sure toward low G + C content in environments not subjected to ultraviolet radiation, but the nature of this pressure remains an open question.

Note added in proof: A recent report on the sunlight sensitivity of the yeast *Saccharomyces cerevisiae* (*33*) adds support to our argument. Yeast is killed by sunlight, but is enormously more sensitive if a mutant lacking the excision repair system is used: thus DNA is the target. The bulk of the damage is pyrimidine dimers as shown by the fact that a double mutant lacking both excision repair and photorepair is much more sensitive to sunlight than the excision repair mutant alone.

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Attention and Psychological Change in the Young Child

Analysis of early determinants of attention provides insights into the nature of psychological growth.

Jerome Kagan

One of the great unanswered psychological questions concerns the mechanisms responsible for the transformations in organization of behavior and cognitive structure that define growth and differentiation. Until recently most of these changes were viewed as the product of learning. The child was presumably born unmarked, and the imposing hand of experience taught him the structures that defined him. Hence, many behavioral scientists agreed that learning was the central mystery to unravel, and conditioning was the fundamental mechanism of learning. There is a growing consensus, however, that conditioning may be too limited a process to explain the breadth and variety of change characteristic of behavioral and psychological structures. What was once a unitary problem has become a set of more manageable and theoretically sounder themes.

Category of Change

It is always desirable to categorize phenomena according to the hypothetical processes that produced them. But since psychology has not discovered these primary mechanisms, it is often limited to descriptive classifications. One category includes alterations in the probability that a stimulus will evoke a given response, which is a brief operation-

The author is professor of developmental psychology at Harvard University, Cambridge, Massachusetts 02138.

al definition of conditioning. Half a century of research on the acquisition of conditioned responses has generated several significant principles, some with developmental implications. It is generally true, for example, that the acquisition of a conditioned response proceeds faster as the child matures (*1*). Although the explanation of this fact is still not settled, it is assumed that, with age, the child becomes more selectively attentive and better able to differentiate the relevant signal from background noise. Thus a newborn requires about 32 trials before he will turn his head to a conditioned auditory stimulus in order to obtain milk; a 3-month-old requires about nine trials (*2, 3*).

A second category of change refers to the delayed appearance of species-specific behaviors after exposure to a narrow band of experience. A bird's ability to produce the song of its species (*4*) or a child's competence with the language of his community (*5*) requires only the processing of particular auditory events, with no overt response necessary at the time of initial exposure. The environment allows an inherited capacity to become manifest. Close analysis indicates that the development of these and related behaviors does not seem to conform to conditioning principles, especially to the assumption that the new response must occur in temporal contiguity with the conditioned stimulus. This class of phenomena suggests, incidentally, the value of differentiating between the acquisition of a disposition to action and the establishment of and successive changes in cognitive structures not tied directly to behavior. This distinction between behavioral performance and cognitive competence is exemplified by the difference between a child's learning to play marbles and his ability to recognize the faces of the children with whom he plays.

A third category of change, and the one to which this essay is primarily devoted, involves the initial establishment and subsequent alteration of representations of experience, called schemata (singular: schema). A schema is a representation of experience that preserves the temporal and spatial relations of the original event, without being necessarily isomorphic with that event. It is similar in meaning to the older term "engram." Like the engram, the construct of schema was invented to explain the organism's capacity to recognize an event encountered in the past. Although the process of recognition is not clearly understood, the neurophysiologist's suggestion that a cortical neuronal model is matched to current experience captures the essential flavor of the concept (*6*). It is important to differentiate between the notion of schema as a representation of a sensory event and the hypothetical process that represents the organism's potential action toward an object. Piaget (*7*) does not make this differentiation as sharply as we do, for his concept of *sensory-motor scheme* includes the internal representation of the object as well as the organized action toward it.

There is some evidence that some form of primitive representation of experience can be established prior to or soon after birth. Grier, Counter, and Shearer (*8*) incubated eggs of White Rock chickens (*Gallus gallus*) from 12 to 18 days under conditions of quiet or patterned sound. Within 6 hours after hatching, each chick was tested for responsiveness to two auditory stimuli, the 200-hertz tone presented prenatally and a novel 2000-hertz sound. The control chicks moved equivalent distances toward both sounds; the experimental chicks moved significantly closer to the 200-hertz sound than to the novel one. Similarly, infant laughing gulls (*Larus atricilla*) 6 to 13 days old seem able to form representations of their parents' calls, for they orient toward and approach the calls of their own parents but orient away from the calls of other adult gulls (*9*).

A central assumption surrounding early schema formation states that the first schemata represent invariant stimulus patterns that are part of a larger context characterized by high rate of change (movement, contour contrast, and acoustic shifts). Hence a schema for the human face should develop early, for the face is characterized by an invariant arrangement of eyes, nose, and mouth within a frame that moves and emits intermittent, variable sounds. Experimental observations of young infants suggest that the face is one of the earliest representations to be acquired. Since the establishment of a schema is so dependent upon the selectivity of the infant's attention, understanding of developmental priorities in schema formation should be facilitated by appreciation of the principles governing the distribution of attention. These principles will be considered in the sections that follow.

Contrast, Movement, and Change

Ontogenetically, the earliest determinant of duration of orientation to a visual event is probably inherent in the structure of the central nervous system. The infant naturally attends to events that possess a high rate of change in their physical characteristics. Stimuli that move, have many discrete elements, or possess contour contrast are most likely to attract and hold a newborn's attention. Hence, a 2-day-old infant is more attentive to a moving or intermittent light than to a continuous light source; to a solid black figure on a white background than to a stimulus that is homogeneously gray (*10, 11*). The newborn's visual search behavior seems to be guided by the following rules (*12*):

If he is alert and if light is not too bright, his eyes open up.

If his eyes are open but no light is seen, he searches.

If he sees light but no edges, he keeps searching.

If he sees contour edges, he holds and crosses them.

The preference for the study of contour is monitored, however, by the area of the stimulus field, and there seems to be an optimum amount of contour that maintains attention at a maximum. Four-month-old infants exposed to meaningless achromatic designs with variable contour length were most attentive to those with moderately long contours (*13*). Karmel (*14*) has reported that, among young infants, duration of attention to meaningless achromatic figures is a curvilinear function of the square root of the absolute amount of black-white border in the figure.

The behavioral addiction to contour and movement is in accord with neurophysiological information on ganglion potentials in vertebrate retinas. Some cells respond to movement; others, to onset of illumination, to offset, or to both. Objects with contour edges should function better as onset stimuli than do solid patterns, because the change in stimulation created by a sharp edge elicits specialized firing patterns that may facilitate sustained attention (*15*).

There is some controversy over the question of whether contour or complexity exerts primary control over attention in the early months, where complexity is defined in terms of either redundancy or variety or number of elements in the figure and where contour is defined in terms of the total amount of border contained in the arrangement of figures on a background. Existing data support the more salient role of contour over complexity. McCall and Kagan (*13*) found no direct relation, in 4-month-olds, between fixation time and number of angles in a set of achromatic meaningless designs. Rather, there was an approximate inverted-U relation between attention and total length of contour in the figure. Similarly, fixation time in 5-month-old infants was independent of degree of asymmetry and irregularity in the arrangement of nine squares; however, when these indices of complexity were held constant but area and amount of contour were varied, fixation times were a function of contour (*16*). Finally, the average evoked cortical potentials of infants to checkerboard and random matrix patterns were independent of redundancy of pattern, but they displayed an inverted-U relation with density of contour edge (*17*).

Although indices of attention to auditory events are considerably more ambiguous than those used for vision, it appears that stimuli that have a high rate of change, such as intermittent sounds, produce more quieting and, by inference, more focused attention than continuous sounds (*18*). Nature has apparently equipped the newborn with an initial bias in the processing of experience. He does not, as the 19th-century empiricists believed, have to learn what he should examine. The preferential orientation to change is clearly adaptive, for the locus of change is likely to contain the most information about the presence of his mother or of danger.

Discrepancy from Schema

The initial disposition to attend to events with a high rate of change soon competes with a new determinant based largely on experience. The child's attentional encounters with events result, inevitably, in a schema. Somewhere during the second month, duration of attention comes under the influence of the relation between a class of events and the infant's schema for that class. One form of this relation, called the discrepancy principle, states that stimuli moderately discrepant from the schema elicit longer orientations than do either minimally discrepant (that is, familiar) events or novel events that bear no relation to the schema. The relation between attention and magnitude of discrepancy is assumed to be curvilinear (an inverted U). Although an orientation reflex can be produced by any change in quality or intensity of stimulation, duration of sustained attention is constrained by the degree of discrepancy between the event and the relevant schema. Consider some empirical support for the discrepancy principle.

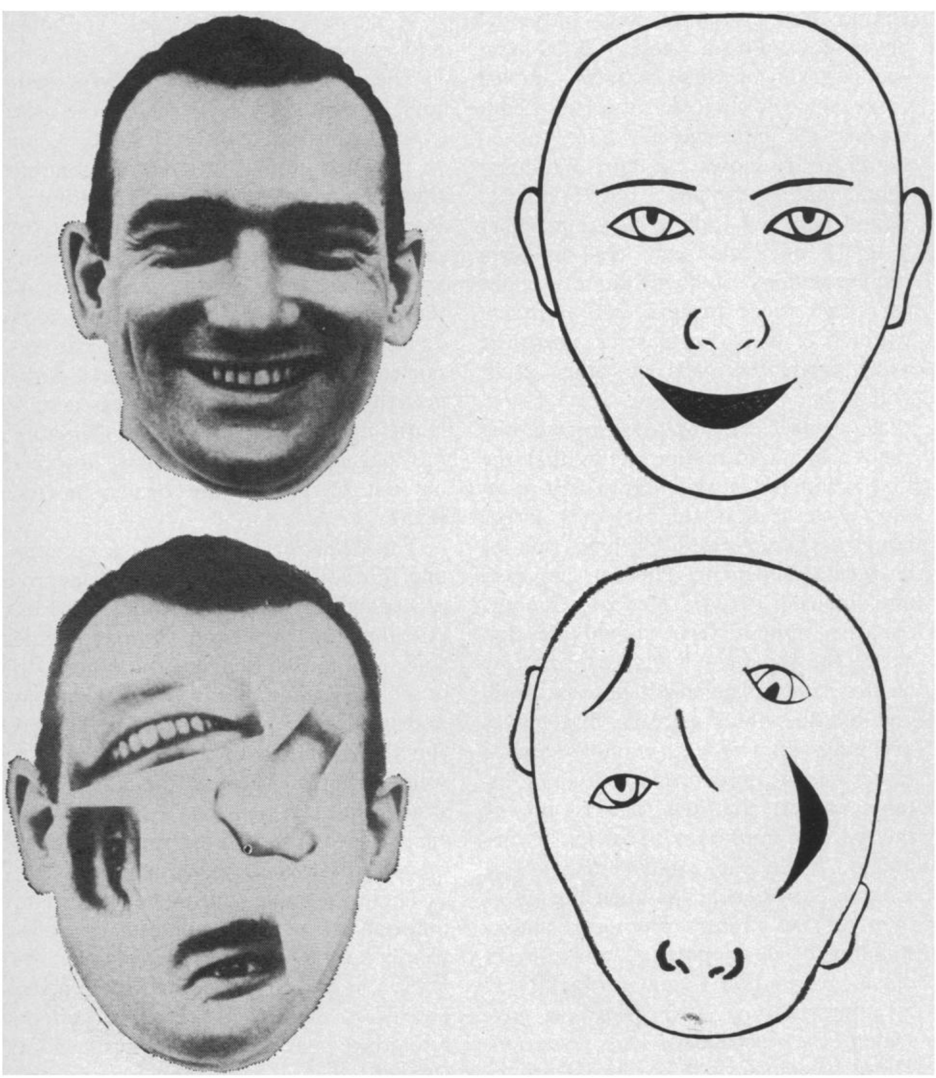


Fig. 1. Achromatic representations of four facelike stimuli shown to infants.

One-week-old infants show equivalent fixations to an achromatic representation of human faces (see Fig. 1) and a meaningless achromatic design, for contour is assumed to be the major determinant of attention at this early age. Even the 8-week-old shows equivalent fixations to a three-dimensional representation of a face and an abstract three-dimensional form (*19*). But a 4-month-old shows markedly longer attention to the regular achromatic face than to the design (*13*), presumably because he has acquired a schema for a human face and the laboratory representation is moderately discrepant from that schema. If the representation of the face is too discrepant, as when the facial components are rearranged (see Fig. 1), fixation times are reduced (*20, 21*).

Fixation times to photographic representations of faces drop by over 50 percent after 6 months and are equivalent to both regular and irregular faces during the last half of the first year (*20, 21*). This developmental pattern is in accord with the discrepancy principle. During the opening few weeks of life, before the infant has established a schema for a human face, photographs of either regular or irregular faces are so discrepant from the infant's schema that they elicit equivalent epochs of attention. As the schema for a human face becomes well established, between 2 and 4 months, the photograph of a strange face becomes optimally discrepant from that schema. During the latter half of the first year, the face schema becomes so well established that photographs of regular or irregular faces, though discriminable,

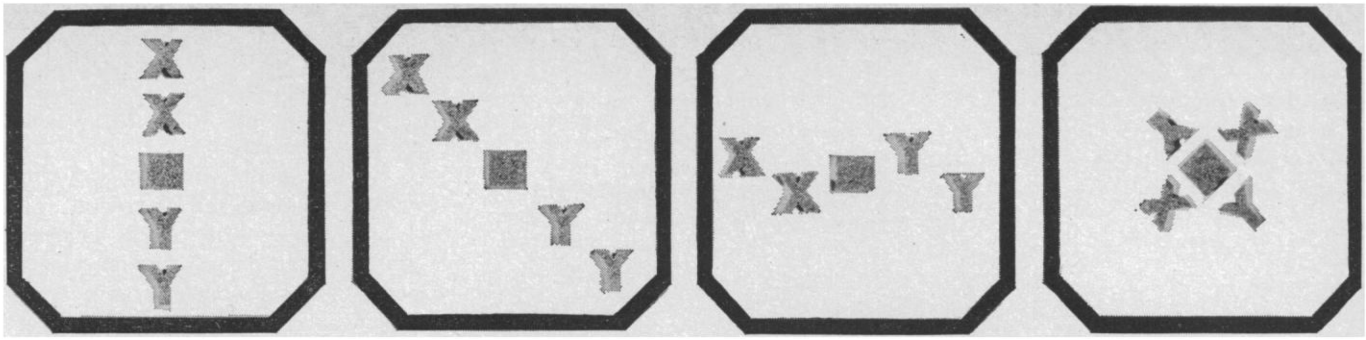


Fig. 2. Standard (far left) and three transformations shown to infants in study of reaction to discrepancy.

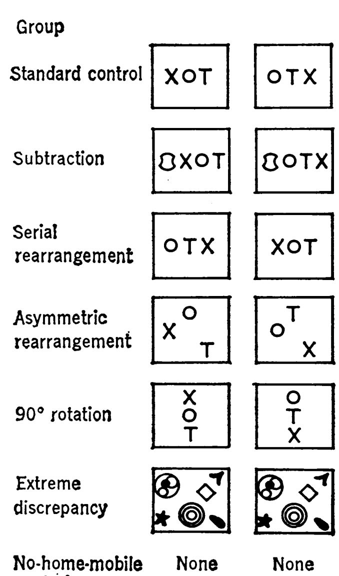
are easily assimilated and elicit short and equivalent fixations.

A second source of support for the discrepancy principle comes from research designs in which familiarity and discrepancy are manipulated through repeated presentation of an originally meaningless stimulus, followed by a transformation of the standard. Fixation times are typically longer to the transformation than to the last few presentations of the habituated standard (*22*). For example, 4-month-old infants were shown three objects in a triangular arrangement for five repeated trials. On the sixth trial, infants saw a transformation of the standard in which one, two, or three of the original objects were replaced with new ones. Most infants displayed longer fixations to the transformation than to the preceding standard. When the analysis was restricted to the 42 infants who displayed either rapid habituation or short fixations to the last four presentations of the standard trials 2 through 5), an increasing monotonic relation emerged between amount of change in the standard (one, two, or three elements replaced) and increase in fixation from the last standard to the transformation (*23*).

Although fixation time cannot be used as an index of sustained attention to auditory stimuli, magnitude of cardiac deceleration, which covaries with motor quieting, provides a partial index of focused attention. Melson and McCall (*24*) repeated the same eight-note ascending scale for eight trials to 5-month-old girls; this repetition was followed by transformations, in which the same eight notes were rearranged. The magnitude of cardiac deceleration was larger to the discrepant scale than to the preceding standard. The curvilinear form of the discrepancy principle finds support in an experiment in which 5½-month-old male infants were shown a simple stimulus consisting of five green, three-dimensional elements arranged vertically on a white background (far left in Fig. 2). The order of stimulus presentation was SSSSSS-SSTSSTSSTS, in which S was the standard and T was one of three transformations of differing discrepancy from the standard. Each infant was shown only one of the three transformations in Fig. 2. The magnitude of cardiac deceleration was larger to the moderate transformation of the standard (oblique arrangement of the five elements in Fig. 2, second from left) than to the two more serious transformations (*22*). This finding is partially congruent with an earlier study on younger infants that used the same stimuli but established the schema over a 4-week period. The girls, but not the boys, displayed larger decelerations to the transformations than to the standard (*25*).

The most persuasive confirmation of the curvilinear relation between attention and discrepancy was revealed in an experiment in which firstborn, 4-month-old infants were shown a three-dimensional stimulus composed of three geometric forms of different shape and hue for 12 half-minute presentations (*26*). Each infant was then randomly assigned to one of seven groups. Six of these groups were exposed to a stimulus at home that was of varying discrepancy from the standard viewed in the laboratory. The seventh was not exposed to any experimental stimulus. The mother showed the stimulus to the infant, in the form of a mobile above his crib, 30 minutes a day for 21 days. The seven experimental groups are summarized in Fig. 3.

Three weeks later each subject returned to the laboratory and saw exactly the same stimulus he viewed initially at the age of 4 months. The major dependent variable was the *change in fixation time* between the first and second test sessions. Figure 4



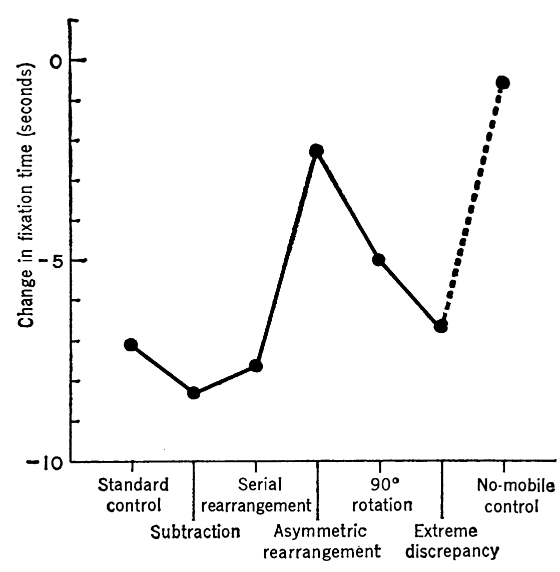


Fig. 3 (left). Summary of the home mobile conditions of the seven experimental groups. The drawings illustrate in schematic form the stimulus to which each child was exposed at home. Fig. 4 (right). Change in mean total fixation time across the two test sessions for each of the seven experimental groups.

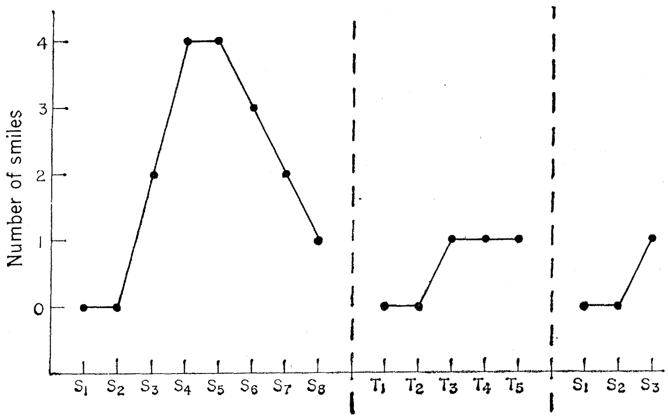


Fig. 5. Frequency of smiling to the light episode for a 7½-month-old girl (*S*, standard presentation; *T*, transformation).

illustrates these change scores for total fixation time across the first six trials of each session.

The infants who saw no mobile at home showed no change in fixation time across the 3 weeks, which indicates that the laboratory stimulus was as attractive on the second visit as it had been on the first. The infants who had an opportunity to develop a schema for the asymmetric and vertical rotation mobiles and, therefore, could experience a moderate discrepancy on the second visit, showed the smallest drop in attention across the 3 weeks. By contrast, the infants who experienced a minor or major discrepancy showed the greatest drop in interest ($F = 5.29$, $P < .05$). There was a curvilinear relation between attention and stimulus-schema discrepancy.

The incidence of smiling to familiar and discrepant stimuli also supports the discrepancy principle. It is assumed that the infant is likely to smile as he assimilates an initially discrepant event (*7*). Hence, very familiar and totally novel stimuli should elicit minimum smiling, whereas moderately discrepant events should elicit maximum smiling. The smile to a human face or a pictorial representation of a face during the first 7 months is most frequent at 4 months of age among infants from varied cultural settings (*27*). It is assumed that, prior to 4 months, the human face is too discrepant to be assimilated, and after this time it is minimally discrepant and easily assimilated. The smile of assimilation is not restricted to human faces. Three different auditory stimuli (bronze bell, toy piano, and nursery rhyme played by a music box) were presented to 13-week-old infants in two trial blocks on each of 2 successive days (*28*). Frequency of smiling was lowest on the first block of trials on day 1, when the sounds were novel, and on the second block on day 2, when they had become very familiar, but highest on the two intermediate blocks, when the infant presumably was able to assimilate them after some effort.

A final illustration of the display of the smile as a sign of assimilation comes from a study in progress in which 60 children, 5½ to 11½ months old, watched a hand slowly move an orange rod clockwise in an arc until it contacted a set of three differently colored light bulbs. As the rod touched one of the lights, all three turned on. This 11-second sequence was repeated eight or ten times (depending upon the age of the child) during which most children remained very attentive. Each child then saw only one of four transformations for five successive trials: (i) the bulbs did not light when the rod touched them, (ii) the hand did not appear, (iii) the rod did not move, or (iv) no hand appeared and no bulbs lit, but the rod moved. After the fifth presentation, the original sequence was repeated three more times. The proportion of infants who smiled was largest on the sixth repetition of the standard and on the third presentation of the transformation. Figure 5 illustrates the pattern of smiling to this episode for one 7½-month-old girl who displayed maximum smiling on trials 4 and 5 of the initial familiarization series and trials 3, 4, and 5 of the transformation series, during which the hand did not appear. Thus both duration of fixation and probability of smiling seem to be curvilinearly related to degree of discrepancy between an event and the child's schema for that event. Moreover, the child seems to become most excited by moderately discrepant events that are perceived as transformations of those that produced the original schema. If the infant does not regard a new event as related to a schema, he is much less excited by it. To illustrate, 72 infants, 9½ and 11½ months old, were exposed to one of two different transformations after six repeated presentations of a 2-inch (5-cm) wooden orange cube. The infants exposed to the novel event saw a yellow, rippled, plastic cylinder differing from the standard in color, size, texture, and shape. The infants exposed to the moderate transformation saw a 1-inch (2.54-cm) wooden orange cube, in which only size was altered. Almost half (43 percent) of the females in the moderate group displayed an obvious increase in vocalization when the smaller cube appeared, suggesting they were excited by this transformation. By contrast, only one female exposed to the novel yellow form showed increased vocalization, and most showed no change at all ($P < .05$). There was no comparable difference for boys.

The onset of a special reaction to discrepancy at about 2 months may reflect the fact that structures in the central nervous system have matured enough to permit long-term representation or retrieval of such representations. It is probably not a coincidence that a broad band of physiological and behavioral phenomena also occur at this time. The latency of the visual evoked potential begins to approach adult form, growth of occipital neurons levels off, alpha rhythm becomes recognizable (*29*), the Moro reflex begins to disappear, habituation to repeated presentations of a visual event becomes a reliable phenomenon (*30*), and three-dimensional representations of objects elicit longer fixations than two-dimensional ones (*11*).

Activation of Hypotheses

Two empirical facts require the invention of a third process that influences attention and, subsequently, produces change in cognitive structures. The relation between age and fixation time to masklike representations of a human face (see Fig. 6) decreases dramatically across the period from 4 to 12 months, but it increases, just as dramatically, from 12 to 36 months (*21*). If discrepancy from schema exerted primary control over attention, increased fixation times after 1 year should not have occurred, for the masks should have become less discrepant with maturity. Furthermore, educational level of the infant's family was independent of fixation time prior to 1 year but was positively correlated

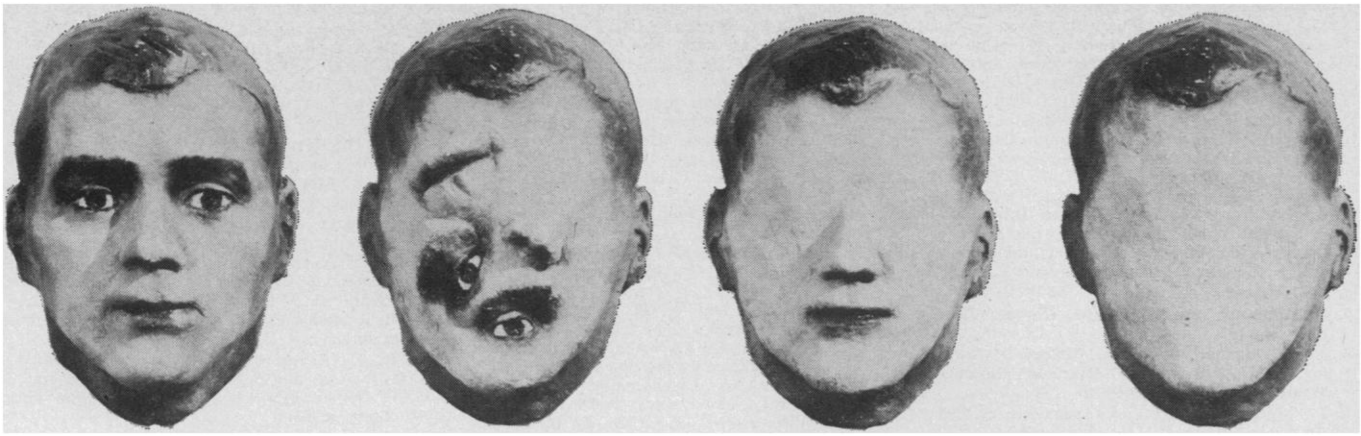


Fig. 6. Facelike masks shown to infants from 4 to 36 months of age.

with fixation time (correlation coefficient of 0.4) after 1 year (*21*). These data suggest the potential usefulness of positing the emergence of a new cognitive structure toward the end of the first year. This structure, called a *hypothesis*, is the child's interpretation of a discrepant event accomplished by mentally transforming it to a form he is familiar with, where the "familiar form" is the schema. The cognitive structure used in the transformation is the hypothesis.To recognize that a particular sequence of sounds is human speech rather than a series of clarinet tones requires a schema for the quality of the human voice. Interpretation of the meaning of the speech, on the other hand, requires the activation of hypotheses which, in this example, are linguistic rules. The critical difference between a schema and a hypothesis is analogous to the difference between the processes of recognition and interpretation and bears some relation to Piaget's complementary notions of assimilation and accommodation (*7*).

It is assumed that the activation of hypotheses to explain discrepant events is accompanied by sustained attention. The more extensive the repertoire of hypotheses, the longer the child can work at interpretation and the more prolonged is his attention. The interaction between discrepancy and the activation of hypotheses is illustrated in the pattern of fixation times of 2-year-olds to four related stimuli: a doll-like representation of a male figure; the same figure with the head placed between the legs; the same figure with the head, arms, and legs rearranged in an asymmetric pattern; and an amorphous free form of the same color, size, and texture as the other three. Duration of fixation was significantly longer to the two moderately discrepant forms (8.5 seconds) than to the regular figure (7 seconds) or to the free form (5.5 seconds) (*21*).

In sum, events that possess a high rate of change, that are discrepant from established schemata, and that activate hypotheses in the service of interpretation elicit the longest epochs of attention. These events are most likely to produce changes in cognitive structures, for the attempt to assimilate a transformation of a familiar event inevitably leads to alterations in the original schema.

Summary

This article began by suggesting that different processes are likely to mediate alterations in behavior and cognitive structure and that conditioning principles do not seem sufficient to explain all the classes of change. Although the acquisition of conditioned responses, the potentiation of inborn capacities, and the establishment of schemata probably implicate different processes, all three involve selective attention to sensory events, whether these events function as conditioned stimuli, releasers of innate response dispositions, or the bases for mental representations. Hence, better understanding of the forces that control selectivity and duration of attention should provide insights into the nature of psychological growth, especially the lawful alterations in cognitive structure that seem to occur continually as a function of the child's encounter with discrepant events. The heart of this article was devoted to this theme. It was argued that events that possessed a high rate of change in their physical characteristics, that were moderately discrepant from established schemata, and that activated hypotheses in the service of assimilation had the greatest power to recruit and maintain attention in the young child.

Unfortunately, quantification of the fragile process of attention is still inelegant, for an infant displays a small set of relatively simple reactions to an interesting event. The infant can look at it, vocalize, be quiet, thrash, smile, or display changes in heart rate, respiration, or pattern of electrocortical discharge. Each of these variables reflects a different aspect of the attention process. Fixation time provides the clearest view and seems controlled by movement, contour, discrepancy, and the activation of hypotheses. Smiling seems to reflect the state that follows effortful assimilation. Cardiac deceleration occasionally accompanies attention to discrepant events, but not always, and vocalization can index, among other things, the excitement generated by a stimulus that engages a schema. It is important to realize, however, that a specific magnitude for any of these responses serves many different forces. The future mapping of these magnitudes on a set of determinants will require a delicate orchestration of rigorous method, ingenious theory, and a keen sensitivity to nature's subtle messages.

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Science **167**, 1273 (197 A. J. Neuringer, *ibid.* **166**, 399 (1969)]. One interpretation of this phenomenon assumes that when an organism is alerted or aroused, for whatever reason, he issues those responses that are prepotent in that context. This view is congruent with the demonstration that intracranial stimulation of the hypothalamus elicits behaviors appropriate to the immediate situation [E. S. Valenstein, V. C. Cox, J. W. Kakolewski, *Psychol. Rev.* **77**, 16 (1970)]. If food is available, the rat eats; if water, he drinks; if wood chips, he gnaws. Intracranial stimulation, like transfer from the home to the experimental chamber, alerts the animal, and prepotent behavior is activated.
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NEWS AND COMMENT

Higher Education: Administration Silent on Institutional Aid

"[An] educational format appropriate for an elite may not be appropriate for a country in which over 50 percent of our youth are now enrolling in college. . . . The most basic issue for us today is not what do our institutions of higher education require, but what kind of higher education does our society require?" —From a speech by Elliot L. Richardson, Secretary of Health, Education, and Welfare, before the National Association of State Universities and Land-Grant Colleges (NASULGC), 11 November 1970.

"A commitment to educate massive numbers of new students [as made by *President Nixon last March*] *is meaningless which does not accept the responsibility to provide the dormitories, classrooms, laboratories, and faculty necessary to do the job. . . . Sooner or later, the federal government will have to undertake an adequate program of institutional aid."*—From a position paper adopted by NASULGC.

The Nixon Administration, a target of much of the campus unrest over the past 2 years, now seems inclined to take a long, philosophical look at the objectives of higher education. And, while the Administration has been advocating a massive new loan program to put post–high school education within reach of the poor, it is also urging greater educational "diversity" and more "career" education. Some students will resentfully, but perhaps accurately, regard this as code language meaning that many of them should stop thinking about room at the top, or anywhere near it, and should go into vocational rather than academic studies.

A college degree continues to be regarded as a ticket to the good life, but increasing numbers of students are either being denied admission to public institutions for lack of space or are finding the price too stiff to pay. Last week in Washington, spokesmen for NASULGC, which was holding its annual meeting, noted that this fall NASULGC institutions had to turn away nearly 90,000 qualified applicants. Moreover, about half of the institutions belonging to NASULGC's sister organization, the American Association of State Colleges and Universities, also had had to reject some qualified applicants.

And, besides lack of space, there was the problem of rising costs. "Universities have been forced to increase fees or tuition rates—approximating a doubling in 10 years—to a point where it is increasingly difficult for students from middle and lower income families to afford to go to college," said Richard A. Harvill, outgoing president of NASULGC and president of the University of Arizona. "This is the central problem facing our universities today," he added. "The land-grant institutions and the other state universities were established to make higher education available to the masses of the people. At this critical juncture in our national life, we cannot price educational opportunity out of their reach . . . [and] we cannot expect our young people to go heavily into debt and be faced with the burden of repayments at the time of life when level of earnings make them least able to repay." NASULGC is afraid that the establishment of a large new federal program of student loans would, unless coupled with a broad-based program of institutional support, be used to justify making students pay the full cost of their education.

The Association supports a proposal by Representative George P. Miller (D–Calif.), chairman of the House Committee on Science and Astronautics, to have the National Science Foundation make institutional support grants. For the first year an appropriation of $400 million would be authorized for this program; for the years thereafter, the authorization would equal 20 percent of all funds allocated by federal agencies for the support of