence of a history of experience with representations. Although it has been amply demonstrated that human observers may have compelling experiences of depth when presented with photographs (e.g., Smith & Smith, 1961), it is not known whether experience with photographic representations is a necessary condition. A recent study by Hochberg and Brooks (1962) found that a child "is capable of recognizing pictorial representations of solid objects without specific training or instruction [p. 628]." They infer, therefore, "that there must be an unlearned propensity to respond to certain formal features of lines-on-paper [p. 628]." This does not answer our question; however, it does lead to the expectation that similar results will be obtained for depth perception.

In a later study Hess (1956b) examined a more general question: "When an organism first perceives the environment can it accurately see where things are [p. 74]?" Specifically, the experiment attempted to determine whether the chick's ability to localize and peck accurately at objects is innate or learned. Chicks were hatched in darkness and divided into two experimental groups and one control group. The experimental chicks were fitted with hoods containing prisms which displaced the visual field either 7 degrees to the right or 7 degrees to the left. The control chicks were fitted with hoods which did not contain image-displacing lenses. When they were 1 day old the chicks were tested for pecking accuracy. They were allowed to peck at a small brass nail embedded in modeling clay. The clay provided a visual record of the location of the chick's pecks.

The following is the rationale of this procedure. If spatial localization is learned then the early responses of the chick should be randomly distributed in the visual field. Only through practice should the pecks converge upon and finally strike the target. If this is a valid analysis of the development of localization, then the displacing prisms should not affect the development of localization. In terms of this analysis the experimental and control groups both must learn to localize objects through a gradual process of trial and error pecking. On the other hand, if spatial localization is innate then the first pecks of the experimental chicks should cluster about a point 7 degrees to the right or left of the target while the pecks of the control chicks should center about the target. The results agreed with the latter expectations.

Following the test on the first day Hess divided each of the three groups in half. Half of each group was placed in a living enclosure in which grain was scattered loosely on the floor. The other half of each group was placed in a box which contained bowls of mash. When the chicks were 3–4 days old, they were tested again. There was no difference between the two halves of the control group. Both halves showed an increase in accuracy and both were in good physical condition. The two halves of the experimental group also improved their accuracy of pecking. However, their improvement was represented by a tighter cluster 7 degrees to the right or left of the target. The two halves of the experimental groups differed markedly in physical health. The group whose living cage contained bowls of mash was as healthy as the control group. The half whose living cage contained scattered grain only were in poor physical condition. Two of these chicks died on the next day. Hess concluded that spatial localization is innate for the chick and that the chick is unable to unlearn the innate localization of objects even when survival is at stake. A similar absence of adaptation is observed in the persistent spatial disorientation which results from the more dramatic modifications of sensory input produced by surgical procedures (Sperry, 1951, 1958). For example, surgical rotation of the eyes, producing an inverted visual field, leads to mislocalization without any subsequent adaptation.

Conclusion

No simple decision about the genesis of space perception is possible. Nor does it seem likely that a conclusion of general applicability is forthcoming. Instead the trend of the evidence strongly suggests that separate statements will have to be made about each of the various stimulus correlates of depth perception. For example, there is evidence that motion parallax is an unlearned correlate of relative distance while differences in textural density are learned correlates (Walk & Gibson, 1961). This conclusion was clearly anticipated by Carr (1935) in his treatise on space perception:

> There is no single phenomenon or problem of space. It is impossible to make any statement as to the native or empirical nature of space *in general* [p. 5; italics added].

This conclusion poses two questions whose resolution would provide further clarification of the issue. The first concerns the modifiability of innately determined perceptual preferences by later experience. It seems likely that the various stimulus correlates of depth perception will vary in their susceptibility to the modifying influence of special experience. The second question concerns the nature of the learning processes which underlie the formation of associations between specific cues and the concomitant visual experience of depth. This latter question is an extremely difficult one as Pastore (1956) has pointed out in his critique of the empiristic viewpoint. Nevertheless, as evidence is obtained (e.g., Hess, 1950) that certain cues are learned, the need for an analysis of this question becomes compelling.

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