Slant Perception and Shape Constancy in Infants

Abstract. *Three experiments investigated shape constancy in human infants between 50 and 60 days of age. The first showed that such infants possess some capacity for shape constancy. The second confirmed this finding and showed that the capacity is not attained by correlation of perceived projective shape with perceived orientation.*

Earlier (*1*) I presented evidence that human infants between 40 and 70 days of age display some degree of size constancy. The research I now report was designed to discover whether such infants are also capable of shape constancy; the problem is of theoretical interest. Strong empiricist theories of perception (*2*) tend to assume that shape constancy only becomes possible when the organism has become familiar with all possible retinal projections of an object; they assume that one learns how an object looks in various orientations, and that one infers from seeing a recognized "look" of an object that one is seeing that object x in some particular orientation. Obviously these theories would be refuted by any demonstration of shape constancy with infant subjects and unfamiliar shapes. A second major class of theory (*3*), which assumes that shape constancy is attained by correlation of projective or retinal shape with perceived orientation, has not been confirmed with adult subjects (*4*); its adherents claim that this is because by adulthood the correlation process has become so automated that its components cannot be separately reported. If the hypothesis were true, it should surely be demonstrable with infant subjects. My results indicate that 50- to 60-day-old infants do manifest some degree of shape constancy and that it does not result from correlation of perceived projective shape with perceived orientation.

The first experiment used eight infants 50 to 60 days old. The infant under test reclined in an infant seat placed on a brown, wooden table, at 45 deg. His head was clasped between two yielding pads, the left pad containing a microswitch whose closing operated an event recorder placed beneath the table. Immediately before each infant seat an experimenter was stationed beneath a gap in the table. When the event recorder closed, the experimenter emerged and 'peek-a-booed' at the infant. Two meters from each infant's eyes a wooden board, 25 by 50 by 2.5 cm, was placed on a turntable. The board, of unfinished white wood, stood on its long edge, turned 45 deg anticlockwise from the infant's fronto-parallel plane; its center of rotation lay in the infant's medial plane. The room was otherwise unfurnished; the walls were of coarsely textured brick. Illumination was provided by a roof light of the same length as the table, which minimized shadows. The experimenter could introduce a screen between himself and the infant for stimulus changes and rest periods.

During training, the board in the above orientation served as conditioned stimulus (CS); the leftward head movement, as conditioned response (CR); and the "peek-a-boo," as reinforcement. Initially the infants were trained to respond only in the presence of the CS. After this was accomplished, behavior was shaped in daily 30-minute sessions until the infants were working at a rate of one response per 2.0 seconds on a variable-ratio schedule on which every fifth response, on average, was reinforced, the exact interval between reinforcements varying randomly. The training procedure is described in greater detail elsewhere (*1*).

After 1 experimental hour at this level, generalization testing was begun. Four stimuli were presented during testing: (i) the CS in its original 45 deg orientation; (ii) the CS in the fronto-parallel plane; (iii) a trapezoid in the fronto-parallel plane, whose retinal projection was then equal to that of the CS at 45 deg; (iv) this trapezoid at an angle of 45 deg. Each stimulus was presented for four 30-second periods in counterbalanced order. No reinforcement was given during testing. In terms of difference from the CS the four presentations may be classified as follows: (i) no change; (ii) same objective shape, different projective shape, different orientation; (iii) different objective shape, same projective shape, different orientation; (iv) different objective shape, different projective shape, same orientation.

The mean numbers of responses elicited by the four presentations were (i) the CS, 51.00; (ii) the same objective shape in a different orientation, 45.13; (iii) that which projected a retinal shape identical with that of (i), 28.50; and (iv), 26.00. The difference between (i) and (iii) was highly significant ($t = 12.08$; df, 7; $P < .01$). It is obvious that these infants had not learned to respond to a projective or retinal shape but to an objective shape, which could be recognized in a new orientation; to this extent they showed shape constancy. Also in line with this interpretation is the fact that (iii) and (iv) elicited equally few responses ($t = 0.47$; not significant), indicating that they were responded to as if equivalent.

Although this experiment clearly rules out the strong empiricist explanation of shape constancy described above, it is neutral in respect to the second hypothesis: that shape constancy develops out of the correlation of two perceptually prior variables, projective shape and apparent slant. This hypothesis was not confirmed in the following experiment.

Each of nine infants, aged 60 to 63 days after the test, was trained to make a head movement as CR to the rectangle used in experiment 1, presented at a 5-deg anticlockwise orientation, as CS in the manner described above. Behavior was shaped to the same criterion level of responding on a variable-ratio schedule. Then in three successive sessions each infant performed once on each of the following three tasks (see Table 1).

1) The rectangle described was exposed in four orientations, turned 5, 15, 30, or 45 deg anticlockwise. Each orientation was presented 30 times in random order for 5-second periods. Only responses made while the rectangle was at 5 deg from the frontal plane were rewarded, and these were rewarded continuously. Reinforcement time was not included in presentation time, so that several 15-second reinforcements could be obtained during a 5-second presentation.

2) This condition was exactly like the first except that the stimuli used were only projectively equivalent to those used in condition 1. Four trapezoids casting the same retinal image as the rectangle at 5, 15, 30, or 45 deg were all shown in the fronto-parallel plane (*5*).

3) This condition differed from the others in the nature of the stimuli

used. An opaque cardboard screen, 1 by 1 m, was placed 10 cm before the rectangle. An aperture, 10 by 20 cm, was cut in it so that, while the body of the rectangle was visible, its edges were not. Thus only orientation per se was available to differentiate presentations of the rectangle in its four orientations. Order of testing was counterbalanced across infants.

In all conditions only stationary positions of stimuli were ever visible; transitions were never seen. These three conditions were designed to present the infant with, respectively, a form in space (having objective shape, projective shapes, and orientations with only the first invariant); a set of projective shapes with orientation invariant; and finally a set of orientations, with projective shape invariant. The developmental hypothesis being tested asserts that at this stage of development, shape judgments result from deduction from two perceived components, projective shape and orientation. This should mean that discrimination performance, shown by the difference between the numbers of responses elicited by rewarded and unrewarded stimuli, should be best under condition 1, where the infants had both projective shape and orientation as differentiating features. This prediction was not confirmed. Discrimination performance was poorer under condition 1 than condition 2 ($t = 6.06$; $P < .01$) or condition 3 ($t = 4.97$; $P < .01$) (*6*). In fact, examination of performance in condition 1 indicates very little discrimination between the four presentations; only one presentation, the rectangle at 45 deg, was significantly differentiated from the rewarded presentation ($t = 1.08$; $P < .1$).

Table 1. Proportions of responses elicited by rewarded stimulus that were elicited by unrewarded stimuli in the three presentation conditions described in the text.

Condition	Proportion at orientation			
	5°	15°	30°	45°
1	1.0	1.04	0.98	0.90
2	1.0	.70	.64	.55
3	1.0	.86	.78	.77

The putative advantage of the last experiment was that every subject served as his own control. The training conditions and the stimulus situation were such that discrimination in condition 1 should have been easier than in the other two conditions. As I have pointed out, there are two differentiating variables available in condition 1 to only one in conditions 2 and 3.

In addition, all infants were trained with a condition-1 CS, which fact should have facilitated discrimination in condition 1; in fact it did not. This can be interpreted to mean that the subjects showed such a high degree of shape constancy that the same shape in different orientations literally looked the same, or so very similar that discrimination was too difficult to be formed in the time given. However, there are objections to this interpretation: it could be argued that little response strength transferred from training to conditions 2 or 3 because the rewarded stimuli differed so much in the three conditions that the data are not truly comparable. In order to meet this objection a third experiment was run.

Three groups of five infants were each run through one condition of experiment 2. One group was trained with the rectangle at 5 deg as CS; the second, with a projectively equivalent trapezoid in the frontal plane as CS; and the third, with the 5-deg orientation of the surface behind the screen as CS. The groups were equated for total number of reinforcements received. After response rate reached a criterion of one response per 2 seconds, the four stimuli in each condition were each presented for four 30-second periods, in counterbalanced order, without reinforcement, after the paradigm of experiment 1. The results (Table 2) show that significantly more responses were elicited by the novel stimuli in condition 1 than in condition 2 or 3 ($P < .01$ by the *t*-test), whereas there was no significant difference between the numbers of responses elicited by the three CS. If one accepts the basic logic of the generalization experiment, this can only mean that the infants in condition 1 perceived the novel stimuli as more like their CS than did the infants in the other two conditions; that variations in orientation of the same object, with projective shape and orientation variant, and only real shape invariant, produce a higher degree of identity or "sameness" than do variations in projective shape alone, with orientation invariant, or variations in orientation, with projective shape invariant.

Table 2. Mean numbers of responses elicited in experiment 2.

Orientation (deg)	Responses under conditions (No.)		
	1	2	3
5	50	48	56
15	48	40	40
30	46	35	30
45	44	30	31

These three experiments taken together strongly indicate that young humans possess the capacity for shape constancy, the capacity to detect the invariants of shape under rotational transformation in the third dimension. The data of experiments 2 and 3 seem in fact to show that response to a shape invariant is more primary than response to a simple variable such as orientation. In both experiments it was shown that rotation of an object into the third dimension did not produce the response decrement that was produced by rotation of a surface without limiting contours. In the latter case there was of course no shape invariant to respond to.

It thus seems that the capacity-limited perceptual machinery of the infant is set to respond to high-order invariants, and to ignore low-order variables such as orientation, when both are present, so that in these experimental situations it is difficult for the infants to respond to the low-order but differential variable orientation.

The notion that invariants and variables may compete for central access within the perceptual system is useful in the present context: it may also explain the paradox that adult subjects may show perfect shape constancy while hopelessly misjudging orientation, and vice-versa (*7*).

This explanation constitutes a reformulation of the problem of the development of shape constancy; it shifts the emphasis from an attempt to understand how infants learn to compute "real shape" from projective shape and orientation to an attempt to understand how the ability to *simultaneously* register orientation and real shape develops. It shifts the emphasis from development of specific local functions, such as the constancies, to development of a general capacity to simultaneously handle multiple variables and invariants.

This shift may have some merit

in that it points to a resolution of the apparent contradiction between the fact that perceptual capacities undoubtedly do change with age, and the fact that many local functions make their appearance very early in life.

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References and Notes

1. T. G. R. Bower, *Psychon. Sci.* **1**, 365 (1964); *Science* **149**, 88 (1965).
2. H. Helmholtz, *Physiological Optics III* (Optical Society of America, 1935).
3. For example, J. Piaget, *Les Mécanismes Perceptifs* (Presses universitaires de France, Paris, 1962); S. Klimpfinger, *Arch. Ges. Psychol.* **88**, 599 (1933). My discussion and experiments are aimed only at those theories of shape perception that assume that projective shape and perceived orientation precede shape constancy in perceptual development, and that projective shape, orientation, and real shape are separately registrable attributes of an object in space. Some projective shape-slant correlation models are not committed to the position of separate registration.
4. B. Stavrianos, *Arch. Psychol.* **61**, 5 (1944).
5. To ensure that the trapezoids used were pictorially equivalent to the rectangle in its various orientations, the latter was photographed in all four positions, and matte enlargements were pasted on the visible surfaces of the corresponding trapezoids.
6. The sequential testing methods that I used decreased total numbers of responses elicited on successive days without affecting the pattern of responding on any given condition. Therefore numbers of responses elicited by the unrewarded stimuli are expressed as proportions of the numbers elicited by the rewarded stimulus, thus cancelling absolute differences and allowing the pattern to appear clearly.
7. K. Eissler, *Archiv. Ges. Psychol.* **88**, 487 (1933).
8. Supported by the Milton Fund through Harvard University. I thank E. J. Gibson, J. J. Gibson, and H. N. Ricciuti for help and advice.

27 December 1965

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An Examination of "Transfer of Learning" by Nucleic Acid

Abstract. *Nucleic acid extracted from brains of trained animals and injected intraperitoneally into naive animals produced no "transfer of learning" effect on several tasks under many conditions. P^{32}-Labeled RNA was not found in the brain after intraperitoneal administration. Even intraventricular injections of nucleic acid produced no "transfer" effect.*

A recent article (*1*) clearly indicates the excitement currently generated in neurobiology by the discoveries in the field of molecular genetics. As pointed out, the application of such findings to an understanding of some of the long-existing problems of biological memory seems very promising. The research activities of many individuals attest to the current efforts directed toward a grasp of the relationships between nucleic acids, proteins, and biological memory (*2*). There are reports (*3*) that "transfer of learning" effects have been accomplished through the extraction of nucleic acid from the brains of trained animals and its subsequent injection into naive animals. Such a finding would, indeed, seem to furnish the first direct relation between nucleic acids and biological memory. We have used many different testing devices over a wide range of conditions and now report our unsuccessful attempts to find "transfer of learning" effects.

In the first study 20 mice (male Swiss-Webster albino, approximately 60 days of age) were trained on a two-choice brightness discrimination task to swim to the nonpreferred, darker alley. Ten additional animals were trained always to turn left regardless of the light's position. A raised platform in the correct alley allowed the mice to escape from the water (18°C). Each trial began when the platform was submerged, so that the mice were forced to swim to the appropriate one of the two remaining alleys. An error was recorded whenever the "dark-trained" animals entered the lighted alley or the "left-turn" animals entered the right alley. Every animal was given six training trials each day for 11 days. The intertrial interval was 30 seconds. After the training, the dark-trained animals were divided into two groups: group I consisted of ten animals that made no more than one error on the last 18 training trials; and group II consisted of ten animals that made as many as four errors out of the last 18 training trials.

Two groups of dark-trained animals, the left-turn group, and a group of untrained mice were killed, and their brains were quickly removed. The brains from each group were placed in cold phenol containing 0.15M NaCl (1 : 1) and homogenized with a tissue grinder. The aqueous phase was removed after centrifugation, and the nucleic acids were precipitated with two volumes of ethanol. The precipitate was collected by centrifugation and dried in a stream of air. The total nucleic acid collected for each group was then resuspended in 2.0 ml of 0.15M NaCl (*4*). A group of ten test animals served as recipients of each extract; each animal received intraperitoneal (I.P.) injections of 0.2 ml of the appropriate preparation. Ten mice were injected with 0.15M NaCl to serve as additional controls. In this and subsequent studies all animals were coded at the time of injection, and testing was completed without knowledge of the animals' prior treatments.

Eighteen hours after injection, the spontaneous activity of each animal was determined automatically for a 2-minute test interval. The activity was tested in a rectangular apparatus with a floor of metal plates that, when bridged by a mouse, activated an electromagnetic counter. Two hours later, the experimental animals were given six trials in the water maze with the same procedures described. The activity measures and the discrimination tests are presented in Table 1*A*. There were no significant differences between any of the experimental groups on either of the two behavioral measures.

Since the preceding study failed to produce any evidence of "transfer of learning," the extraction procedure was altered slightly to follow more closely one procedure reported to have given "transfer of learning" effects (*3*). This involved the addition of $MgCl_2$ to the nucleic acid before precipitation (*5*). Male Swiss-Webster mice were trained in the water "Y" maze. The procedures were the same as described except that all 20 mice were given six trials on a light-dark discrimination daily for 7 days. By the end of training, none of the trained animals had committed more than one error out of the last 12 trials. The mice were divided into two matched performance groups of ten animals each. A group of ten naive mice was also used. The brains were removed and processed in the usual manner, except that for the extraction of the brains of the naive group and one trained group, ethanol plus 0.1M $MgCl_2$ was used for precipitation (*3*). All of the resulting precipitates were resuspended in 0.15M NaCl to a final volume of 5 ml. The ten animals in each of the three groups injected (I.P.) with nucleic acid and the group injected with 0.15M NaCl were tested for a 2-minute spontaneous-activity sample 15 hours after injections. At 16 hours after the injections, all animals were