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LEVELS IN THE DEVELOPMENT OF VISUAL - MOTOR BEHAVIOR

by

IRIS McGUIRE

A dissertation submitted to the Graduate
Faculty in Psychology in partial fulfillment
of the requirements for the degree of Doctor
of Philosophy, The City University of New
York

1976

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

January 29, 1976
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Chairman of Examining Committee

January 29, 1976
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Abstract

LEVELS IN THE DEVELOPMENT OF VISUAL-MOTOR BEHAVIOR

by

Iris McGuire

The development of visual-motor behavior in early infancy was examined by testing three hypotheses derived from Schneirla's Bi-phasic Approach-Withdrawal Theory. These hypotheses were used to predict age-related changes in the determination of finger movements made by infants from 10 to 25 weeks old in response to visual stimuli that varied in size, illumination and distance from the subject. The hypotheses were:

1. That amount of stimulation (effective intensity) would be a major determiner of the finger movements of younger infants (10 to 15 weeks), but not of older infants (20-25 weeks);

2. That the direction of the younger infants' finger movements would be related to the intensity of the stimuli to which they were exposed, with extension (approach) occurring to weak visual stimuli and flexion (withdrawal) to more intense stimuli; and

3. That size, brightness and distance of visual stimuli would be additive in their contributions to the total effective level of stimulation that determined the responses of the younger infants.

To test these hypotheses, fifteen infants were shown a rotating cone-shaped object and their finger movements were observed. There were two levels each of size, distance and illumination of the cone, with eight possible combinations: near-large-bright, near-large-dim, near-small-bright, near-small-dim, far-large-bright, far-large-dim, far-small-bright and far-small-dim. A predetermined random sequence including all four combinations of brightness and size and a catch trial (no stimulus) presented twice in the near and twice in the far position was repeated for each subject until ½-hour elapsed. Infants were tested only in a quiet, alert state and testing stopped if the subject became fussy or began to cry.

Since different numbers of trials were completed by each subject, ratio scores (number of extensions over total number of flexions and extensions) were used to analyze the results. A 2x2x2x2 analysis of variance (with Age, Size, Distance and Illumination the factors) indicated significant main effects of age and size, a significant age x size interaction and a significant 4-way interaction. The mean extension ratios for each age group to stimuli grouped according to differences in size, size-and-distance, size-and-illumination, distance-and-illumination, and distance-size-and-illumination indicated: 1. The older infants had higher extension ratios to all stimuli than did the younger infants; 2. Both groups had higher extension ratios to smaller

than to larger stimuli. However, the size effect was greater for the younger than for the older infants; and 3. When the responses to the various dimension combinations were examined, the extension ratios of the younger infants were found generally to follow an intensity gradient, with highest extension ratios to the least intense stimuli, lower ratios to the intermediate stimuli, and lowest extension ratios to the most intense stimuli. The extension ratios of the older infants were high to all stimuli, displaying no intensity-related gradient.

These results were discussed in terms of a levels approach to understanding developmental changes in early infancy. The directional responses of the younger infants were considered to be low-level, intensity-determined, and consistent with the A-W Hypothesis that there would be approach toward effectively weak stimuli and withdrawal from effectively intense stimuli. Finally, the effects of size, distance and illumination were considered additive in their contributions to the total intensity which determined the younger infants' directional responses.

Implications of these findings for the interpretation of studies of infant visual fixation were discussed, and a mechanism which might account for the transition from early intensity-determined to more complexly-determined response patterns was suggested.

PREFACE

This thesis is concerned with the development of visual-motor behavior from the viewpoint of a comparative-developmental psychology. It has grown out of an interest in the evolution and development of perceptual-motor patterns and from a belief that analysis of the similarities and differences observed in the behavior patterns of animals at different phyletic levels, and at different stages of development within those levels, can lead to an understanding of mechanisms basic to adaptation and adjustment.

The comparative approach which provides the conceptual background for this study comes primarily from the writing of T.C. Schneirla and his students, although the work of Heinz Werner and others has also had an influence. Because the theoretical foundation is central to understanding why and how this study was done, an extensive account of Schneirla's approach to the study of development is included. First, other approaches to the study of visual-motor development will be discussed. Then Schneirla's approach will be examined in detail and hypotheses derived from this approach will be applied to the investigation of visual-motor responses in human infants.

There are a number of people without whom this project would never have been completed. They include Dr. Gerald Turkewitz, my advisor, who provided the inspiration for the study, as well as the initial design of the apparatus. I thank him for always contributing just the right combination of guidance, understanding and encouragement to provide an effective level of stimulation necessary to elicit my approach to this project and keep me from reaching a withdrawal threshold.

I am also grateful to Drs. Ethel Tobach and H. Philip Zeigler for serving on the supervisory committee and to Drs. Richard Held and Lila Ghent-Braine for serving as outside readers of the manuscript.

For help with the statistical analyses, I am grateful to Drs. John Van Laer and Howard McGuire; and for scoring many hours of videotapes I am especially grateful to Barbara Ritter, Cecelia Daum, Gerald Turkewitz, Steven Atwood, Judith Gardner and David Lewkowicz. Ruth Laut and Carole Weiner are thanked for tabulating data, and Skip McGuire is acknowledged for his drawings of the test chamber and his constructive comments on its construction. Special thanks also go to Holly Ruff, Katherine Lawson and Judith Gardner for their helpful criticisms of the manuscript. Finally, I am grateful to all the parents who participated in this project by bringing their infants to be observed.

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Chapter I

Introduction:

Approaches to the Study of Visual-Motor Development

Philosophical Roots

Since Darwin, there has been considerable interest in how organisms interact with their environments in the evolution of certain structural and functional capacities. The emergence of man as a tool-maker and possessor of material culture has been in part attributed to the evolution of the hand, with its tactually sensitive fingertips and opposable thumb (Campbell, 1966; Washburn, 1960; Washburn and Avis, 1959). The suggestion has also been made that the appearance of the precision grip permitted manipulation and investigation of objects in a way that was not previously possible, creating selective pressures which led to the evolution of a larger brain and expanded perceptual and cognitive capacities (Campbell, 1966; Washburn and Avis, 1959).

While the relationship between perceptual and motor functioning in the evolution of man has been acknowledged, the reciprocal nature of this relationship has not been particularly emphasized. Consequently, although some attention has been given to the role that motor behavior may play in the development of perception, relatively little attention has been given to the role that sensory processes may play in the initiation and development of motor behavior.

Although they were not concerned with the origins of motor behavior, the British empiricist philosophers did devote considerable thought to the role that experience with the environment plays in the development of visual perception. In his earliest work (1709), Berkeley suggested that visual perception of space and objects is not innate, but comes as the result of visual association with tactile, kinesthetic and proprioceptive experience. Since certain aspects of the logic underlying Berkeley's position are still current, they will be considered here.

In his <u>Essay Towards a New Theory of Vision</u> (1709), Berkeley undertook to prove that man cannot directly perceive the physical world. To illustrate his position, he described the visual system as dependent upon the tactile and other senses for information about space and objects. As evidence, he later cited (1732) the Chesseldon report of a man born blind and restored to sight as an adult, who could not recognize objects or guide his movements visually. This was considered proof that touch educates vision in object perception, since the subject only gradually learned to discriminate shapes and forms using the visual modality. It is by no means clear, however, that this specific case supports the general proposition that touch is the educator of vision.

The subject, who was an adult, presumably had many years to build up ways of reacting to his environment through use of modalities other than sight. Therefore he might have had to: 1. learn to incorporate new visual sensations into perceptual patterns formerly built upon tactile and other sensations, or 2. unlearn or suppress old perceptual habits which might either compete with newly developing ones or mask perceptual capacities already present when his eyes became functional. Thus his slow acquisition of visual functioning as an adult cannot be assumed to be the same as the process which takes place during normal development.

Experiments with adults continue, however, to be cited as support for developmental hypotheses (see discussion of microgenetic approach, pages 25 to 27, below). In addition, many of these studies have tried to disprove Berkeley by showing that vision dominates touch, rather than that touch educates vision. It should be noted, however, that Berkeley's focus was not upon the dominance of one sense or another, but on the more generalized notion that experience is necessary in order for perception to develop. Berkeley's argument would have been equally consistent if he had chosen to illustrate the ways in which vision educates touch. In fact, in another work (1710), Berkeley's immaterialism led him to consider all sensory input to be on the same level, i.e. equally removed from reality (Luce and Jessop, 1948). Thus, demonstrations by modern nativists that visual capacities precede, dominate or educate the sense of touch do not invalidate the core of Berkeley's argument.

A more telling criticism of Berkeley and the other empiricists is that they viewed perception as a somewhat passive, one-way process involving the reception and mental transformation of sensory-motor information. Man was thought of as reacting to his environment during the perceptual process, rather than interacting with it. Recently, however, Piaget (1969) has suggested that knowledge of the real world requires the continuous interaction of the observer with his environment. According to Piaget, perception is neither a passive nor a unidirectional process, but an observer-directed process of organization and reorganization that depends upon action as an important source of information. As a result of observing the development of visual-motor coordination in his own children, Piaget (1952) has stated that not only does perception structure the reactive environment, but activity structures the perceptual environment as well.

Although the philosophical approach leads to interesting hypotheses about the nature of perceptual-motor behavior and its development, only studies that involve systematic observation and experimentation can properly test these hypotheses.

Naturalistic Studies, Psychometric Scales and the Early Maturation Approach

Because early systematic studies of the course of development of eye-hand coordination took a maturational view, in which it was assumed that motor skills would emerge as soon as the supporting neuromuscular systems were ready, they were mainly descriptive, focusing on the motor aspects of such behavior. These studies included naturalistic observation of children by their parents, cross-sectional studies for the purpose of constructing psychometric tests, and longitudinal studies for the purpose of describing the sequence of emergence of motor skills.

Castner (1932) has compiled the observations of investigators in the 1890's through the 1920's who kept diaries of the reaching and grasping behavior of their own children in natural situations.

He found that "the significant changes involved are in general too subtle or gradual in their appearance, and the movements too rapid, to expect any adequate account of them to be obtained from observations of this type" (1932, p. 117). He further noted that different observers varied widely in the age reported for grasping an object purposively, and that it "was impossible to determine if this response actually shows such wide variation in appearing . . . or whether the apparent variability is due to differences in the observers' points of view" (1932, p. 115).

In the late twenties, the development of psychometric scales of motor coordination was initiated by Gesell (1929) primarily to identify the normal course of development in preschool children for diagnostic test construction. A great deal of attention was given to systematic observation of age-related changes in the development of motor coordination in large groups of children, employing the cross-sectional method in order to establish achievement norms. McGraw (1946) describes the original Gesell tests and outgrowths of those tests applied by others (*e.g*. Buhler, Bayley, Goodenough), as providing standardized items which might indicate *when* certain skills were achieved, but say nothing about *how* the development of particular functions occurs.

The longitudinal studies of Shirley (1931, a, b; 1933) were aimed at describing an orderly sequence of maturational events characterized primarily by the apparently sudden emergence of new motor skills. In her sample of 25 children studied during the first two years of life (1931a) and in her review of other studies (1933), Shirley emphasized the similarities in perceptual-motor development, while minimizing the differences. She did report, however, that the order of appearance of motor items did not follow the expected sequence in about 15% of her cases. She also could not account for the different rates of development observed in her subjects. Nonetheless, she firmly believed that "motor development unrolls in a definite sequence that holds consistently from baby to baby, and even from baby to animal young. The nature of the sequence clearly indicates its dependence upon the biological laws of growth" (1933, p. 265).

While Shirley was concerned with the maturation of motor behavior in general, Halverson (1931), Castner (1932), and McGraw (1941) conducted studies specifically concerned with the development of reaching and grasping. Although their work was primarily descriptive rather than experimental, their carefully controlled conditions and cinemagraphically recorded observations contributed a great deal of information about the normal pattern of reaching and grasping that develops during the first year of life. Halverson (1931) described in detail several different types of manual approach toward a one-inch cube during the first six months of life, while Castner (1932) added detailed descriptions of the finer aspects of prehensile activity which take place after reaching and grasping are firmly established at five months. McGraw's (1941) study presented an overview of reaching and grasping during the first year of life, stressing the interrelatedness of the visual and motor aspects of reaching and grasping from the very earliest stages of development. She also included a discussion of the possible neuro-anatomical correlates of the behavior changes she observed.

While the studies described above presented useful information about the pattern of development in early infancy, they (and most other studies throughout the twenties and thirties) assumed a maturational view of development in which growth and differentiation of the musculature were seen to occur with the passage of time, with function emerging as an inevitable consequence of structural "readiness." Reference to the importance of the environment was made in passing, but attention was primarily paid to simply cataloguing normative sequential refinements in motor abilities and/or correlating them with neuroanatomical developments. Stimuli used included balls, cubes, watches, pellets, string, etc.--diverse objects that were either dangled in front of the infant or rapped on a table to get the infant's attention. Most observers seemed to assume that if the infant fixated on the object or tracked it with his eyes, it was perceived as an object, and the assumption was that all movements of the arms and hands in the direction of the stimulus were purposive.

Thus Castner (1932) stated in his summary of the early studies of prehension that "crude groping toward an object . . . is true reaching, lacking only the ability to direct the movements accurately . . ." (p. 134). The dates he summarized for the establishment of "grasping a visually-located object" ranged from the tenth week to the sixth month, with Gesell placing tests of this ability at six months, Hetzer and Wolf placing it at five months, and Figurin and Desinova reporting that twenty Leningrad children reached for an object held just within reach at four months, although they could not maintain contact or manipulate the object until later. McGraw (1941) did not describe reaching as purposive until about 8½ months of age.

This lack of agreement among the various observers about when reaching occurs may stem from the use of different criteria for describing "reaching." In addition, if different mechanisms underly reaching at different stages of development, the tendency to view differences in reaching at different stages of development along a quantitative rather than a qualitative dimension may be confusing. For example, many of the experimenters mentioned above seem to have assumed that similarities in arm extension appearing at different stages of development reflected the same underlying processes. For example, Halverson (1931) considered the clumsy, circuitous "reach" of an infant of 16 weeks to be initiated by the same process as the sophisticated straight approach of an infant of 40 weeks:

> "The types of processes involved . . . vary not in kind . . . but in their relative amount and combinations. . ." (p. 253).
>
> "There are poorly aimed and poorly directed approaches, but no aimless or directionless ones. An infant of any of these ages advances upon the object of his desire by the only route he can follow by virtue of the stage of development of his neuromuscular system . . ." (p. 252).

McGraw (1941) seems to have been the only one at that time who noted an "autonomous quality of the movements" before the fourth month of age. She did not describe "distinctly deliberate qualities" (p.138) in reaching-prehensile activity until her subjects had reached ages of about 8½ months. Halverson and the others had placed adult-type reaching much earlier, and assumed that early unsuccessful attempts reflected equal intention on the part of the infant, but were inaccurate because of the infant's immature motor equipment. McGraw (1941) suggested that neuro-muscular maturation provided different bases for behavior at different stages, and that before the fifth month, motor patterns are probably controlled by subcortical processes.

Although McGraw stated that there are different mechanisms underlying behavior at different stages, her focus was on describing the way in which neuromuscular maturation leads to the emergence of visual-motor skills. In later years, however, she came to question the general utility of the maturation concept, stating (1946) that "maturation is probably the interrelationship of a multitude of factors which determine the course of behavior development" and that the maturation-learning dichotomy was a "cumbersome conceptual framework" (p. 364) which she predicted would be replaced by more useful approaches to the study of development.

Modern Maturationists

Unfortunately, even unwieldy concepts are not readily abandoned, and aspects of the "maturation approach" still permeate the views of modern developmental psychologists. For example, views strongly reminiscent of Halverson come from Bruner's (1973) discussion, "Organization of early skilled action," where "intention" is seen as the initiator of action from the earliest stages of development, as soon as the infant has the opportunity to see the results of his own movements. Such early activity, according to Bruner, consists of instinctively triggered "constituents" or "subroutines" which "appear at a certain stage of development . . . ready formed" (p. 3). Appropriate objects in the environment serve as the releasers which arouse intention and lead to a series of constituent acts, each of which is purposive, although they "do not yet occur in the correct order for successful object capture" (p. 2). Extensive practice is then necessary before harmony between the intention system and the effector system is established and coordinated activity can take place.

Bruner thus presents a modern teleological view of development in which preformed "constituents" of larger behavior patterns occur instinctively in response to environmental releasers, with "correct orchestration" of these elements the only to-be-learned factor before intention can be fulfilled. Reaching is motivated by the same underlying mechanism (intention) throughout development, while only the appropriate application of the components of reaching is developed over time.

Similarly, in a recent study (Seth, 1972) of eye-hand coordination in infants from 20 to 52 weeks of age, the problem was stated in terms of the "changing, maturing, in part learned organization of visual-motor skill" (p. 35). In this study, visual regard and movements of the arms and hands were observed in response to three items from the Gesell scales (1934), including presentation of a cube, a pellet and a bell. At twenty weeks of age there was more looking at the bell than at the cube, and at the cube than at the pellet, with the bell also eliciting more hand movements than the other stimuli. At later ages, the attractiveness of the bell was maintained, but the effectiveness of the cube and pellet increased slightly and then decreased with age. The findings were discussed in general maturational terms, with acceptance of Halverson's and Castner's suggestions that infants reach toward objects according to their obtainability and the infants' "interest in" them.

It should be noted, however, that these kinds of observations (Bruner, 1973; Seth, 1975) can be explained without using ubiquitous motivational constructs such as "intention" or "interest." One such alternative explanation is discussed in detail below (pages 94 to 96).

The studies described above seem to have generally assumed the existence of object perception and common motivational processes in infants of different ages while studying the development of the motor aspects of reaching and grasping. Other investigators have utilized "the reaching response" to assess the perceptual capacities of infants. In these studies, the goal has been to find out when perceptual capacities such as size constancy first appear. Thus, after reviewing the literature on reaching and grasping in infants up to one year of age, Cruikshank (1941) decided that although "gross errors in reaching occur before six months . . . the reaching response" is nonetheless a reliable "behavioral indicator" (p. 332) for analyzing infant perception of size constancy.

Three situations were presented to children from 10 to 50 weeks old and "similarity of responding" in the three situations was observed. Although it is not completely clear from Cruikshank's description, it seems that she decided, for each age level, what the characteristics of "the reaching response" were, in terms of the kinds of approach movements of the hands and arms that were made to a 19 cm rattle presented 25 cm from the eyes of the supine infant. Subsequent responses under two other conditions were then considered "reaching" if they were sufficiently similar to those observed initially. The three conditions were presented in random order and were: Rattle A (19 cm) presented at 25 cm from the infant's eyes, Rattle B (the same rattle) presented at 75 cm from the eyes, and Rattle C (a rattle three times the size of the first, but of the same form and color) presented at 75 cm from the infant's eyes.

Cruikshank found that at all ages "reaching" occurred to all three rattles, but that there was more responding to the near, small rattle than to the two far rattles. This was interpreted as an indication of depth perception. The finding that there was some responding to rattles B and C was interpreted as indicating lack of size constancy, especially since there was a slight tendency to respond more to Rattle C (which had the same retinal size as A) than to Rattle B. Whether or not one agrees with Cruikshank's conclusion that size constancy is not present until six months or later, there are important problems in interpreting her findings which are similar to those mentioned above in discussing the maturationists' studies of motor development.

Cruikshank considered "reaching" to be initiated by the same process at different ages. Moreover, she built upon this assumption by using "the reaching response" as an indicator of different perceptual abilities at different ages. It should be noted, however, that extension of the arms at different ages may have different causes, which may or may not involve changes in perceptual ability. Similarities in overt behavior at different stages of development cannot by themselves be taken as evidence that the underlying mechanisms are the same. (See discussion of levels concept, pp. 35-42, below). The basis for extension of the arms may change throughout development, as may the capacity to process information on a perceptual or cognitive level. Thus arm extension by itself cannot be used to indicate either intention, size constancy or depth perception at different ages. Although it is possible, as Cruikshank stated (1941) that infants under six months have depth perception, but not size constancy, her experiment does not establish this conclusion.

A more recent series of studies by Bower (1974) is also based on many of the same assumptions as Cruikshank's work. Although Bower has done a number of studies relevant to perceptual-motor development, many of them are open to question on methodological grounds. An example comes from a study which Bower claims (1974) supports the view that visually-directed reaching and grasping takes place in infants as young as six days of age. Bower, Broughton and Moore (1970 b) used the "reaching response" and orientation to a visual target to assess intentionality of reaching in the following experiment: Eleven infants from eight to 31 days old were preselected for their ability to wear polaroid goggles for three minutes without crying. During the test session, these infants were presented with virtual objects[1] which appeared at 40 cm from the infant's eyes and were brought in slowly to an average of 20 cm until "reaching" began. The object was then left there until "reaching" ceased, or crying began. A "control" group was tested in a similar situation

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[1] Three-dimensional, non-tangible images of objects that are projected in space by the use of polaroid filters and are seen as three-dimensional only when viewed through polarized lenses.

with real, rather than virtual objects; these infants did not, however, wear goggles.

The results were that all the infants in the experimental group cried, but none of the "controls" did. This was intepreted as an indication that the virtual object produced frustration, and that the crying on the part of the infants who "reached" for the objects indicated that there was intention in their behavior, based on the expectation of a tangible object. The fact that these infants were wearing goggles was dismissed because "the group was pre-selected for its ability to wear goggles without crying for three minutes, much longer than any of them managed in the experiment . . . It therefore seems reasonable that it was not the situation which produced the frustration, but the consequences of attempting to reach for the virtual object" (1970 b, p. 680).

Although this is an ingenious investigation, it suffers from a number of shortcomings. Instead of going into a detailed criticism of the entire design of the study, this discussion will be limited primarily to the role of the goggles and the uncontrolled factors they introduced into the experiment, although the authors claimed they were unimportant. It is not clear why the subjects were not simply preselected for goggle-wearing ability and then divided into test and control groups, both of whom wore goggles. In that way, the effects of goggle-wearing could have been separated from the effects of presentation of the virtual objects. Instead, it is quite possible that although wearing goggles did not by itself lead to crying during the pretests, the added stimulation from the visual stimuli during the experimental session might have been sufficient to bring about crying at that time. Furthermore, the virtual images were advanced toward the infants, rather than being presented at a fixed location. Similarly advancing stimuli have been demonstrated independent of goggle-wearing to lead to disturbance in the young of many species (Schneirla, 1959). Several interpretations of these findings are discussed below (pages 52-53). At this time, however, the suggestion is made that rather than being frustrated by the lack of substance of the virtual objects, these infants might simply have been responding to a high level of stimulation caused by the combined discomfort of the goggles and the rate of change of stimulation caused by the "looming" virtual objects. Thus, frustration is not necessarily an accurate characterization of these infants' behavior.

The second criterion for intention used by Bower, et al. (1970b), was called "orientation" and was assessed in terms of how close to the target the infants' hands were "at the zenith of each arm extension" (p. 680). Because the results were that 70% of the infants' arm movements were within 1.5 cm of the object, their behavior was considered oriented. It is by no means clear, however, that orientational accuracy of the arms is an indicator of purposive activity, since accurate orientation seems to characterize the behavior of all organisms, including bacteria (Jennings, 1906) and plants (Loeb, 1918).

Factors such as these should be considered when interpreting the results of the other ingenious studies by Bower and his associates in which sophisticated capacities such as intentional reaching (Bower, 1974), avoidance behavior (Bower, Broughton & Moore, 1970a) and object constancy (Bower, 1972) are attributed to infants whose behavior may actually be more simply determined.

Enrichment Studies

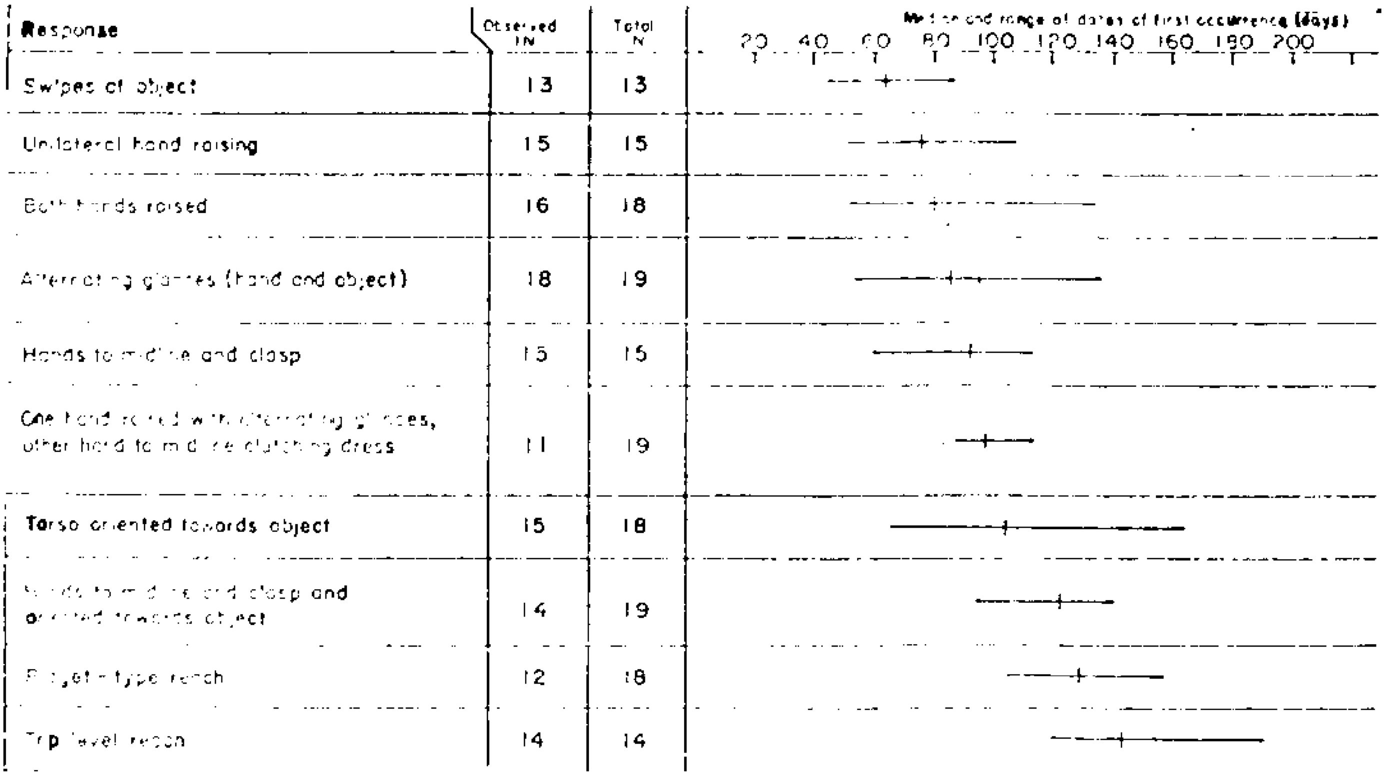
A longitudinal study of visual-motor development was done by White, Castle and Held (1964), who questioned the maturationist tendency to view development as a fixed, unalterable process. Following Piaget's interactionist model, they considered reaching to be the result of both genetic and experiential factors, and sought to examine the flexibility of the developmental process by looking at specific environmental factors that might alter the rate and sequence of development of perceptual-motor skills.

In order to obtain normative data, they observed the appearance of such behaviors as swiping, hands to the midline and clasp, top-level reaching, etc. during the first six months of life in infants living in a Massachusetts institute for illegitimate children. The median and range of these activities are presented in Table I, and are similar to those reported by previous investigators, e.g. Shirley (1933), McGraw (1941) and Gesell (1934), who observed normally reared infants.

Armed with this normative data, White, et al. were then able to experimentally study the effects that manipulation of environmental factors can have on the development of reaching. Using subjects from the same population of institutionalized infants, they found that the rate and sequence of appearance of visual-motor skills were not as unchangeable as others had supposed, e.g. Gesell (1934), Halverson (1931), and Shirley (1933) etc. Groups of infants who were reared in

Table I

Normative Data[1] on the Development of Visually-Directed Reaching



Response	Observed N	Total N
Swipes of object	13	13
Unilateral hand raising	15	15
Both hands raised	16	18
Alternating glances (hand and object)	18	19
Hands to midline and clasp	15	15
One hand raised with alternating glances, other hand to midline clutching dress	11	19
Torso oriented towards object	15	18
Hands to midline and clasp and oriented towards object	14	19
Piaget-type reach	12	18
Top level reach	14	14

---

[1] From White, Castle & Held, 1964. Reprinted with permission by the Society for Research in Child Development, Chicago

a relatively barren environment were exposed to selectively "enriched" environments in order to observe the effects that such enrichment might have with respect to the timing of the appearance of activities such as hand regard, swiping, and visually-guided reaching. The goal was to examine the flexibility of sensory-motor development and the relationship between visual-motor performance and experiential antecedents.

In the first experiment (White and Castle, 1964), twenty minutes of extra handling was given to each of ten infants every day from the sixth to the 36th day of life. Except for a slight but non-significant indication that the handled infants were visually more attentive than controls, no changes in any measures of visual-motor behavior were found.

Subsequent studies involving more specific kinds of stimulation proved more effective. For example, infants who wore red and white striped golfers' gloves (White, 1970) from the ages of 21 to 105 days showed advanced onset of hand regard, while infants given the opportunity to view and touch red and white pacifiers mounted to each side of the crib from days 36 to 68 showed earlier hand regard, swiping, and prehensile activity, as well as greater consistency of attention (White and Held, 1966). Massive enrichment, consisting of brightly-colored mobiles, crib bumpers and pillows was shown (White and Held, 1966) to retard the appearance of hand regard and swiping, but to advance the appearance of top-level reaching. Accurate reaching appeared earlier for this group than for controls, but not as early as for the group with only moderate enrichment (the pacifiers).

These studies indicate the plasticity of visual-motor development, with environmental stimulation having a significant influence on the course of development. Although it was shown that stimulation from the environment does affect the rate and sequence of appearance of visual-motor activity, the mechanisms underlying these effects were not examined.

Deprivation and Rearrangement Studies

Insight into the mechanisms underlying visual-motor development has been sought by interfering in the relationship between visual and motor sources of stimulation or observing the consequences of naturally occuring disturbances in this relationship. Thus, humans blind from birth who subsequently had their vision restored, victims of brain damage by accident and disease, and permanently blind infants with no other medical problems have been studied, as well as experimentally-deprived subjects who have experienced visual-motor deprivation or been subjected to rearrangement of the visual field by wearing distorting lenses. Deprivation has been long or short term, involved infant or adult subjects, and human or other animals. Although the conditions for deprivation studies have differed, certain questionable assumptions have been common to many of them.

Most deprivation experiments, for example, have involved manipulating an animal's experiences for some period of time, ending the manipulation, and then testing the animal for particular behavioral capacities. In such experiments the assumption has often been that if following deprivation the capacity under investigation is present, that capacity must be innate, genetically determined, or the result of maturational processes independent of experience. On the other hand, if the behavior is absent, experiential factors are considered essential for development. However, the presence of a capacity after deprivation may indicate that the subject was merely deprived of unessential factors, while the absence of the capacity may be due to degeneration of capacities that originally were present.

In a typical deprivation experiment (Riesen, 1947), chimpanzees were raised in total darkness until sixteen months of age. They were then introduced to light, and tested for various visual-motor behaviors such as pupillary dilation, visual pursuit of objects, ability to reach for objects, etc. Because these animals behaved as if they were blind, the original interpretation of these results was that experience is necessary in order for normal visual-motor coordination to develop. This position was weakened, however, when it was found that the optic discs of these animals had failed to develop properly (Riesen, 1950).

This experiment illustrates the kind of problem encountered when total deprivation of a particular factor is carried out. To avoid physiological damage, other experimenters have changed only some aspects of the relationship between visual and motor sources of stimulation, instead of trying to eliminate visual stimulation completely.

Thus, in subsequent experiments (Riesen, 1950), translucent goggles which prevented patterned light stimulation, but permitted diffuse light were used. With this modified deprivation, retinal development was grossly normal, but there were still deficits in visual-motor behavior, indicating that the experience of patterned light is necessary for normal visual-motor behavior to develop. More recent experiments have shown, however, that although patterned light is necessary, it is not a sufficient condition for the normal development of coordinated visual-motor behavior. The opportunity to perform self-initiated movements of the body in a patterned light environment is also necessary. Kittens passively transported in gondolas through a patterned environment were found to be deficient in tests of visual-motor coordination such as visually-guided paw placement and performance on a visual cliff (Held & Hein, 1965). Their yoked-control counterparts who were permitted active voluntary movement in the same environment showed no such deficiencies.

This series of experiments indicates the interpretational problems which deprivation studies often encounter. The requirements for visually-guided activity have grown from experience with light, to experience with patterned light, to the experience of the reafferent stimulation that comes from self-initiated movement in a patterned-light environment. Thus, although deprivation experiments have led to the isolation of individual factors necessary for the normal development of visual-motor behavior, all the conditions sufficient for such development have not been found.

Instead of restricting the amount of visual or motor activity that an organism is permitted, other experimenters have had subjects wear goggles that reverse, invert or otherwise alter the visual field. Such studies can be considered special forms of deprivation (the subject so treated is deprived of normal visual stimulation), and have many of the same methodological and interpretational problems.

Additional problems appear when a nature-nurture division is sought. An example comes from an experiment by Hess (1956) in which chicks did not adapt to distorting lenses, continuing to peck inaccurately at grain while wearing lenses that shifted their fields of vision several degrees to one side. This was interpreted by Hess as evidence that the visual-motor coordination of chicks is innately determined and independent of experience. In a similar experiment, however, Rossi (1968) found that although chicks did not adapt to lenses, removal of the lenses resulted in pecking errors in the direction opposite to those made when the lenses were worn. This showed that the lenses did have an influence and that experiential factors are not neatly separable from so-called innate factors in development.

Another problem inherent in deprivation-rearrangement investigations is related to the testing situation and the experiential history of the subjects. Most of our knowledge about naturally-occurring long-term visual deprivation in man comes from Von Senden's (1960) compilation of reports of individuals blind from cataracts whose eyesight was restored at various ages by removal of the cataracts. In a recent reanalysis of Von Senden's work, Wallace (1975) noted that although younger subjects were reported to use their new visual modality more easily than older subjects, at first they often refused to look at objects and would close their eyes when trying to get around in familiar places. In almost every case, subjects resorted frequently to older, more comfortable habits of acoustically and tactually guided locomotion, rather than coping with the hazards involved in using their visual capacities. Many never learned to utilize vision.

This suggests the importance of considering a deprived subject as an organized, integrated creature who has developed patterns of behaving which are adjustments to a deprived state, and which might interfere with functioning once deprivation is ended. As pointed out by Wallace (1975), introduction of vision into the world of a well-adjusted blind person should be expected to have a disorganizing effect. Similarly, the sudden introduction of light into the world of a dark-reared animal should also be expected to disrupt performance, especially since testing usually takes place in the light. Perhaps a more informative approach would be to compare subjects' in-the-dark performances to their performances in the light. In this way, the emphasis would be on how dark-reared animals adjust (or fail to adjust) to changes in their environment (when light is introduced), rather than how their visual-motor behavior compares to that of animals that were never deprived.

The closest investigators have come to the approach described above is the visual rearrangement study in which both the course of adaptation to visual distortion and readaptation to normal stimulation are observed. Such experiments have been conducted in non-developmental studies of human adults and developmental studies of other animals. First the adult studies will be considered, then the developmental studies.

The Microgenetic Approach

The results of adult rearrangement studies aimed at elucidating the relationship between vision and touch have led some investigators (Harris, 1965; Rock and Harris, 1967) to conclude that the adaptation that takes place when one views one's hands through distorting lenses is proprioceptive in nature, rather than visual. That is, after distorting lenses are worn for short periods of time, adult subjects experience a change in the "felt position" of their hands, rather than a change in the visually perceived location of their hands.

Pick, Hay and Pabst (1963) agreed with Harris (1965) that visual-motor adaptation is proprioceptive rather than visual. They found that in tests with the hand not viewed during prism-wearing or in tests using the auditory modality, subjects displayed errors in pointing at sounds or straight ahead, which were equal in size and distance to the displacement of visual targets caused by the prisms. However, these effects appear to be only short term. Hay and Pick (1966) found that if lenses are worn for long periods of time and subjects are permitted to view their whole bodies, then visual adaptation takes place, and such adaptation appears to be more enduring as the distorting lenses are worn for longer periods of time.

Similar phenomena can also be found in the early reports of Kohler (1964) and Stratton (1897) who both noticed that under certain conditions after wearing distorting lenses for about two weeks, proprioceptive information dominated over visual information in determining perceptions. For example, Kohler (1964) mentioned that after thirteen days of wearing reversing prisms, if he ran downhill quickly without thinking about how things looked, he automatically made the correct stepping movements and the world looked "correct." However, when he reached the safe lower ground and began thinking about it, the world again appeared to be reversed (p. 155). Similarly, Stratton reported (1897) that when rocking in a chair wearing reversing lenses, nothing in his peripheral field of vision was reversed until he started thinking about it (p. 355). There is now some agreement among investigators that although initially the "felt" position of things changes to conform to visual input, if lenses are worn for long periods of time the visual impressions begin to change, and eventually things "look the way they feel," without proprioceptive or tactile changes.

Experiments such as these (see also Rock and Victor, 1964), which provide interesting information about the nature of adult adaptation to visual distortion, have also been used to make statements about early development, employing what I shall call the microgenetic generalization. Some of the major proponents of this approach and their experiments have been reviewed by Harris (1965). In general, they assume that the processes of adaptation to distorting lenses and readaptation to normal stimulation in adult subjects are the same as, or very similar to, the processes that originally take place during development. Thus, results from adult studies are taken as evidence of early developmental processes as well. For example, on the basis of experiments using adult subjects, Harris (1965) generalized his findings to early development and took the position that visual perception is innate and remains constant throughout development. In this view, a child develops a feeling for where his or her limbs are located that is based upon innate visual knowledge: "So when a baby stares raptly at his outstretched hand, he is probably finding out where his hand is, not what his visual sensations mean." (1965, p. 442).

It is important to note, however, that an infant may differ from an adult in many aspects of functional organization (see discussion of levels, pp. 40-41, below), and that any generalizations about early developmental processes based solely on examination of adult functioning are open to question.

For example, Rock and Harris (1967) claim to have evidence enabling them to reject Berkeley's empiricist position that touch educates vision during development. In these experiments, adult subjects wore lenses that reduced the apparent size of three dimensional objects, distorted the shape (made objects appear narrower), or displaced the image to one side. There was thus contradictory information from vision and touch when subjects were permitted to manipulate the objects while wearing the lenses. In each case, vision was shown to dominate over the tactile sense when subjects using touch reported the size, shape and location of objects consistent with visual appearance, and also indicated that their tactile sensations from objects conformed to their visual impressions of them. This has been termed "visual capture" (Rock and Harris, 1967) and refers to the observation that vision often affects the sense of touch so profoundly that when there is a conflict, the felt sensations (proprioceptive and tactile) may actually change to conform to visual sense impressions.

Although vision has been shown to clearly dominate the other senses in determining adult perception, the demonstration of dominance is not the same as the demonstration of primacy. In other words, to show that vision dominates perception is not the same as showing that visual perceptual capacities come first developmentally. Further, the assumption that visual dominance in the adult indicates visual dominance in the infant presupposes that there is no developmental change in the relationship between sensory systems during development. Even if an adult's position sense (e.g. the felt position of his arm) changes to conform to information from the visual system (which has been distorted in some way), that indicates that vision is dominant in the adult, but it tells nothing about the earlier organization of intersensory relationships. Thus, although the findings of their experiments clearly support the hypothesis that vision is dominant over touch in an adult conflict situation, the interpretation offered by Rock and Harris (1967), that vision educates touch during development, was not tested, nor does it follow from the data.

Other investigators have focused on the role of movement in the course of adaptation to distortion or recovery from deprivation. Hebb (1949), on the basis of his (1937) and Riesen's (1947) observations, suggested that movement was necessary in order for sensory associations in the visual system to build up. His interpretation of the role of movement was further supported by Riesen's (1960) and Riesen and Aarons' (1959) findings that chimpanzees and kittens did not develop normal visual-motor behavior after restriction of body movement during development. Movement was seen by these investigators as providing opportunities for associations of visual stimuli as a result of contiguous stimulation from the moving body and its surroundings.

Held and his associates took a different view of the role of movement, based on a series of studies of adult adaptation to rearrangement of the visual field and developmental studies of deprivation of visual-motor stimulation in kittens and monkeys. They concluded that movement - produced stimulation is necessary for the development of visual-motor coordination, not because it provides opportunities for association between visual stimuli, but because it provides opportunities for the correlation of reafferent stimulation from self-produced movements and changes in the visual field.

Developing a clever technique for studying the effects of optical rearrangement on such eye-hand behavior as localizing spatial targets, Held and Gottlieb (1958) found that adaptation to prisms that shift the visual field to one side is independent of error recognition, but dependent upon the opportunity to view the moving hand. Their apparatus prevented subjects from seeing their hands and errors in marking intersecting points on a grid while wearing wedge prisms that shifted images slightly to one side. They found that virtually no compensation for displacement occurred unless the subject had the opportunity to watch his hand move during visual displacement.

Held and Hein (1958) used Held and Gottlieb's (1958) technique, but modified it to permit experimenter control over the subjects' hand movements. Comparing no movement of the hands, passive movement, and self-produced movement conditions, they found that no adaptation to optical displacement occurred unless subjects were permitted to view the self-produced movements of their hands during visual displacement. Held and Schlank (1959) found similar results in a study of compensation for lenses that increased the optical distance between the subjects' hands and eyes. In this study, compensation also took place only when subjects were permitted to view voluntary movements of their hands.

These studies supported the view that reafferent stimulation from self-produced movement is necessary for adaptation to visual displacement. However, all these studies involved movements of only the hands and wearing of displacing lenses for short periods of time, conditions under which adaptation was not complete. Held and Bossom (1961) explored the role of movement of the entire body during both long and short term wearing of displacing prisms. They found that complete and exact compensation for displacement of the visual field occurred only during long-term exposure when subjects were permitted voluntary movement of their whole bodies in a natural environment while wearing the distorting lenses.

In their discussion of these findings, Held and Bossom (1961) discussed the advantages of the visual rearrangement technique for studying visual-motor processes, pointing out that although developmental studies are essential for deciding developmental questions, such studies are "time consuming, expensive, and not . . . well suited . . . to the factorially designed studies . . . required to isolate the critical variables common to both early development and adaptability to rearrangement in the adult" (p. 37). They stated that adult rearrangement and neonatal deprivation are complementary techniques that can be used to understand processes underlying visual-motor coordination. On this basis, they interpreted the results of their studies as evidence that self-produced reafferent stimulation in a patterned light environment is necessary both for adult adaptation to displaced vision and for normal development of visual-motor coordination in infancy.

Developmental Studies

The developmental aspects of this position were then tested directly in Held and Hein's (1965) gondola study which was described earlier (p. 21, above). The passively transported kittens' failure to develop normal visual-motor coordination was interpreted as further evidence that self-produced reafferent stimulation in a patterned environment is necessary for normal visual-motor development as well as for adaptation to rearranged vision in adults.

In a related study, Held and Bauer (1967) reared stump-tailed macaque monkeys in an apparatus that prevented them from seeing their bodies from the neck down. These animals were trained to make limb extension movements without viewing their limbs when a milk bottle was presented. After 35 days of training, the animals were permitted to view their limbs and visually-guided extension was prompted by presenting small objects within easy reach. Although extension was observed, it ceased as soon as the monkeys caught sight of their hands and apparently became locked into visual regard of the hand. As this behavior gradually disappeared, accurately-guided reaching took place, leading the authors to conclude that experience viewing the moving limb is necessary in order for visual guidance of the limb to develop normally.

Walk and Bond (cited in Riesen, 1975) have suggested that the deficits observed in this study may be due to the extinction of visual-motor responses, rather than to the absence of visual-motor opportunities. They point out that Held and Bauer's (1967) technique could serve to reinforce a non-visually guided response and extinguish visually-guided ones. They presented monkeys with the same type of training as Held and Bauer, except that their monkeys were rewarded for visually-oriented movements. In their experiment, extension toward a dowel stick which protruded vertically through the top of the monkey's chamber could be correlated with visual input because the monkeys were able to see the top of the stick. When each monkey was permitted to view its hands after 36 days, reaching was awkward, but oriented, and was not interrupted by prolonged hand regard. Riesen (1975) has interpreted this finding as evidence that the lack of visual-motor control in Held and Bauer's animals was not due to absence of reafferent stimulation correlated with visual input. He takes the position that many aspects of visual-motor coordination are present at birth and that reinforcement of oriented movements in the presence of visual stimuli is necessary for maintainance of visual-motor behavior.

Although there is general disagreement about the mechanisms underlying normal visual-motor behavior, it is generally accepted that early experience is necessary for the maintainance of cortical cells that respond selectively to different features of visual stimuli and may also be necessary for their development. Most of the information regarding the specificity of responsiveness of the cells in the visual cortex has come from the work of Hubel and Wiesel (reviewed in Riesen, 1975). They found that feature detectors in normal kittens' visual systems were present at birth and similar in number and distribution to cells in the visual cortices of adults.

Hirsch and Spinelli (1970, 1971) and Blakemore and Cooper (1970, 1971) emphasized the need for early environmental stimulation in order for the development of feature detectors to continue normally. Both these teams of investigators found that although cortical cells are responsive at birth to visual field elements of certain orientations, this specificity increases during development and can be altered if abnormal stimulation is presented during development. Thus, kittens who were reared under conditions in which their exposure to patterned stimulation was restricted to only horizontally striped fields or only vertically striped fields developed cortical response fields that were different from each other and from normally-reared kittens. Specifically, the cortical cells of kittens who had seen only horizontal stripes fired only in response to horizontally oriented stimuli, while the cortical cells of kittens who had seen only vertical stripes were responsive only to vertically oriented stimuli. These animals also responded behaviorally as if they were oblivious to stimuli that were differently oriented from those to which they were exposed during early development. The horizontally-reared animals avoided horizontally-oriented obstacles, but bumped into vertically oriented poles placed in their paths; while the vertically-reared animals avoided vertical poles, but not horizontally oriented bars (Spinelli, 1975; Blakemore and Cooper, 1970).

Although electrophysiological evidence suggests that experience is necessary at least for the maintainance of the neuro-physiological substrate upon which visual-motor behavior depends, the issue of whether visual connections are merely disrupted by lack of stimulation during deprivation or require stimulation throughout development is still not resolved.

In summary, the various approaches described above have led to only a limited picture of visual-motor development. Studies of maturation contributed a description of the normal developmental sequence that coordinated visual-motor behaviors follow; while enrichment studies found that the sequence of emergence of visual-motor skills is plastic and can be modified by manipulation of environmental factors. The results of deprivation and visual re-arrangement studies taken together suggest that the experience of observing self-initiated movements of the body in a patterned light environment is necessary for normal visual-motor behavior to develop. However, there is still disagreement as to all the conditions <u>sufficient</u> for visual-motor development, and about the mechanisms underlying visual-motor development. Electrophysiological studies have found that the specificity of cortical cells responsive to visual-field elements of certain orientations increases during development, and that the degree of specificity can be altered by presenting abnormal stimulation during early development. However, here too, there are unresolved questions about the way in which early abnormal experience functions in these experiments. Some experimenters maintain that innate visual connections are disrupted by restricting experience, while others believe that visual connections are not innate, but require stimulation throughout development.

Chapter II

Schneirla's Comparative-Developmental Approach

While the various approaches described above have contributed substantially to our knowledge of the conditions necessary for normal visual-motor development, the mechanisms underlying this development are still not completely understood, and many of the conflicts in the data remain to be explained. Any approach which may help to organize this body of information and resolve apparent conflicts is useful for understanding developmental processes.

Schneirla's comparative-developmental approach provides one such organizing framework. It contains: 1. An emphasis on qualitative differences in the mechanisms underlying response patterns at different developmental stages (The Levels Concept) and 2. An hypothesis that accounts for early directional responses in all animals at early stages of development (The Approach-Withdrawal Hypothesis). These concepts are interwoven into an approach to the study of development that permits the integration of a large body of information about human infancy, and leads to the formulation of useful hypotheses that provide the framework for further investigation. However, Schneirla's concepts have been interpreted in ways that differ from the interpretations which are used in this study. Therefore, in order to clarify the concepts as they apply to this study of visual-motor development, they will be discussed in detail in this chapter, and examples of their application in other areas will be included. Hypotheses derived from this approach will then be directly applied to the experimental investigation of the development of infant visual-motor responses, in an effort to understand the changing bases of extensor movements in early infancy.

The underpinnings of this general approach were first presented in detail in an Encyclopedia Brittanica definition of Psychology, Comparative (1948) where the central goal of comparative psychology was considered to be the achievement of an understanding of the evolution and development of behavior. In that article, as well as in subsequent publications[1], the focus for comparative psychology was placed on the differences, as well as the similarities, in the behavior patterns that have developed in all living species as a consequence of their varied capacities for adaptation and adjustment to changing environmental conditions. One of the principal goals of this approach was to elucidate basic processes of interest to humans--including motivation, learning, social behavior, etc.--by analytic investigation of the similarities and differences between humans and their non-human contemporaries.

The problems of comparative psychology were formulated in terms of comparative-developmental questions, in the belief that the study of the ontogeny of behavior patterns in different species would provide the proper perspective for comparisons across phyletic levels.

The Concept of Levels of Functional Organization

The levels approach is a method of ranking the psychological capacities of animals in which animals are described as "higher" or "lower" in terms of the kind of functional organization they bring to

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[1] Schneirla's major theoretical papers have been collected in Selected Writings of T.C. Schneirla, Aronson, L., Tobach, E., Rosenblatt, J. and Lehrman, D. (Eds.), San Francisco: W.H. Freeman, 1972.

the problems encountered in adjusting to environmental changes. Thus an animal has "higher" psychological status not according to the complexity of its equipment or the adaptive value of its behavior patterns, but according to the degree of flexibility it has in reorganizing the responses available to it in changing situations. In each case, the criteria for high or low status rest not on how adaptive a given behavior pattern is, but on the nature of its organization: Stereotyped behavior is lower than flexible behavior; peripheral control is lower than central control; sensory-motor mechanisms are lower than cognitive ones; reflexive behavior is lower than purposive, etc., because in each case, the higher level of organization permits a wider range of responses to changing environmental circumstances.

In order to apply the levels concept, it is necessary to carefully analyze behavioral differences as well as similarities. In that respect it differs fundamentally from approaches such as Hullian learning theory, Skinnerian behaviorism, and Lorenzian ethology, in which monomorphic constructs are used. For example, behaviorists have generally been concerned with the description of similarities observed in many species, rather than analysis of the basis for these similarities, or examination of similarities in relation to the differences found across phyletic levels and at different ontogenetic stages.

The concept of levels of functional organization, however, emphasizes <u>qualitative</u> <u>differences</u> in the learning, motivational, perceptual and social behavior of animals. This emphasis on differences is an attempt to guard against easy usage of monomorphic constructs which might lead people to slip the behaviors of many different species into convenient bins labelled "aggression," "hunger," "instinct," etc., instead of examining the factors which lead to the development of behaviors that have surface similarities, but different underlying causes. Use of the levels concept also helps curb tendencies toward zoomorphism (endowing humans with the attributes of other animals), anthropomorphism (endowing other animals with human capacities) and "adultomorphism" (endowing infants with adult capacities, Birch and Turkewitz, 1966), by encouraging examination of the different bases for behavior at different phyletic levels and at different stages of individual development.

The levels concept is a discontinuity concept, applied to both phyletic and individual development, with the understanding that although each new level may incorporate gains from previous levels, it is nonetheless qualitatively different in terms of the basis upon which new patterns are organized. Examples of the way in which this discontinuity concept has been usefully applied come from the areas of motivation, perception, learning and social behavior.

In order to illustrate the way in which a levels approach can be useful, an example from the field of motivation will be discussed in some detail. Then the approach will be applied to the study of human infancy.

The example is an examination of "hunger," a construct that has been operationally defined by some behaviorists in terms of food deprivation, while others have often loosely applied it in many different contexts.

Because depriving many different organisms of food--infant or adult, rat, cat, monkey or man--usually leads to eating once food is available, there is a tendency to infer the existence of a common motivational process. The construct is labelled with the adult-human term "hunger" and anthropomorphically applied across species and to all stages of development as if it represented the same process: Rats, cats, babies and adults all eat after food deprivation because they are "hungry."

Looking at behavior developmentally, and employing the levels concept, however, enables us to see that: 1. the states of food deprivation and "hunger" are not necessarily the same; 2. feeding as a response to food deprivation is not organized in the same way in different species or at different ontogenetic stages; and 3. feeding as a response to food deprivation may be a lower level response which developmentally precedes "hunger."

First, it can be easily shown that the causes of feeding in such diverse animals as the amoeba, the blowfly, the sea anemone and the rat are not at all the same. Each animal differs in important ways from the others in the organization of its feeding patterns. Analysis of feeding in the amoeba, for example, illustrates the fact that lower level activity is not directly determined by its beneficial aspects or purposive in any sense. In this animal, approach movements and ingestion take place in the presence of both nutritive and non-nutritive substances, as long as they provide low-intensity mechanical stimulation on the body surface (Schaeffer, 1920, cited in Maier and Schneirla, 1964). Most substances which are soluble in the amoeba's protoplasm and easily assimilated are also effective approach stimuli. However, there are many assimilable substances that are not ingested either because they are too intense, evoking withdrawal, or they are too small, not moving, or otherwise insufficient to evoke approach responses.

While feeding in the amoeba is directly determined by stimulation of the cell membrane, feeding in the sea anemone is somewhat more complexly determined, but still at a low level of organization. In the anemone, there is a nerve net system which transmits energy from one body part to another. This is a connecting system, however, not a controlling one (Parker, 1919, in Maier and Schneirla, 1964). Local excitation leads to feeding behavior as the result of the sequential stimulation of body parts determined by their spatial relationship. Thus, although the nerve net permits coordination of body parts, it is still a peripheral, rather than a central mechanism that governs the anemone's responses.

At a somewhat higher level of organization, feeding in the blowfly is not completely peripherally determined. Dethier and Bodenstein (1958) analyzed the basis upon which the blowfly ceases to feed, and found that feeding will continue until the sensory threshold of the blowfly's oral receptors becomes elevated as a result of adaptation. Adaptation has a short time course, and feeding resumes until adaptation occurs again, with alternation of feeding and adaptation continuing beyond nutritional need and until death unless inhibited by negative feedback from the gut. "Hunger" in the blowfly is not centrally motivated, but determined by fluid in the gut inhibiting sensory input to the brain by way of the recurrent nerve from the gut. Thus, in the blowfly "hunger can be equated with . . . absence of inhibitory impulses carried by the recurrent nerve" (1958, p. 20).

At a still higher level of organization, the well-known latent learning experiments with rats illustrate central processing that certainly reflects a higher level of organization than that observed in the anemone and the blowfly. Rats that were permitted to wander through a maze without food reinforcement were able to complete the maze without errors on the first trial after food was introduced (Tolman and Honzig, 1930).

In the same sense that the mechanisms underlying feeding in the amoeba, the blowfly and the rat differ, the basis for feeding at different stages of development in the same species can also differ. Thus, feeding in the human infant can be seen as qualitatively different from feeding in the adult in terms of the way in which it is organized.

In the human infant, food deprivation seems to lead to a state of arousal (indicated by crying, etc.) which can be diminished by feeding or many rhythmical, soothing stimuli (rocking, patting on the back, singing a lullaby, etc.). Feeding at this stage of development is only one of several sources of stimulation whose effects are equivalent for reducing tension. Furthermore, a satiated baby who is aroused (e.g. by pinching a toe) will resume nursing even though having just been fed (Jensen, 1932).

At this stage, pinching leads to feeding behavior independently of nutritional state, while the tension resulting from food deprivation can be satisfied by a variety of stimuli (only one of which is food). This represents a different kind of organization from that seen in an older infant who anticipates being fed when hearing mother open the refrigerator door, and stops crying as soon as the bottle is seen on the way to the mouth. This behavior reflects a level of organization higher than that of the newborn, but lower than that of the adult who feels "hungry" for an ice cream cone shortly after a full meal.

Thus feeding in the human infant and the human adult represent levels of organization that are quite different. It should also be pointed out, that at later developmental stages, a particular individual may operate contemporaneously at a low level in some areas and at a high level in others. Thus, although an individual (or species) may attain a higher level of organization at later stages of development, lower level patterns are not necessarily lost.

Application of the levels concept has led to reinterpretation of behavior ranging from learning (e.g. Schneirla, 1962) to perception (e.g. Schneirla, 1954) to social behavior (e.g. Tobach and Schneirla, 1968; Schneirla, 1941, 1951, 1953). In each case, a monomorphic construct is displaced by the more complex view that there are qualitative differences in the psychological organization of different species at different phyletic and individual stages of development.

In the above example, species were ranked according to differences in the way in which feeding responses were determined. Using the criteria described earlier (pp. 35-36) higher levels were identified primarily in terms of behavioral plasticity, with central control considered higher than peripheral control, etc. The levels approach was also applied to human infancy, with different developmental stages distinguished according to the same criteria.

Another basis for distinguishing different stages of development comes from examination of the aspects of stimulation to which animals are responsive. For example, infants who are capable of responding only on the basis of quantitative aspects of stimulation (*e.g.* loudness, brightness) may be considered to behave on a lower organizational level than infants who are also capable of responding to the qualitative aspects of stimulation (*e.g.* taste, shape). Data about infant behaviors such as eye-turning, duration of visual fixation, visual evoked potentials, heart rate on the visual cliff and finger movements can all be integrated by use of the levels approach, when the infant's ability to respond to the qualitative aspects of stimulation is considered. (See pages 52-59 below).

However, before specific evidence is discussed, the Approach-Withdrawal Theory, which provides an hypothesis for distinguishing between earlier and later stages of development that may apply to visual-motor behavior, will be discussed.

Biphasic Approach-Withdrawal Theory

The Approach-Withdrawal Hypothesis. Understanding the theoretical foundation of Approach-Withdrawal Theory (Schneirla, 1959, 1965) is central to understanding why and how this study of visual-motor development was done. Therefore, the main principles of that theory which relate to this study will be presented here in detail.

The Approach-Withdrawal Theory is a description of the basis upon which all behavior in all animals is organized *at early stages of development*, and upon which all behavior in animals at low phyletic levels is organized *throughout their life history*. The main hypothesis, the approach-withdrawal principle, is that there is a forced-reaction relationship between the kind of response an organism makes and the intensity of stimulation that the organism receives, such that low intensities of stimulation tend to evoke what are known as approach reactions, while high intensities evoke what are known as withdrawal reactions.

In general, an approach response orients the animal toward an external source of stimulation. Often this response also serves to decrease the distance between the subject and the external source of stimulation. Examples of such episodic responses are precocial birds' pecking at certain objects, nestling movements, pleasure calls, the head-lunge response of lizards, gaping responses in altricial birds, and the following of certain objects moving away at a slow rate (Schneirla, 1965). What all these responses have in common is that they are governed by the phasic arousal of A-processes.

A-processes (both tonic and phasic), are in general energy-conserving processes necessary for the continuing development, survival and well-being of the organism. At higher phyletic levels, tonic A-processes correspond to the functions governed by the parasympathetic branch of the autonomic nervous system, including patterns of regular respiration and heart rate, blood pressure, digestive and other visceral, vegetative functions.

Phasic A-processes are episodically aroused processes which underly overt actions (approach-type responses) such as food-getting. Both the tonic and the phasic aspects of the A-system are responsive to low-energy input, and both serve to promote the ongoing life functions of the organism. In addition, tonic A-processes may serve a reinforcing function, providing a facilitative background for the development of phasic approach responses to A-stimuli.

W-processes are energy-expending, interruptive processes corresponding at higher phyletic levels to mechanisms governed by the sympathetic branch of the autonomic nervous system. They include rapid breathing and heart rate, increased blood pressure, suppression of digestion, etc. W-processes appear later in ontogeny than A-processes and are usually phasic, although under conditions of chronic stress, they might in some aspects become tonic (as in Selye's general adaptation syndrome, 1956).

W-stimuli are those which effect a high-magnitude energy input, including stimuli which are rapidly changing, high intensity, large, complex, moving toward the subject, irregular in spatial or temporal pattern, etc. Again, the common aspect of stimulation in all these cases is a high-magnitude energy change in input.

It is central to A-W theory that the W-processes have higher thresholds than the A-processes, responding to only high magnitudes of effective stimulus input. Thus, the A- and W-systems may often involve the _same structures_, but in functionally different ways.

At lower phyletic levels, the relationship between intensity of stimulation and response direction is direct and mechanical, and does not show any ontogenetic change. Thus in the amoeba, effectively mild stimulation in the form of weak light, heat, chemical concentration or tactile stimulation has a direct effect upon the gel-sol state of the protoplasm, with the area on which the stimulus falls becoming more fluid, and the protoplasm flowing in that direction. With effectively more intense stimulation, the process is reversed, and the flow of protoplasm is in the opposite direction (Maier and Schneirla, 1964). The amoeba never reaches a higher level of organization.

However, during ontogenesis in higher phyletic levels, specializations occur so that there is a progressively indirect route between stimulus and response, and *apparent* contradictions and reversals of the approach-withdrawal intensity relationship may take place. Thus, there are species whose A-processes are aroused as light intensity increases, while others become more active as light intensity decreases.

In addition, the kinds of responses observed will depend upon situational factors. For example, the local approach response of a precocial bird to an external A-stimulus might be a peck, in the feeding situation, or locomotion toward an A-stimulus that is gradually moving away. The same animal's withdrawal response to a high-intensity stimulus sufficient to arouse the W-system might involve turning the head away, or walking away. Approach and withdrawal responses are not classified as such according to how much of the animal's body moves toward or away from the stimulus source; nor are they to be conceived of as physically equal and opposite. Rather, they are *functionally* antagonistic responses, that are the result of activation of different response systems.

Effective Stimulus Intensity. A-stimuli include all those sources of energy which result in low-magnitude, regular input. The focus is on an *end result* of stimulation that can be brought about in many ways. The influence of any particular external stimulus depends upon *all* the following factors:

1. the state of the organism (e.g. whether aroused or quiescent);
2. the nature of the receptors (i.e. their stimulus filtering properties, e.g. rods vs.cones);
3. the receptor thresholds (e.g. whether light or dark-adapted);

and, finally,

4. the objective external stimulus intensity.

In this view, effective intensity is considered to be the sum of all stimulation, both external and internal. "Effectiveness" depends upon whether or not total stimulation is sufficient to reach either the A-system or W-system thresholds. As long as objective and effective intensity are not confused, pleas for clarification (e.g. Hailman, 1970) become unnecessary: In general, A-stimuli will be gradually changing, low intensity, small, regular, simple in pattern, slowly moving away, etc. It should be noted that these are only general characteristics shared by stimuli that may be effective in eliciting approach responses. What all these characteristics have in common is that they represent low magnitude, regular energy change at a level sufficient to arouse A-processes. Because effective intensity at any given time is the result of all the factors described above, in addition to all the characteristics of the external stimulus, there is no a priori way of predicting whether any particular stimulus will be effective in eliciting approach or withdrawal. This has been a point of misunderstanding on the part of several of Schneirla's critics. Hailman (1970) for example, insists upon "restricting attention to only the physical stimulus," then complains that the meaning of A-stimulus is unclear (p. 151).

Clearly, an objective, physical stimulus could be of "high intensity and decreasing simultaneously" (Hailman, 1970, p. 151). But, as pointed out above, objective intensity is only one of the factors to be considered in determining whether a particular physical stimulus will be effective in eliciting approach or withdrawal. *E.g.*, a bright light (high physical intensity) which is *gradually* decreasing in intensity might lead to an approach response by a light adapted worm, or a withdrawal response by a dark-adapted worm. If it is *rapidly* changing in intensity, it might lead to withdrawal whether the animal is light or dark adapted, if the sudden change results in input sufficient to reach the W-system threshold. Receptor thresholds, internal state and objective external intensity must all be considered before predictions can be made.

It has also been suggested that the concept of effective intensity is incapable of negation and circular (Hailman, 1970), "because any stimulus that elicits approach can be said to be of low intensity, and there is no logical possibility of finding a behavioral system that does not fit the theory " (p. 151).

Later in this thesis, several studies of auditory- and visual-motor behavior in human infants which have used the concept of effective intensity without circularity will be presented. At this time, however, the general logic behind such experiments will be examined in order to show that the notion of effective intensity is not in fact circular. There are at least two approaches: in one, state is kept constant while external, physical stimulation is varied.

As mild but increasing amounts of stimulation are presented to subjects that have been equated for state, approach responses should be observed when stimulation reaches the A-system threshold. Approach responses should then be observed until a level of stimulation above the W-system threshold is introduced. There should then be withdrawal responses to this and any other stimuli that are objectively more intense. If there is an approach response to any stimulus which is more intense than that which first evoked withdrawal, the approach-withdrawal hypothesis is refuted.

A curve of responsiveness plotted as a function of intensity is presented in Figure 1, which is one possible representation of the approach-withdrawal intensity relationship. It should be noted that if an approach response occurs to an intensity above that which evoked withdrawal, with all other factors held constant, the approach-withdrawal hypothesis is disproved.

A second approach to examining effective intensity would be to hold external, physical stimulation constant and vary the condition of the organism. Exposure to light, for example, could be varied so that different subjects were at different levels of adaptation to light. Subsequent changes in these subjects' responses to fixed values of external stimulation could then be observed. It would be expected that at early stages of development dark-adapted animals would display withdrawal responses from the same objective stimuli to which light-adapted subjects displayed approach.

As presented above, the approach-withdrawal principle and the concept of effective intensity are not simple concepts. However,

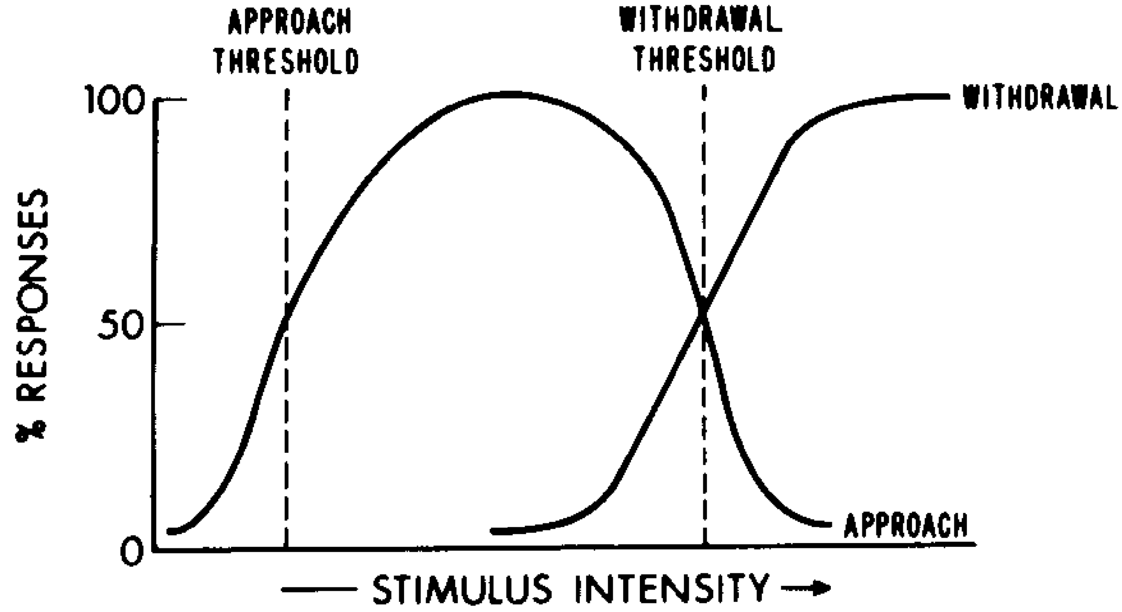

Figure 1: A Model of the Approach-Withdrawal Intensity Relationship. Approach responses begin at low intensities of stimulation, reach maximum frequency at moderate intensities and decline as intensity reaches the withdrawal threshold. Withdrawal responses begin as stimulus intensity reaches the withdrawal threshold and continue to occur at high intonsities of stimulation. If approach responses occur to intensities above the withdrawal threshold, the Approach-Withdrawal Hypothesis is refuted.

in the original formulations (Schneirla, 1959, 1965) they were not presented in sufficient detail to avoid misinterpretation and confusion. For example, the important restriction--that this relationship between effective intensity and response direction was meant to apply only to very early stages of development--was mentioned, but not emphasized. Thus, several experimenters, e.g. Pfaffman (1961) and Jaeger and Hailman (1973), incorrectly used data from the studies of organisms, regardless of phyletic level and stage of development, as evidence against the approach-withdrawal hypothesis.

However, the approach-withdrawal hypothesis is meant to apply throughout the entire lifetime of organisms only at the lowest phyletic level. While findings such as Jaeger and Hailman's (1973) for adult annurids and Pfaffman's (1961) for adult humans provide interesting information about intensity-response relationships at advanced stages of development, they are not relevant to approach-withdrawal theory, which predicts response direction only at early developmental stages.

When phyletic level and stage of development are taken into consideration, there is evidence from several sources that supports the approach-withdrawal hypothesis. Variations of the experimental strategies described above (pages 47-8), which were performed for the amoeba (Mast, 1926, cited in Maier and Schneirla, 1964), the worm (Hess, 1924, cited in Maier and Schneirla, 1964) and various insects (Maier and Schneirla, 1964) led to the formulation of the hypothesis that effective intensity is the result of both external and internal stimulation. Subsequent studies (e.g. Hammer and Turkewitz, 1975;

Turkewitz, Fleischer, Moreau, Birch and Levy, 1966) support the formulation that effective intensity is the result of both external and internal factors which determine the directional responses of human infants at early developmental stages.

In addition to the limitation of the theory's applicability only to early stages of development, there are other important limitations which should be discussed. One is related to the *a priori* specification of "early stage of development." While this is an empirical question which can only be answered by careful observation of each particular species under consideration, complications arise from the possibility that sensory-motor systems may develop at different rates, so that identification of low-level, intensity-determined patterns of response in one system cannot be generalized to other systems without experimental verification. *I.e.*, it is quite possible that at a particular age in a particular subject, one system (*e.g.* the visual-motor) has reached a higher level of organization than another (*e.g.* the auditory-motor), which is still operating at a lower level of organization. Thus, if negative results are found for any one sensory-motor system, they may always be attributed to that system's having reached a later stage of development. In other words, experiments that do not seem to support the approach-withdrawal hypothesis may always be criticized on the grounds that they have not examined behavior at a developmental stage that is "early enough."

Another limitation of the theory stems from its inherent complexity. Approach-withdrawal theory, with its emphasis on the complex interrelationships among factors that must be considered in every individual case, can be exceedingly cumbersome to apply. This is not to say that an appreciation of the complexities of real events should be sacrificed in order to present a simpler model that is more easily applied. However, in many cases the theory lends itself to application only with great difficulty, and in some situations it may even be methodologically untestable.

For example, failure to get withdrawal responses neither supports nor refutes the theory, since failure to obtain withdrawal can be attributed to the experimenter's failure to present sufficiently intense stimuli. In practice, certain kinds of stimulation cannot be presented in concentrations sufficient to achieve withdrawal. _E.g._, sugar is not held in high concentrations in saliva; certain odors continue to act as attractants when presented in the highest concentrations possible, etc. Because approach responses to _stimuli established as above the withdrawal threshold_ provide the only evidence that negates the theory, it is not easy to see how the theory can be applied in some areas of investigation. Nonetheless, it has proved useful in certain situations, and it often provides a more parsimonious description of behavior at early developmental stages than has been previously offered.

For example, if effective intensity determines responsiveness at early stages of development, certain early developmental phenomena can be reinterpreted. The "disturbed" reactions of neonatal birds to "hawk" models passed over the nest are not interpreted as being due to innate perception and "fear" of predators, but as withdrawal responses to the rapid rate of change of stimulation caused by the moving figure (Schneirla, 1965). In the same way, the crying observed by Bower, Broughton and Moore (1970b, and discussed on pp. 13-15 above) when virtual images were advanced toward infants, can be seen as the result of the increasing optical expansion pattern produced by these "looming" stimuli. This interpretation is further supported by Ball and Tronick's (1971) finding that infants from two to eleven weeks of age respond with integrated withdrawal movements to the visual expansion pattern of "looming" objects projected on a screen. Although these authors discussed their findings in other terms, the rapid rate of change of the intensity of the stimuli presented can be seen as eliciting withdrawal in these infants without assuming higher level processes such as perception.

It is interesting to note that although effective intensity is not a simple concept, similar concepts have been formulated by other investigators to describe the organization of behavior at the earliest stages of development. For example, Heinz Werner (1948) referred to the "syncretic" organization of infant responsiveness, while Piaget (1952) refers to early infancy as the "sensory-motor period." Werner (1948) described consciousness in early infancy as a "mere state of feeling, a total sensation in which object and subject are merged" (p. 65). In Werner's terminology, "primitive" organization is syncretic in the sense that it is diffuse and undifferentiated. To put it differently, "things do not stand out there, discrete and fixed in meaning. . .; responses are determined by the whole vital motor-affective situation" (p. 59). Similarly, Piaget's sensory-motor period has been described as "a reflex level of self-world undifferentiation"(Flavell, 1963, p. 86).

Although approach-withdrawal theory has limitations such as described above (pages 48-51), it nonetheless provides useful hypotheses about the nature of early developmental processes that have guided recent research and have led to interesting findings concerning behavior in early infancy. For example, Turkewitz, Fleischer, Moreau, Birch and Levy (1966) examined the relationship between feeding condition and flexor-extensor movements in infants less than two days old. They found that there was more flexion than extension of the fingers just before feeding (when proximoceptive visceral stimulation from stomach contractions is intense) and more extension than flexion after feeding (when proximoceptive stimulation is of lower magnitude). This provides support for the suggestion that internal stimulation is an important contributor to the effective level of stimulation that leads to directional responses in early infancy. In this case, one interpretation of the results is that before feeding, ambient stimuli in the external environment, in combination with heightened internal stimulation, provided a level of stimulation sufficient to reach the W-system threshold.

It should be noted that while the direction of responses in very young infants can be measured in relation to external stimuli and have important consequences for the organisms' subsequent responses, these early movements are hypothesized to be the result of the arousal of A-processes brought about by supra-threshold stimulation, and need not be thought of as responses _to the direction of external stimuli_. In this view, infants flexed their fingers more than they extended them before feeding because a total level of intensity was achieved that reached the W-system threshold. Flexion was seen as a result of flexor muscle dominance, which is the pattern observed in vertebrates exposed to strong stimulation; while extensor dominance occurs with mild stimulation (Sherrington, 1906, cited by Schneirla, 1959).

To further explore the relationship between effective intensity and directional responses, Hammer and Turkewitz (1975) looked at eye movements in human neonates in response to auditory stimuli. Based upon prior findings (Turkewitz, Birch, Moreau, Levy and Cornwell, 1966) that the right ear has a lower threshold to auditory stimuli than the left, it was hypothesized that the same objective stimulus would be effectively more intense when presented to the infant's right ear than when presented to his left. The A-W hypothesis that there should be towards-turning to effectively weak stimuli and away-turning from effectively strong stimuli was supported by the finding that there was significant towards-turning when a 90 db white noise was presented to the left ear, and significant away-turning when the same objective stimulus (90 db) was presented to the right ear.

Developmental changes in the effectiveness of intensity as a determiner of infant visual attention have also been recently examined. Ruff and Turkewitz (1975) showed infants from six to 24 weeks old pairs of bullseye and striped patterns of five different sizes for each pattern. Their hypothesis was that as infants got older, stimulus intensity, as determined by the size of the stimuli, would decrease in its effectiveness as a determiner of looking. They found that infants ten weeks old and younger responded on the basis of size, looking more at the larger stimulus of the pair, regardless of pattern. Older infants, however, preferred the bullseye, regardless of its size or the size of the striped pattern with which it was paired. This supported the intensity hypothesis for attentional responses at early stages of development when two-dimensional stimuli were presented.

The Additive Nature of Stimulus Dimensions. If it is the intensity, not the quality of a stimulus that determines the nature of responsiveness at early stages of development, many different kinds of stimuli may be effectively equivalent in producing approach responses (if input is low) or withdrawal responses (if input is sufficiently high to reach the W-system threshold). Since the focus is upon the end result of stimulation, stimuli of different modalities, external and internal stimuli, and stimuli of different dimensions within a modality can be seen as additive and to some extent interchangeable in their effects upon response direction. To put it differently, approach responses may be brought about in many different ways, as long as the resulting input is low level and regular.

In this view, newly hatched precocial birds follow their parents not because of perceptual recognition of the parents' appearance, but because the nature of the avian receptors promotes regular neural discharge as a result of stimulation from the parent (Schneirla, 1965). It is therefore not only the parental figure that leads to approach responses in these animals: any stimulus appropriate to the avian receptors can elicit approach at early stages of development if it is sufficient in magnitude to arouse the A-system. Thus all kinds of different stimuli (from green boxes to flashing lights) have been effective A-stimuli leading to following responses in precocial birds (Schneirla, 1965).

Consideration of the additive effects of stimuli from many different sources also is relevant in the analysis of early movement patterns and the basis upon which later patterns develop out of earlier ones. It leads to the suggestion that in neonates there can be substitution between stimuli in different modalities (i.e. a tactile stimulus can be equal to a visual stimulus) as long as total input is of the same effective magnitude. It also suggests the possibility that early embryonic proximoceptive (tactile, chemical, proprioceptive) elicitation of movement provides a basis for later teloreceptive (visual, auditory)elicitation by means of stimulational equivalence. That is, the development of motor responses to auditory and visual stimuli may be based upon the stimulational equivalence of these stimuli to proximoceptive stimuli that controlled the responses earlier in ontogeny.

In addition, if intensity is considered to be a general determiner of directional responses in early infancy, then consideration of any particular stimulus dimension to the exclusion of all others becomes misleading, especially when different investigators believe that the factor they are investigating is the relevant one. If each factor is considered a contributor to the effective intensity of stimulation, then all factors become relevant and arguments over which particular factor determines behavior are resolved. An example comes from a current controversy over the determination of infant responses on the visual cliff (Walk & Gibson, 1961).

Although Walk and Gibson (1961) have suggested that motion parallax _is_ depth perception, motion parallax may be just one form of retinal stimulation which, at early stages of development, will arouse either approach or withdrawal processes, depending upon the magnitude of effective input. For example, Simner (1967) found that the approach behavior of chicks toward either the shallow or deep sides of the visual cliff could be manipulated by changing the size of the squares of which the checkerboard patterns were composed. Walk and Waters (1974) found that both texture of the surfaces of the cliff and motion parallax influenced the preferences of chicks and rats; while Karmel (1969) found that the contour density of patterns to which rats and chicks were exposed determined their responses on the visual cliff. Together, these findings suggest that at early stages of development it is not "depth perception," an innate fear of height, or any one factor (such as parallax) that leads to the differential responding of neonates in the visual cliff situation. Rather, these responses are related to changes in stimulus intensity which can be brought about in several different ways (_e.g_. by manipulating the size, texture, motion parallax or contour density of visual elements).

This interpretation of stimulus intensity as a determining mechanism underlying behavior on the visual cliff at early stages of development is further supported by a study of the behavior of prelocomotor infants on the visual cliff (Campos, Langer, and Krowitz, 1970). There was significant cardiac deceleration on the deep side as compared to acceleration on the shallow side of the cliff. There was significantly more "looking down" on the deep than on the shallow side, and there was significantly less fussiness and crying, "a total picture obtained on the deep side . . . of motor quieting . . . All of these criteria characterize quieting rather than fear" (p. 197). The authors interpreted these results as "consistent with the view that infants perceive depth at the ages tested" (p. 197), calling these responses "non-specific orienting responses" that indicate "discrimination" even though the responses were in a direction other than expected. Again, an alternative explanation is possible: The fact that the infants responded differently toward the deep and shallow sides of the cliff does not demonstrate the basis for their differential responsiveness. Although the authors did not see it this way, the "orienting responses" they observed can be interpreted as low level, intensity-determined responses of the A-system, rather than evidence of the perceptual discrimination of depth.

In summary, the levels concept and the approach-withdrawal theory provide a useful framework for understanding certain aspects of infant behavior, including behavior on the visual cliff, visual fixation, eye turning, and finger movements. In each case, when behavior was found to be intensity-determined, it was considered to reflect a low level of organization characteristic of early stages of development. In the following chapter, the levels concept and the concept of early stimulational additivity are applied to the study of finger movements in human infants in order to understand the changing bases of visual-motor behavior in early infancy.

Chapter III

Levels in the Organization of Visual-Motor Responses in Early Infancy

Hypotheses

This study investigates the possibility that there will be qualitatively different levels of organization during human infancy, which will be reflected in different mechanisms for determining directional visual-motor responses.

Although there has been considerable attention paid to both the development of increased accuracy of reaching (e.g. Castner, 1932; Gesell, 1934; Halverson, 1931; McGraw, 1941; Shirley, 1933) and the conditions necessary for the development of accurate reaching (e.g. Blakermore & Cooper, 1970; Dews & Wiesel, 1970; Held & Bauer, 1967; Held & Hein, 1963; Riesen, 1975; Spinelli, 1974; Walk & Bond, 1971; White & Held, 1966), there has been little or no attention paid to the mechanisms responsible for determining the direction of early limb movements or the stimulus conditions that elicit extension at different stages of development.

The current investigation seeks mechanisms which may account for the initiation and direction of visual-motor responses in human infants at different ages. It explores the hypothesis (Schneirla, 1959, 1965) that at early stages of development, directional responses are determined by the intensity of stimulation which organisms receive, while at later stages of development, intensity no longer plays a major determining role. Applying this suggestion to the development of extension responses in human infants, early movements of the arms and fingers may be related to the intensity of visual stimulation to which infants are exposed. If early movements are elicited by the general-intensity characteristics of stimulation, rather than by the perceptual characteristics of stimuli, these movements can be seen as reflecting a sensory-motor level of organization rather than a perceptual or cognitive level.

The levels approach thus suggests the possibility that there will be qualitatively different levels of organization during human infancy that are reflected in different mechanisms for determining directional visual-motor responses. The approach-withdrawal hypothesis (Schneirla, 1959, 1965) provides grounds for predicting the direction that these early visual-motor responses will take. According to this hypothesis, at early stages of development organisms tend to approach weak sources of stimulation and withdraw from more intense sources of stimulation. Applied to human infancy, early movements of the fingers may be related to stimulus intensity, with weak stimuli eliciting extension and more intense stimuli eliciting flexion.

Finger movements were chosen because they may be important precursors of reaching and grasping, and because it has been suggested (Sherrington, 1906, cited by Schneirla, 1959) that in vertebrates the flexor muscles dominate over the extensors under strong stimulation, while under mild stimulation the extensor muscles dominate over the flexors in the determination of movement. In addition, the direction of finger movements with regard to approach and withdrawal is easily specified: Flexion in general serves to increase the distance between the subject and an external source of stimulation; while extension in general serves to decrease that distance. It should be noted that the approach-withdrawal hypothesis predicts the directional responses of only very young infants. Since the responses of older infants are expected to be determined by factors other than intensity alone, no simple prediction about the direction of older infants' responses is possible under the hypothesis.

If intensity is the main determiner of directional responses in very young infants, then stimulus dimensions would be important in terms of their contributions to effective intensity, rather than in terms of their qualitative characteristics. There are several ways of viewing the roles of stimulus dimensions. Many investigators (e.g. Fantz & Fagan, 1975; Hershenson, Munsinger & Kessen, 1965; Karmel, 1969) have chosen particular dimensions, varied their presentation, and then observed whether or not these variables affected responsiveness. Variables such as contour density, number of elements in a pattern, and number of angles have each been identified in this way as important determiners of infant attention. An alternative view suggests that infants do not respond to these variables in terms of the kinds of stimulation they represent, but are responding in each case to the amount of stimulation presented. In this view, each stimulus dimension makes a quantitative contribution to a general level of intensity which in turn determines responsiveness.

Thus the various dimensions of visual stimuli may be additive in their effects upon response determination in early infancy. Therefore, if stimulus attributes such as size, distance and illumination were varied so that quantitatively different levels of each attribute were presented in combination with different levels of the other attributes, it would be expected that there would be approach to effectively weak combinations and withdrawal from effectively intense combinations.

To test these hypotheses, a three dimensional object was presented in different combinations and levels of size, brightness and distance from the subject to infants from ten to twenty-five weeks old. Finger movements were observed to test the hypotheses that: 1. There would be age-related changes in the basis upon which these movements were determined, with only the younger infants responding on the basis of general stimulus intensity; 2. The direction of the younger infants' responses would be determined by the level of intensity to which they were exposed, with approach (extension) movements elicited by the weak stimuli and withdrawal (flexion) by the more intense stimuli; and 3. The effects of size, distance and illumination would be additive in their contributions to general stimulus intensity; therefore, the finger movements of the younger infants would be a function of the total amount of stimulation, regardless of the manner in which it were achieved.

Subjects

The subjects were six male and eight female infants between the ages of ten and twenty-five weeks, all but one born at the Albert Einstein College Hospital in the Bronx, New York. They were all normal full-term infants who were the product of routine, uncomplicated deliveries and had Apgar scores[1] (Apgar and James, 1962) of 8 or higher taken five minutes after birth.

The age range from 10 to 25 weeks was chosen as a "best guess" about when a transition from intensity-determined to other-determined responsiveness might occur. If intensity-determined responsiveness is considered an indicator of low-level responding characteristic of early developmental stages, there is evidence from several sources that an intensity-determined pattern dominates responses to visual stimuli at least up to about 10 weeks of age. Developmental studies (e.g. Ruff and Turkewitz, 1975 and Fantz, 1966) indicated that the well-known bullseye pattern preference occurs between 10 and 25 weeks of age, but that factors such as the size of the stimulus determined fixation time at earlier ages. Similar results were found when behavior on a visual cliff was observed. As mentioned earlier (pp. 58-9) infants who could not yet crawl responded to the "deep side" of the cliff on the basis of intensity, rather than depth perception, while older infants (six months of age) displayed behavior that indicated they were responding at a higher level of organization.

These findings suggest that a transition from intensity-determined to other-determined responsiveness takes place in the visual-motor system sometime between 10 and 25 weeks of age. It seemed likely that by testing infants within this age range, a similar transition might appear when finger movements were observed.

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[1] An assessment of gross physical condition at birth, including color, respiration, heart rate, muscle tone, etc., performed by the physician at birth. Scores range from 0 through 10 with 8 to 10 usually indicative of good condition.

Addresses were obtained for the parents of 55 infants and letters soliciting participation in the study were sent to thirty families living within commuting distance of the hospital. Of twenty one appointments that were made, four were not kept due to illness or cancellation; insufficient data was obtained from three infants who were too fussy to complete testing; and data from one other infant was unscorable because of technical problems. The result of contacts made through hospital records is shown in Table II. One other subject, who was born at New York Hospital in Manhattan, was apparently healthy at the time of testing and was included in the sample although her Apgar score and birth records were not examined.

Table II

Result of Contacts Made through Hospital Records

	Number	Remainder
Letters sent	30	
Returned undelivered	3	27
No response	6	21
Cancellations	2	19
Absentees	2	17
Insufficient data	3	14
Data unscorable	1	13

The final sample of fourteen infants included in this study is described in Table III which lists their age at testing, birth weight, and sex. All came from middle and upper-middle class families living in the Bronx or nearby suburbs. They were predominantly white, although one had a black father and white mother, two were black, and two were Puerto Rican. All were born between January and June of 1974 and tested between April and September of that year. All were apparently normal and healthy, and, according to their parents' reports, had had no illnesses other than colds up to the time of testing.

Apparatus

Testing took place in a chamber 1.68 meters high, 1.83 meters deep and 1.22 meters wide, enclosed on the top and three sides by uniform light brown curtains. A molded plastic infant seat, fitted into a canvas stroller on a platform 30.48 cm above the chamber floor, stood in the middle of the chamber facing the front curtains. The height and angle of the platform were adjustable, so that infants of varying age and size could be positioned comfortably.

Behind the front curtains was a display panel which ran on wheels along a track and could be positioned from 42 cm to 1.22 meters from the infant seat. The front curtains were hung from a rod along the top of the display panel and were arranged so that equal amounts of curtain framed the sides of the display panel when the curtains were opened. There were drawstrings located behind the panel for opening and closing the curtains.

A diagram of the chamber with the front curtains open and the display panel visible is presented in Figure 2. The display panel

Table III

Age, Sex and Birth Weights of Subjects Observed

ID Number	Sex	Birthweight		Age at Testing	
01	M	8 lbs	3 oz	10 wks	2 days
02	F	6	5	12	
03*	F	7	6	12	4
04	M	8	4½	12	5
05	F	6	4	13	4
06	F	7	4	13	4
07	F	6	4½	14	5
08	M	6	11½	17	5
09	F	6	3	17	5
10	F	7	11	19	6
11	F	6	15	21	
12	M	8	12	23	2
13*	F	7	6	23	6
14	M	7	4½	24	2
15	M	7	5	25	1

* Same subject, tested twice

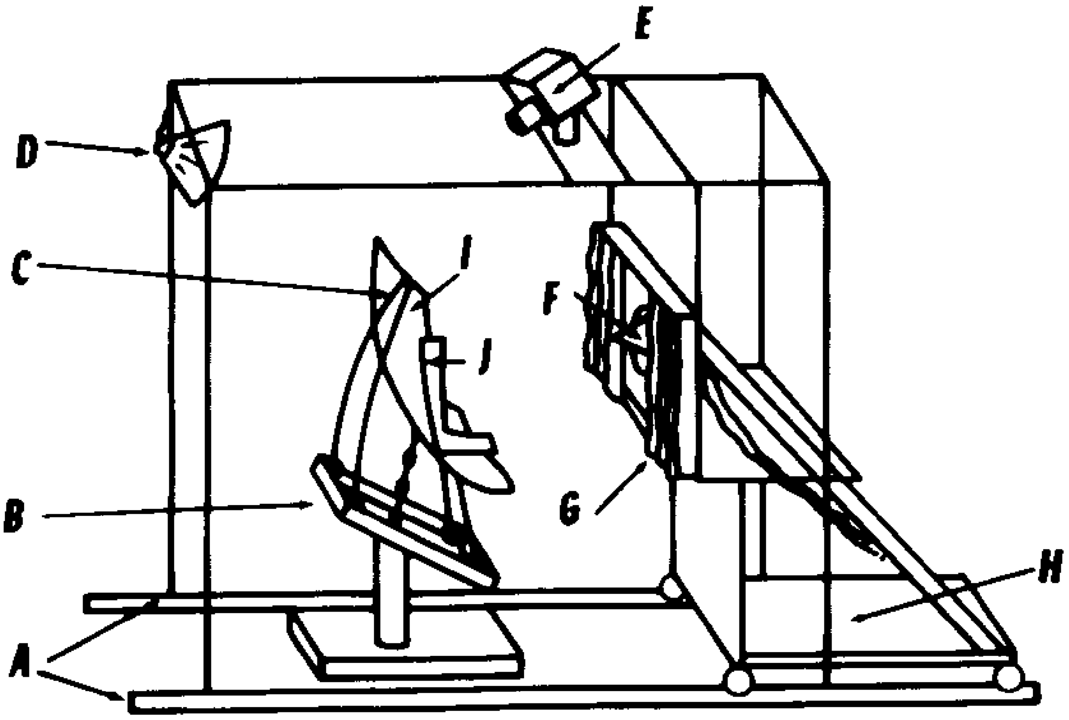

Figure 2: Chamber for Observing Infant Visual-Motor Responses. Infants were placed in molded plastic seat (J), fitted into canvas stroller (I), mounted on adjustable platform (B). Rotating cone (F) was revealed when the observer, sitting at (H) opened the curtains (G). The display panel ran on wheels along tracks (A). Lamp (D) provided additional illumination for the videotape camera (E).

was covered in the same light brown fabric as the curtains and had a round opening at its center with an iris diaphragm that could be opened to diameters from .6 cm to 22.86 cm. A three-dimensional cone-shaped object with a base diameter of 20.32 cm and length of 20.32 cm protruded horizontally through the center opening. The cone was covered in red wool looped-pile fabric and was mounted on a shaft attached to a motor so that it could be rotated. The visible size of the cone was varied by changing the setting of the diaphragm and positioning the cone forward or back through the opening. The cone was also completely removed at times and the opening covered with a piece of cloth that matched the rest of the display panel.

In order to illuminate the cone, a 75 watt flood light was mounted behind the front curtains at each side of the display panel and focused on the cone. These floodlights were wired through a voltage regulator so that the brightness of light reflected by the cone could be varied. Figure 3 shows side and rear views of the testing apparatus.

A third lamp (60 watt incandescent) at the top of the chamber just above and behind the infant seat provided sufficient light inside the chamber for videotaping the subjects' responses. The videotape camera was located outside the chamber and focused on the infant seat through a hole in the top of the chamber. A television monitor behind the display panel permitted observation of the infant while recording was in progress. A tape recorder with earphones provided auditory signals for timing the trials and the intertrial intervals.

The apparatus made it possible to vary the size and brightness

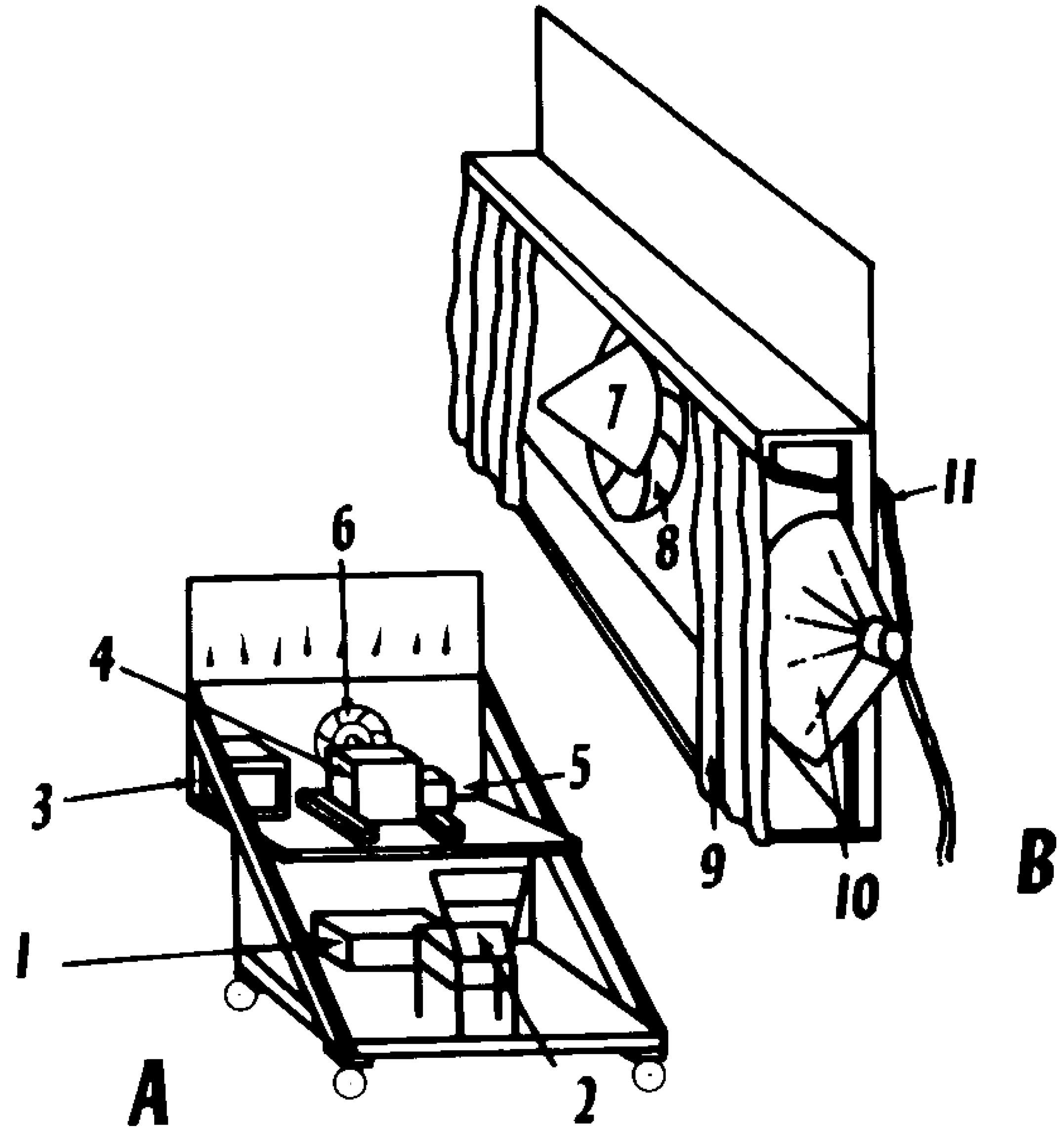

Figure 3: Apparatus for Observing Infant Visual-Motor Responses. A. Rear View: 1. videotape recording machine 2. observer's chair 3. television monitor 4. motor for rotation of cone 5. voltage regulator for side lamps 6. iris diaphragm B. Side view: 7. cone 8. iris diaphragm 9. curtains 10. side lamp 11. curtain drawstrings.

of the cone, as well as its distance from the subject. It also provided a barrier between the mother and the infant, so that there was no interaction between them during the test session. Although the infant could not see the mother, the mother and the observer could watch the infant on the TV monitor, even when the curtains were closed. The videotape equipment also provided a record of the infant's movements which could be analyzed later.

Procedure

As described above (pages 45-56), effective intensity is considered to be the total amount of stimulation to which the subject responds, including both external and internal sources of stimulation. In this study, variations in effective intensity were considered to be combinations of internal stimulation (held constant) and external stimulation (varied). In other words, different levels of effective intensity were achieved by holding state roughly constant (testing only infants who were quiet, alert, well-fed, dry, etc.) and manipulating external stimulation by presenting stimuli whose dimensions varied.

Each infant was presented the same eight stimulus conditions, each representing one of two values for each of three stimulus dimensions. The dimensions and values were: size of cone (large = 17.78 cm, small = 8.89 cm), brightness of illumination (bright = 1200 lux at 50.8 cm, dim = 300 lux at 50.8 cm), and distance from the subject (near = 50.8 cm from the center of the seat, far = 101.6 cm from the center of the seat). There were thus eight stimulus combinations including near-large-bright, near-large-dim, near-small-bright, near-small-dim, far-large-bright, far-large-dim, far-small-bright, and far-small-dim. There was also a "catch" condition which consisted of the unilluminated display panel with the cone removed and the panel of brown cloth covering the opening.

A randomized block of all four combinations of size and brightness and one catch trial was presented to each subject twice in the near and twice in the far position. Thus ten near trials were followed by ten far trials in alternating sequences. A different randomization was used for each subject, and half received the far trials first, while half received the near trials first. This sequence was repeated until half an hour had elapsed on tape or the infant became fussy.

Observation took place in a laboratory at the Rose F. Kennedy Center for the Study of Mental Retardation and Human Development, at the Bronx Municipal Hospital Center. Each baby was seen once, except one who was seen at 12 weeks and again at 23 weeks of age. The time of observation was determined by the mother, who was asked to make an appointment for the time of day when she felt her baby would be most alert, awake and comfortable. Mothers were also asked to have their babies well-fed and rested before testing. Diapers were checked just before testing began and changed if necessary. No baby was tested unless in a quiet, alert state. If a subject became fussy or started to cry, testing was discontinued until the infant was quiet.

Before observation began, the infant was positioned in the infant seat at an angle suited to the infant's age and size. For the younger infants, the seat was tilted back slightly to provide head support; for the older infants it was in a more upright position. Each infant was tested in sitting position and wore a seatbelt in the form of a harness that went between the legs and around the waist, holding the infant securely in the seat but allowing free movement of the arms and legs. The belt was fastened behind the seat, so that the ends were not available for manipulation by the infant.

After the baby was positioned comfortably facing the front curtains, the room lights were turned off so that only the top light illuminated the chamber. The mother and the observer then went behind the display panel, where they could watch the infant on the television monitor while the observer manipulated the stimulus conditions and presented the trials. The curtains were then opened to reveal the display panel with the red cone illuminated and rotating slowly at 34 rpm. The curtains remained open for five seconds, then were closed, marking the end of the first trial.

In order to time the trials, each of which lasted five seconds, the observer wore earphones connected to the tape recorder which presented five-second tones at ten-second intervals. Intertrial intervals were either ten or twenty-five seconds long, depending upon how long it took the observer to set up the next stimulus condition, and how the baby was oriented at the end of the first ten-second interval. For the first few trials, if the observer was ready within ten seconds and the baby was facing forward, the curtains were opened as soon as the tone began. If the baby was not facing forward or if the observer was not ready with the next stimulus, the observer waited until the next five-second tone began and opened the curtains then whether or not the infant was facing forward. After the first few trials, the sound of the curtains acted as an orienting device, and the infant usually looked forward immediately, making it unnecessary to wait before presenting the next trial.

Trials were scored for the nature of the first discernable finger movement after the curtains opened. Possible scores were extension, flexion, or no movement. Trials on which the infant did not look forward within one second of the curtain-opening were omitted from the scoring. The same observer scored all the videotapes; however, each tape was also scored independently by a second scorer. After each tape had been scored twice, the scores were compared, and trials on which there was disagreement were rescored by each scorer independently. If there was still disagreement, a third scorer was used. Trials on which there was no agreement between at least two out of three scorers were noted as "unscorable." A record was kept of the frequency and conditions under which these trials occurred and also for trials on which no movement of the fingers was observed. Such trials occurred at very low frequencies and were not included in the data analysis. As a result, different subjects completed different numbers of trials. If any stimulus condition did not have at least three scorable trials (extensions and/or flexions), a ratio score for that condition was not computed for that subject.

Scorers were trained by having them read typewritten scoring instructions before scoring a practice tape which the observer had previously scored. After scoring the tape, it was then replayed and the trials upon which the scorers did not agree were discussed.

One other practice tape was scored and discussed before the scorer was considered trained.

Reliability was assessed by selecting a pair of scorers from a pool of eight who had scored tapes, and having them score fifty trials from a tape which they had not seen before, but which had been scored by two other scorers. They followed the same procedure as described above, using a third scorer to resolve trials upon which they did not agree. Their final scores were then compared to the scores which had previously been obtained. This procedure was repeated, using another tape and another group of four scorers. In both cases, the agreement among the four observers, judging trials independently, was from 80 to 82% for fifty trials. It should be noted that scoring involved the identification of a complex movement pattern which was often somewhat ambiguous. Scorers were instructed to score the first discernable finger movement which ranged from one finger moving slightly to several fingers moving simultaneously. The task was also complicated by videotapes of low contrast. Nonetheless there were relatively few unscorable trials.[1]

Results

Since one of the main hypotheses of this investigation was that there would be age-related changes in the role of intensity as the determiner of extension movements, the data were first examined to determine the relationship between the intensities of the stimuli presented and the subsequent direction of finger movements.

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[1] A breakdown of total trials presented and the responses scored for each subject can be found in Appendix A.

The response measure used was ratio of finger extensions to the total number of extensions and flexions that occurred on stimulus trials. A ratio score was used because subjects did not complete the same number of trials, making comparisons in terms of absolute numbers inappropriate. This particular ratio was chosen because it provided an index of both extension and flexion: e.g. a ratio of .75 indicated that a subject extended the fingers on 75% of the trials on which there was a scorable response, and flexed the fingers on 25% of these trials.

In order to examine the relationship between finger movements and stimulus intensity, it was necessary to order the stimuli with respect to intensity. Within each dimension, it is easy to rank the stimuli from less intense to more intense, i.e. small is less intense than large, far less than near, and dim less than bright. However, because it was not known how much size, brightness and distance would each contribute to total effective intensity, it was impossible to rank all the stimuli from least to most intense. It was, however, clear that the far-small-dim combination was objectively the least intense, as it represented the lower value for each stimulus dimension; and that the near-large-bright combination was the most intense, representing the higher values for all three dimensions. Therefore, the responses to these two stimuli were examined in order to see if there were age-related differences in responding.[1]

When the extension ratio to the most intense stimulus, the

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[1] Correlations between age and extension ratio scores for all stimulus conditions can be found in Appendix B.

near-large-bright, was correlated with the age of the subject, an R of .68 was obtained ($p < .01$, $N = 15$), indicating that as age increased, the proportion of extension responses to the near-large-bright stimulus relative to flexion responses increased. In other words, younger infants showed lower extension (higher flexion) ratios than did the older infants.

When the extension ratios to the far-small-dim stimulus were correlated with age, the correlation was not significant ($R = -.30$, $N = 15$). Examination of the scores revealed a tendency for all subjects to respond to this weakest stimulus with high ratios of extension. A scattergram of the ratio scores to the near-large-bright and far-small-dim stimuli, illustrating the response patterns described above is presented in Figure 4. The lines of closest fit have been estimated by eye.

To further examine the relationship between age and pattern of responding, the subjects were divided into two groups which clearly differed in age. Two subjects fell exactly in the middle of the age distribution. Since there was no *a priori* reason to assign these two subjects, aged 17.7 weeks, to either a younger or older age group, they were eliminated from further analyses in order to increase the likelihood of finding age effects which might be present.

When responses to the near-large-bright stimulus were examined, the mean ratio of extension for the younger infants (ages 10 to 15 weeks) was 42.1; for the older infants (ages 20 to 25 weeks) it was 86.2, a difference that was highly significant ($t = 2.97$, $p < .01$). The mean ratios of extension to the far-small-dim stimulus were 83.6

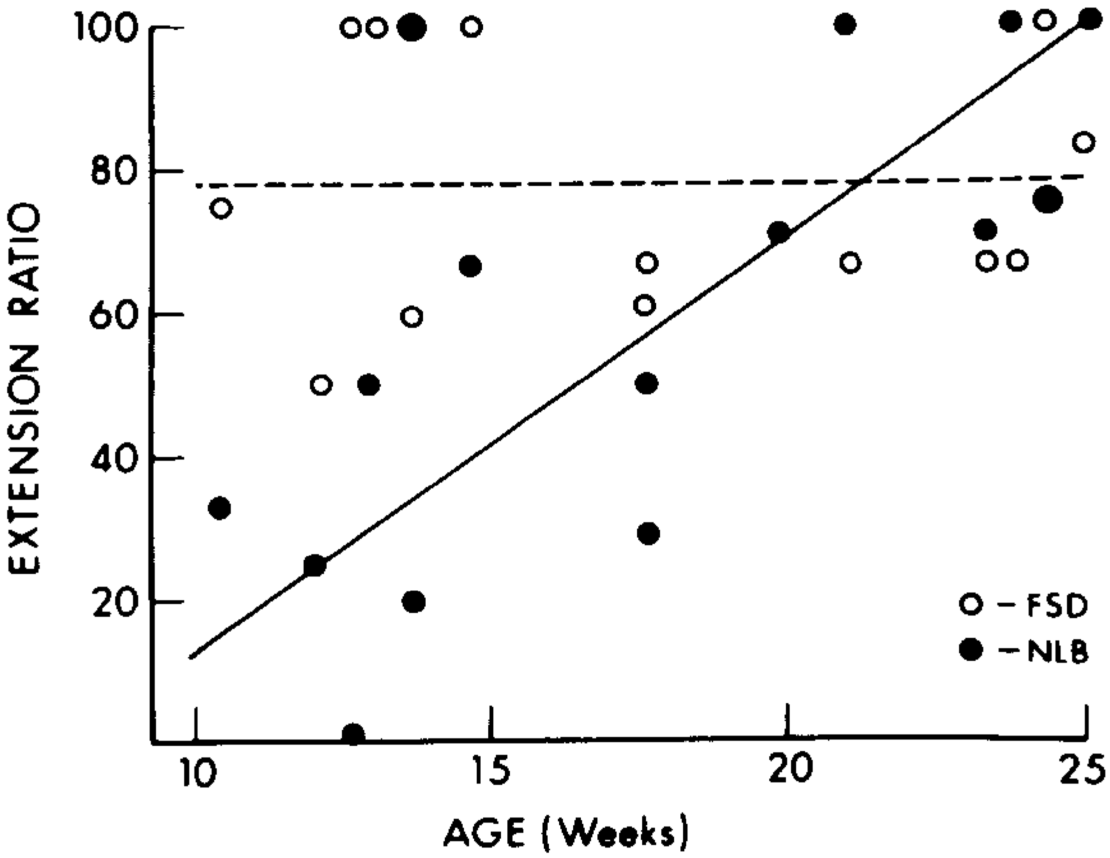

Figure 4: Finger Extension Ratios to Near-Large-Bright and Far-Small-Dim Stimuli. Lines of closest fit were estimated by eye.

and 72.7 for the younger and older groups respectively. Both groups extended more than they flexed, and there was no significant difference between them.

The hypothesis that the younger infants would extend more to weak stimuli and less to intense stimuli, while the older infants would not exhibit any clearcut relationship between intensity and finger movements was also supported by the data. As can be seen in Table IV, the younger infants had significantly higher extension ratios to the weakest stimulus than they did to the most intense one. The older infants displayed high extension ratios to both stimuli and there was no significant difference in response to them.

Table IV

Mean Finger Extension Ratios to Near-Large-Bright and Far-Small-Dim Stimuli

Subjects	Far-Small-Dim	Near-Large-Bright	*t*
Ages 10 - 15 weeks	83.6	42.1	2.02*
Ages 20 - 25 weeks	72.7	86.2	1.48
t =	.44	2.97**	

* = $p < .05$
** = $p < .01$

In order to determine whether the differences found in the response patterns of the two groups were a function of simple age-related differences in finger-movement independent of the stimuli presented (*e.g*. a greater tendency for younger infants to flex their fingers), rather than differences in response to the intensity of the stimuli presented, the responses that the two groups made during non-stimulus trials were compared. If the previously obtained differences were due to age-related response tendencies in general, rather than age-related differences in response to the characteristics of the stimuli presented, it would be expected that the younger and older infants would respond differently in the absence of these stimuli. As can be seen in Table V, when the responses of the younger and older infants were compared for the catch trials, no significant differences were found for extension, flexion or percentage of not responding.

Table V

Finger Response Frequencies of Younger and Older Infants On Non-Stimulus Trials

	Weeks of Age			
Response	10-15	20-25	t	p
Extension	61%	69%	1.14	n.s.
Flexion	15%	21%	.90	n.s.
No Response	13%	07%	1.18	n.s.
Unscorable/ Not looking	11%	03%		

In order to examine the roles of age, size, distance and illumination in determining finger movements, the extension ratio scores were examined in a 2x2x2x2 analysis of variance with age, size, distance and illumination the factors. Age was treated as a "between subjects" variable, and distance, size and illumination were treated as "within subjects." The grand mean was used to estimate the values for four missing scores. As can be seen in Table VI, the only significant main effect was size ($p < .01$). There was a tendency for responses to be age-related, but this did not reach significance ($p = .07$). There was no indication of an age x size interaction. Finally, there was a highly significant four-way interaction ($p < .001$).

The data were then examined to see if there were any source of unusual and extreme variability which might be obscuring the findings. From inspection of Table VII which presents the extension ratios of each subject to each stimulus combination, it is readily apparent that one of the subjects in the younger group (06) displayed a response pattern that was strikingly different from the other members of her group. This was particularly evident when her mean score was compared to that of another subject (05) of the same age and sex, and when her mean score was compared to the scores of all the other members of her group.[1] Subject 06 was therefore eliminated from the analysis, and another analysis of variance was performed.

As can be seen from Table VIII, when this subject is eliminated

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[1] Appendix C contains the means and standard deviations of the extension ratios of each subject. It should be noted that in other samples with the same mean and standard deviation, only 15.3% of the subjects would have scores as extreme or more extreme than subject 06.

Table VI

Analysis of Variance Summary Table for Finger Extension Ratios

Infants 10-15 and 20-25 Weeks Old

Source	df	MS	F	Probability
Age (A)	1	.7622	3.868	.075*
Subjects/Age (S/A)	11	.1971		
Distance (D)	1	.0194	.419	.5308
Age x Distance	1	.0123	.266	.6159
Distance x (S/A)	11	.0463		
Size	1	.3672	15.565	.0023**
Age x Size	1	.0646	2.739	.1262
Size x (S/A)	11	.0236		
Illumination (I)	1	.0408	.503	.4931
Age x Illumination	1	.1241	1.528	.2421
Illumination x (S/A)	11	.0812		
Distance x Size	1	.0183	.359	.5615
Age x Distance x Size	1	.0421	.824	.3834
Distance x Size x (S/A)	11	.0511		
Distance x Illumination	1	.0877	1.510	.2448
A x D x I	1	.0155	.268	.6152
D x I x (S/A)	11	.5809		
Size x Illumination	1	.0183	.286	.6032
A x Size x I	1	.0237	.371	.5548
Size x Ill. x (S/A)	11	.0639		
D x Size x Illumination	1	.0125	.520	.4859
A x D x Size x I	1	.5200	21.639	.0007***
D x Size x I x (S/A)	11	.0240		

* = $p < .10$
** = $p < .01$
*** = $p < .001$

Table VII

Finger Extension Ratios

Ages 10 to 15 Weeks

Subject	Sex	Age	NLB	NLD	NSB	NSD	FLB	FLD	FSB	FSD
01	M	10.3	33	67	100	50	75	25	100	75
02	F	12.0	25	100	100	100	50	60	75	50
03*	F	12.6	0	33	50	50	0	67	0	100
04	M	12.7	50	***	50	25	33	50	0	100
05	F	13.6	20	0	57	62	40	67	40	60
06**	F	13.6	100	100	100	67	100	75	100	100
07	F	14.7	67	50	67	80	50	25	33	100
Ages 20 to 25 Weeks										
10	F	19.9	71	17	71	67	100	***	67	***
11	F	21.0	100	***	80	60	25	50	75	67
12	M	23.3	71	83	60	67	25	100	100	67
13*	F	23.9	100	100	100	100	50	100	100	67
14	M	24.3	75	67	80	80	80	75	100	75
15	M	25.1	100	100	80	100	67	67	100	83

*Same subject, tested twice

**This subject was considered to display a response pattern atypical of her age group

***Insufficient data to compute extension ratio

Table VIII

Analysis of Variance Summary Table for Finger Extension Ratios

Subjects 10-15 and 20-25 Weeks Old
(Omitting Subject 06)

Source	df	MS	F	Probability
Age (A)	1	1.2421	11.065	.0077**
Subjects/Age (S/A)	10	.1123		
Distance (D)	1	.0234	.462	.5122
Age x Distance	1	.0092	.181	.6792
Distance x (S/A)	10	.0507		
Size	1	.4082	22.720	.0008***
Age x Size	1	.1027	5.716	.0379*
Size x (S/A)	10	.0180		
Illumination	1	.0726	.970	.3480
Age x Illumination	1	.1944	2.596	.1382
Illumination x (S/A)	10	.0749		
Distance x Size	1	.0067	.132	.7240
A x D x Size	1	.0683	1.351	.2721
Distance x Size x (S/A)	10	.0505		
Distance x Illumination	1	.0900	1.428	.2596
A x D x I	1	.0210	.333	.5766
D x I x (S/A)	10	.0630		
Size x Illumination	1	.0176	.251	.6275
Age x Size x I	1	.0247	.352	.5663
Size x Ill. x (S/A)	10	.0702		
D x Size x Illumination	1	.0033	.1236	.7324
A x D x Size x I	1	.4874	18.4457	.0016**
D x Size x I x (S/A)	10	.0264		

* = $p < .05$
** = $p < .01$
*** = $p < .001$

from the analysis, both the expected age and age x size effects are significant. The main effect of size ($p < .001$) and a main effect of age ($p < .01$) appeared in addition to a significant age x size interaction ($p < .05$)[1]. The four-way interaction was also significant ($p < .01$). Although all subsequent analyses were performed including and excluding data from subject 06, only the results excluding that subject will be presented here. Analysis including that subject can be found in Appendix D.

Age and Size. The relationship between the age groups and their finger responses to stimuli of different sizes is shown in Figure 5. As can be seen in the figure, both age groups responded with higher extension ratios to the small than to the large stimuli. The age x size interaction resulted from the younger infants' display of much higher extension ratios to the small than to the large stimuli, while the older infants exhibited only slightly higher ratios of extension to small than to large stimuli. When separate analyses of variance[2] were conducted for the younger and older infants, the size effect was found to be significant for both the younger infants ($F = 17.4$, $df = 1,5$ $p < .01$) and the older ones ($F = 1,5$ $p < .001$). Although the differences between the means were small in the case of the older infants, they were highly consistent across subjects and were thus significant differences. The means and standard errors for Figure 5 and all subsequent histograms are listed by age group and

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[1] The mean extension ratios for all four variables can be found in Appendix G. It should be noted that although the illumination effect did not reach significance, it was in the expected direction.

[2] Complete analysis of variance summary tables are presented in Appendices E and F.

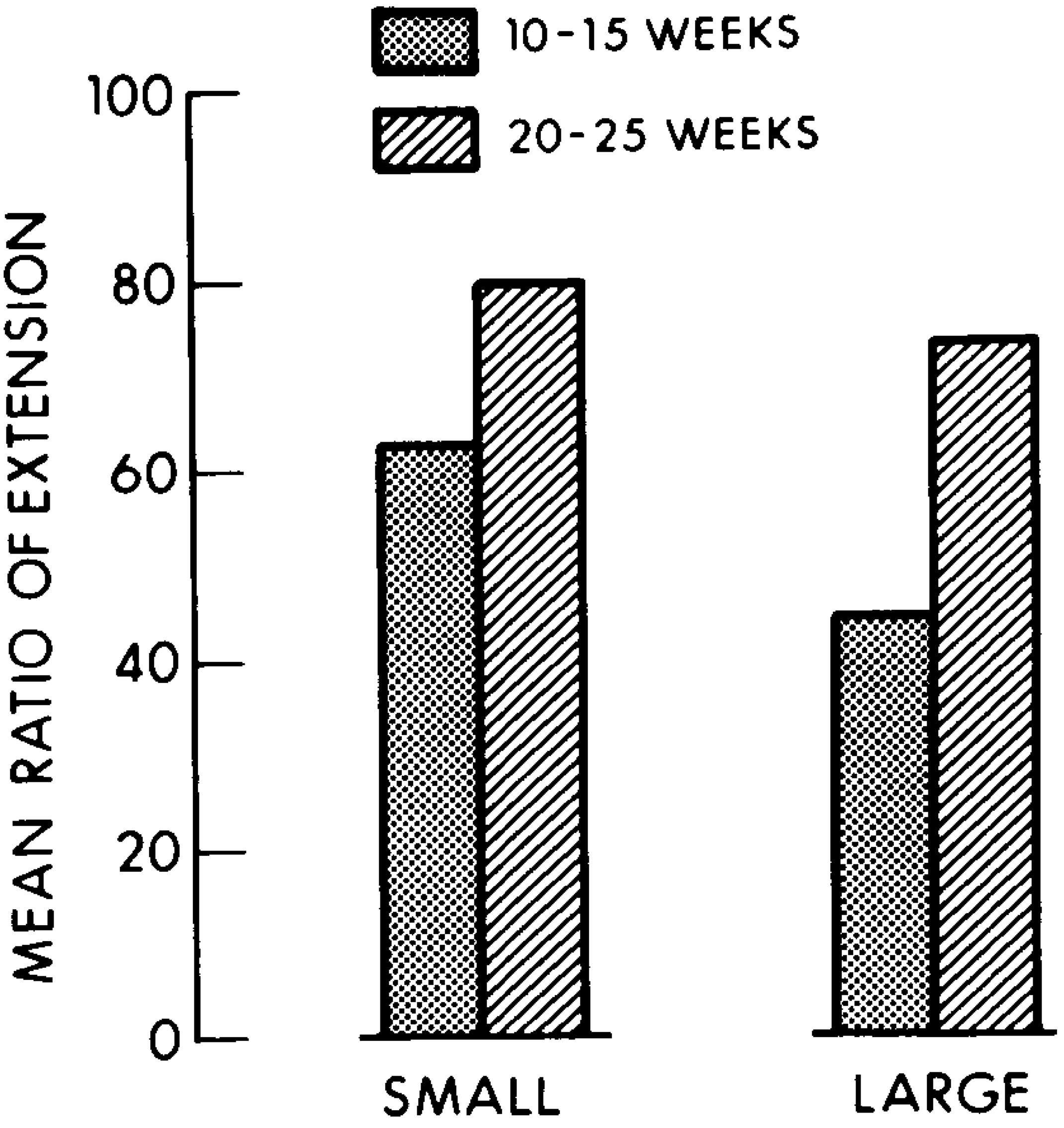

Figure 5: The Relationship between Age and Finger Responses to Stimuli of Different Sizes. For means and standard errors, see Table IX, page 88.

stimulus condition in Table IX.

Size and Illumination. In examining the relationship between age and finger movements to stimuli that varied in size and brightness, the small-dim stimuli were objectively less intense than the large-bright stimuli, since these combinations each represented extreme levels of size and brightness. However, the large-dim and the small-bright stimuli could not be ordered in terms of their intensity, because the relative contributions of size and brightness to intensity were not known. Data from these stimuli were therefore combined, since they were all stimuli of intermediate intensities between the extremes of small-dim and large-bright[1]. It can be seen in Figure 6 that the responses of the younger infants followed an intensity gradient: Their extension ratios were highest to small-dim stimuli, slightly lower to intermediate stimuli, and lowest to large-bright stimuli. The older infants displayed a different response pattern, with high extension ratios to all the stimuli.

Size and Distance. The relationship between age and finger movements to stimuli that varied in size and distance is shown in Figure 7. The far-small stimuli represented the least intense combination, while the near-large represented the most intense. The data from the intermediate stimuli were again combined. As can be seen in the figure, the younger infants had highest extension ratios to the far-small stimuli, lower extension ratios to the intermediate stimuli and still lower extension ratios

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[1] Although the means of the intermediate stimuli are combined in Figure 6 and in subsequent figures, all individual means are presented in Appendix G.

Table IX

Means and Standard Errors, By Age and Stimulus Condition

Histogram	Age Group	Stimulus	Mean	Standard Error
		Size		
Fig. 5	10-15 weeks	Large	.44	.05
		Small	.64	.06
	20-25 weeks	Large	.74	.05
		Small	.80	.03
		Size + Illumination		
Fig. 6	10-15 weeks	B-L	.37	.07
		D-S	.71	.07
		B-S + D-L	.53	.06
	20-25 weeks	B-L	.72	.08
		D-S	.76	.04
		B-S + D-L	.80	.04
		Size + Distance		
Fig. 7	10-15 weeks	N-L	.42	.08
		F-S	.61	.11
		N-S + F-L	.56	.05
	20-25 weeks	N-L	.80	.07
		F-S	.81	.04
		N-S + F-L	.73	.04
		Distance + Illumination		
Fig. 8	10-15 weeks	N-B	.52	.09
		F-D	.65	.08
		N-D + F-B	.49	.06
	20-25 weeks	N-B	.82	.04
		F-D	.75	.04
		N-D + F-B	.75	.05
		Distance + Size + Illumination		
Fig. 9	10-15 weeks	NLB	.33	.10
		FSD	.81	.09
		NLD+NSB+NSD +FLB+FLD+FSB	.53	.05
	20-25 weeks	NLB	.86	.05
		FSD	.73	.03
		NLD+NSB+NSD +FLB+FLD+FSB	.76	.04

N = Near F = Far
B = Bright D = Dim
L = Large S = Small

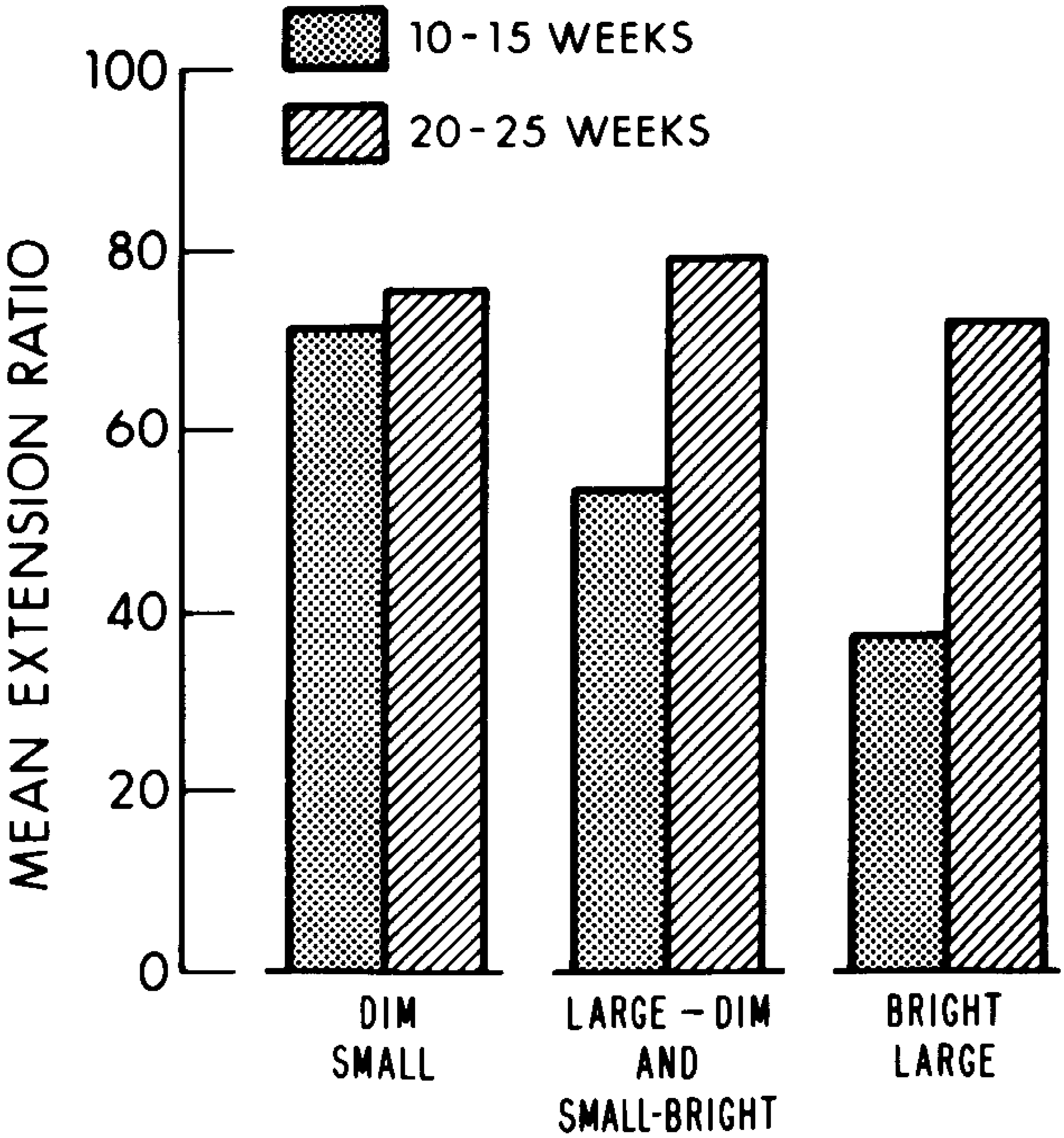

Figure 6: The Relationship between Age and Finger Responses to Stimuli that Varied in Size and Illumination. For means and standard errors, see Table IX, page 88.

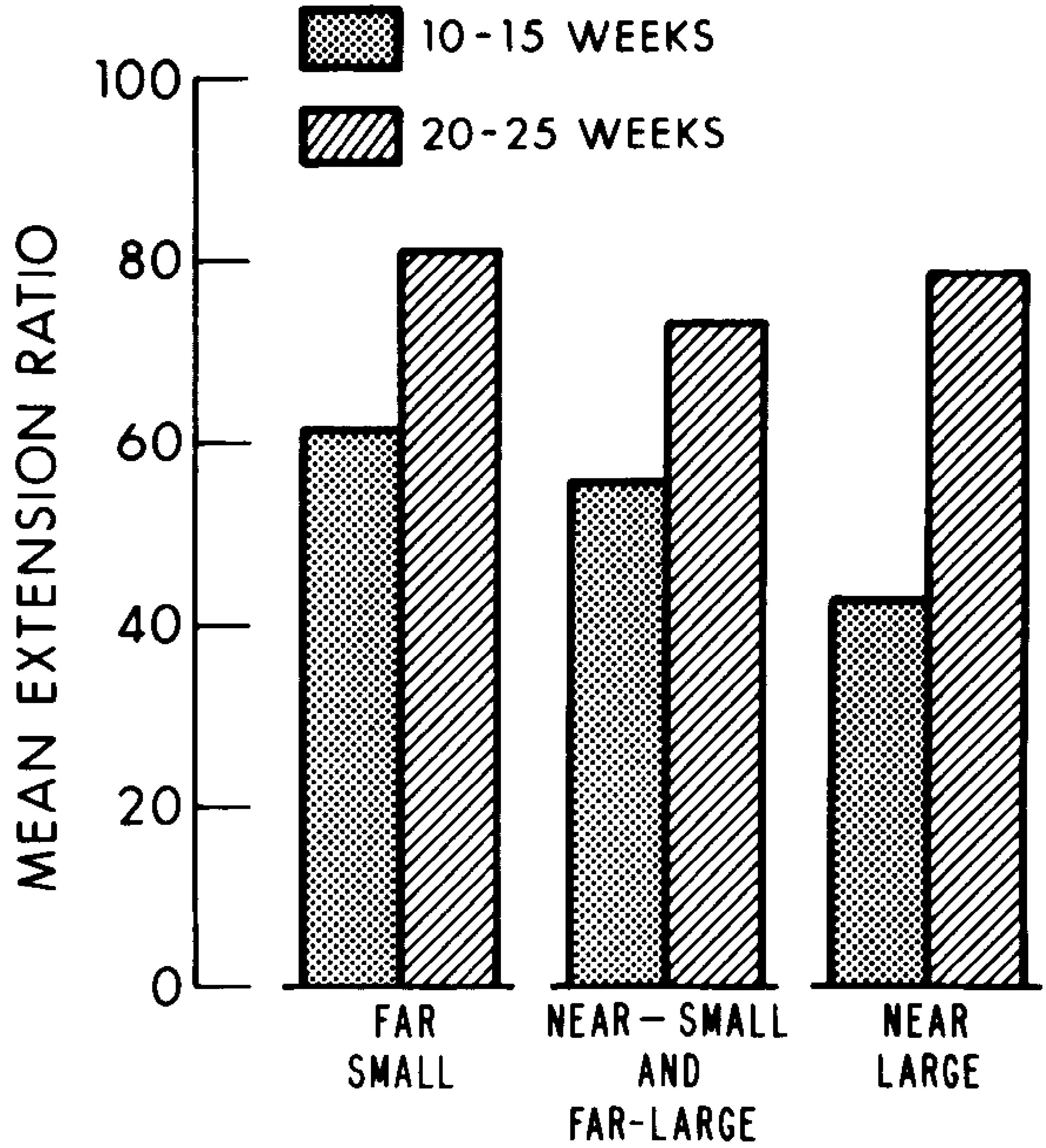

Figure 7: The Relationship between Age and Finger Responses to Stimuli that Varied in Size and Distance. For means and standard errors, see Table IX, p. 88. It should be noted that the retinal images were smaller for far-small stimuli, larger and equal for near-small and far-large, and largest for near-large stimuli. The extension ratios of the younger infants thus follow a clear gradient in response to retinal size, while the ratios of the older infants do not.

to the near-large stimuli. As was the case when size and brightness were analyzed, the older infants did not respond along an intensity gradient. Their extension ratios were uniformly high for all stimulus combinations. It should also be noted that the retinal images were smaller for far-small, larger and equal for near-small and far-large, and largest for near-large stimuli. The extension ratios of the younger infants thus follow a clear gradient in response to retinal size, while the ratios of the older infants do not.

Distance and Illumination. Figure 8 displays the relationship between age and finger movements to stimuli of different distance and illumination combinations. Although a clear gradient was not present, the younger infants did respond with their highest extension ratios to the least intense (far-dim) stimulus combination. The older infants again displayed only slight variations in their extension ratios to all stimuli.

Distance, Size and Illumination. The relationship between age and finger movements to stimuli that varied in distance, size and illumination is shown in Figure 9. Clearly, the extension ratios of the younger infants followed an intensity gradient. Their mean extension ratio was highest to the least intense stimuli (far-small-dim), intermediate to the intermediate stimuli, and lowest to the most intense stimuli (near-large-bright). The older infants exhibited a weak gradient in the opposite direction.

Response Characteristics. Finally, qualitative appraisal of the movements of the infants in this study indicated differences in the form of the responses observed in the younger and older infants. While the younger infants primarily moved their hands and fingers in response to the stimuli

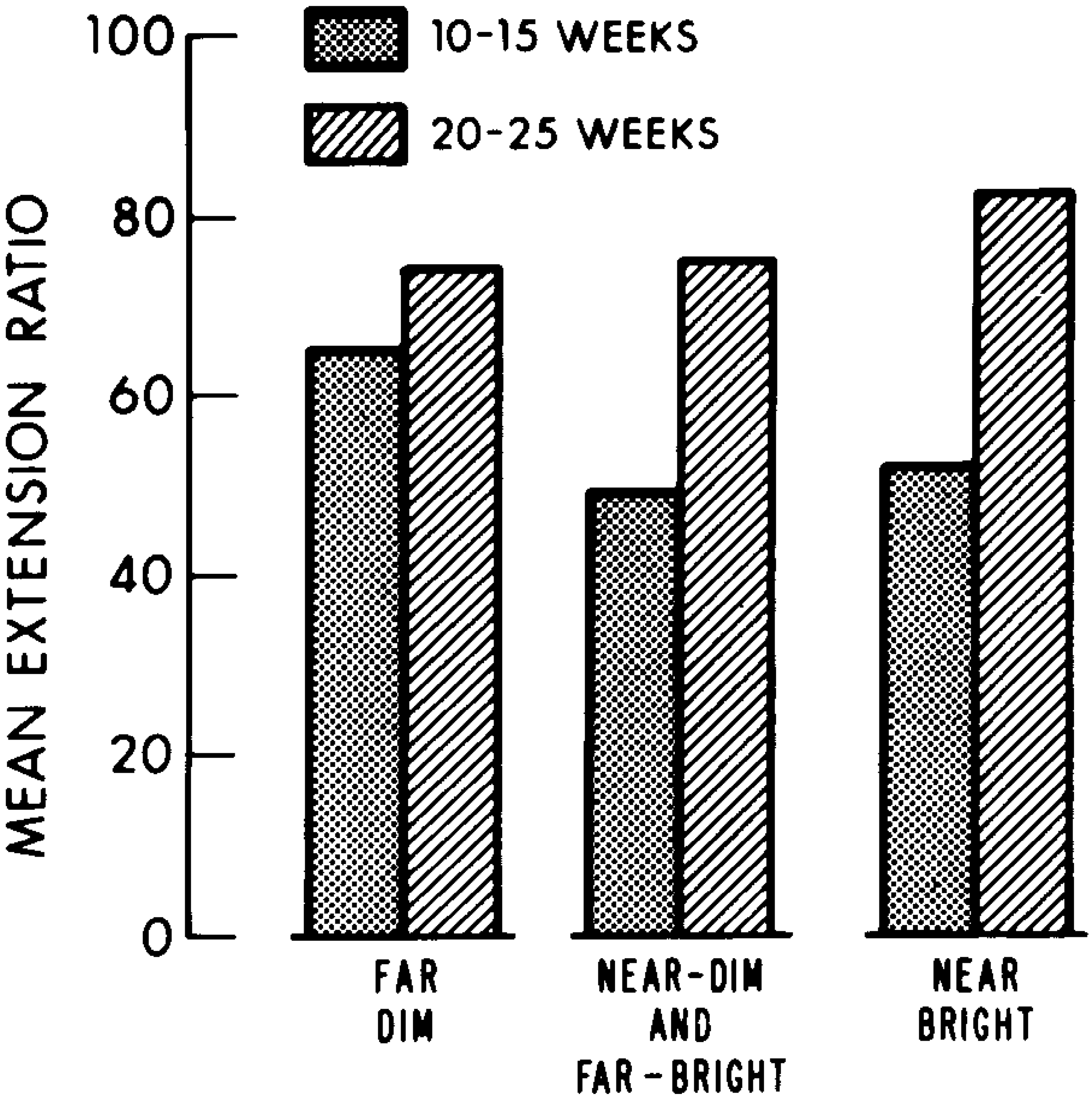

Figure 8: The Relationship between Age and Finger Responses to Stimuli that Varied in Distance and Illumination. For means and standard errors, see Table IX, page 88.

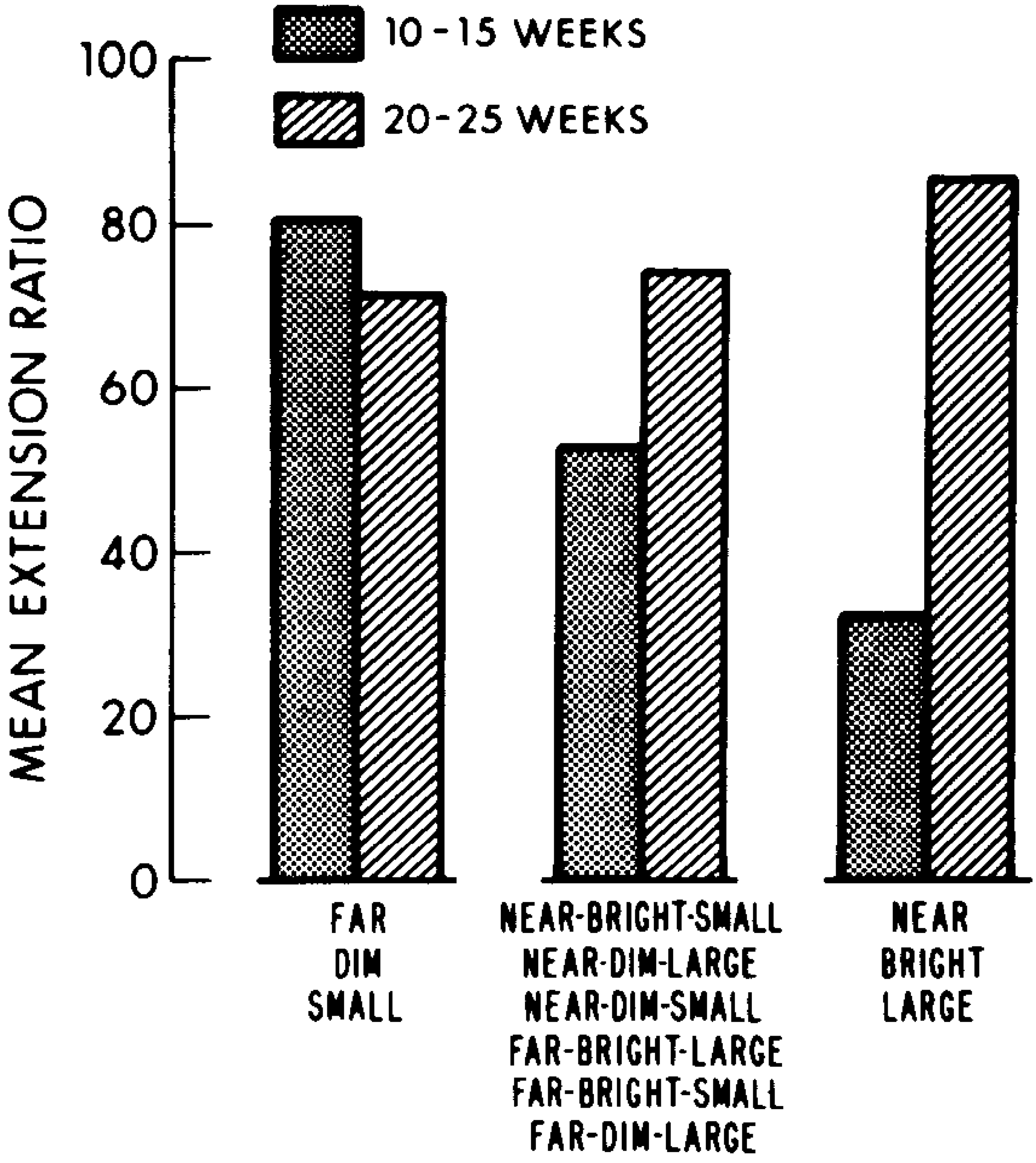

Figure 9: The Relationship between Age and Finger Responses to Stimuli that Varied in Distance, Size and Illumination. For means and standard errors, see Table IX, page 88.

presented to them, making discrete extension and flexion movements, the older infants extended their entire arms and kept them extended during stimulus trials, alternately flexing and extending their fingers while the arms remained extended. No differences were observed in the looking behavior of the two age groups.

Discussion

The results indicated that: 1. The younger infants' responses were clearly related to the intensity of stimulation to which they were exposed, while the older infants' responses showed a different pattern; 2. The direction of the younger infants' responses was related to intensity of stimulation, with a higher proportion of extension to weak stimuli and a lower proportion of extension to intense stimuli; and 3. The dimensions of size, brightness and distance were additive in their contributions to the intensity of stimulation, in the determination of the younger infants' responses. Each of these points will be discussed separately below.

Intensity as the Determiner of Response Direction. The younger infants exhibited response patterns that were consistent with the approach-withdrawal hypothesis. Responses were related to total stimulus intensity, with higher extension ratios (approach) to the least intense stimuli and lower extension ratios (withdrawal) to the most intense stimuli for all attribute combinations at their extremes.

In view of the apparent importance of intensity as the aspect of stimulation which may be most relevant in the determination of behavior in early infancy, attention to the role of the quantitative rather than the qualitative aspects of stimulation may resolve certain conflicts in the interpretation of results from several other studies of early infancy. For example, a controversy is currently developing over the interpretation of early infant "preferences" in looking at visual patterns: After the interesting infant visual fixation studies of Fantz (1963, 1966 and Fantz, Ordy & Udelf, 1962), the suggestion was made that longer fixation of one member of a pair of patterned stimuli indicated that infants perceived the qualitative differences between the stimuli and discriminated on that basis. According to this interpretation, infants "preferred" bullseye rather than striped patterns, and faces rather than other patterned stimuli on the basis of perception of shape and pattern. Birch and Turkewitz (1966) suggested, however, that this kind of fixation pattern might be based on differences in the effective intensities of the stimuli presented, rather than differences in the perceived forms or patterns.

In support of this suggestion, Ruff and Turkewitz (1975) found that when the size of simultaneously presented pairs of bullseye and striped patterns was varied, infants aged ten weeks and younger responded on the basis of size. Consistent preferential fixation of the bullseye, independent of size, began to appear at later ages. The data from the present study indicated a similar effect of retinal size upon the finger movements of the younger infants. In this study the younger infants responded with a clear decline in extension as retinal size increased, while the older infants' responses did not follow a gradient. This suggests the absence of size constancy in the younger infants and its presence in the older infants, a finding contrary to Bower's (1974) position that very young infants exhibit size constancy.

Data collected from other sources can also be interpreted in terms of an effective intensity model. For example, Hershenson, Munsinger and Kessen (1965) found that newborn infants looked longest at patterns with intermediate numbers of angles (ten), rather than fewer (five) or more (fifteen). Thus, looking followed an intensity gradient, increasing for weak stimuli (five to ten angles) and decreasing as the patterns became more intense (contained fifteen angles). Similarly, Karmel found that both infant looking behavior (1969) and cortical evoked potentials (with Hoffman and Fegy, 1974) are described by an inverted U-shaped function of the contour density of patterns in the visual field. They found that infants looked longest (and had highest-amplitude evoked potentials) at intermediate levels of contour per unit area, with less looking (and lower-amplitude evoked potentials) when the contour density of visual stimuli was either increased or decreased. Thus, responses to factors such as size, number of angles, and contour density have each been shown to follow a gradient that is consistent with the approach-withdrawal hypothesis.

The Additivity of Stimulus Dimensions. The findings of this study also indicated that the responses of the younger infants were determined by the level of stimulus intensity, regardless of the way this level was achieved. Factors such as size, brightness and distance appeared to be important mainly in terms of their contributions to the total level of intensity.

In this particular test situation, size was the most important determiner of the infants' responses; the effects of distance and illumination did not reach significance by themselves. However, when distance and illumination were examined in combination with each other, or in combination with size, trends in the expected directions were apparent.

Although size was the most important determiner of the infants' finger movements in this particular situation, it would be theoretically possible to manipulate conditions to increase the effects of brightness and distance, and decrease the effect of size. For example, distance alone might have had a greater effect if the distances between near and far were increased; however, this would have been difficult to accomplish without running into problems of lack of accomodative ability on the part of the youngest infants. Similarly, the differences between the bright and dim stimuli were not extreme because brighter light could have been harmful to the infants' eyes, while dimmer light would have reduced the quality of the videotapes. However, questions of the relative importance of any particular stimulus dimension were not of central interest to this study. Rather, the focus was on the additive aspects of the various stimulus dimensions.

The consideration of additive aspects of stimulus properties has important implications for the conceptualization of stimulus dimensions as variables in infant research. It should be noted that if the principal determiner of infant behavior is non-specific stimulus intensity, much of the confusion concerning the dimensions relevant to behavior in early infancy may be clarified.

One of the problems in the interpretation of the roles of different stimulus dimensions has been that almost all investigators who have sought relevant dimensions have found them, leading to conflicts over which dimension is really the determiner of discriminative responses in early infancy. For example, Karrel (1969) has suggested that the principal determiner of infant looking behavior is the contour density of visual stimuli. However, Fantz and Fagan (1975) and Greenberg and Blue (1975) pointed out that Karmel's experiments confounded the contour variable with the number of elements within patterns. Greenberg and Blue (1975) assessed the effects of numerosity and contour density on the looking behavior of infants two and four months old, and found that these variables act _in tandem_ to determine looking. Similarly, Fantz and Fagan (1975) found that size and number of elements interact in the determination of fixation time for newborns and five-week old infants. Although neither Fantz and Fagan (1975) nor Greenberg and Blue (1975) made this interpretation, the data from both these experiments seem compatible with an intensity model. If contour density, size, number of angles, and number of elements within a pattern all contribute to the total intensity of that pattern, and if intensity is the determiner of infant behavior, then precisely the kinds of additive effects reported above would be expected. In this view, arguments over which dimension determines the responses of very young infants will continue to be inconclusive.

Under certain circumstances contour may be the most powerful contributor to effective intensity, while under other circumstances numerosity or size of elements may dominate. In any case, none of these dimensions need influence infant behavior in terms of perceptual or cognitive processing--their influence may lie in their quantitative contributions to a total level of stimulation which determines responses.

Levels in the Organization of Visual-motor Behavior. Although the behavior of the younger infants can be understood in terms of their responses to the intensities of the stimuli to which they were exposed, the behavior of the older infants cannot be understood simply in those terms. While their extension ratios were higher for small than for large stimuli, the older infants displayed higher extension ratios to all the stimulus combinations than did the younger infants, as indicated by the significant age effect. In addition, their differential responding to small rather than large stimuli was of lesser magnitude than displayed by the younger infants, as indicated by the age x size interaction. This suggests that although intensity still had an effect on the older subjects' responses, it had a lesser effect than observed in the younger subjects. Further, although the older infants had higher extension ratios to the smallest stimuli, they did not display an intensity-related gradient of responsiveness when all factors were assessed in combination (as seen in Figures 6 - 9).

Not only did they fail to follow a simple stimulus-intensity gradient, but qualitative appraisal indicated that the older infants' responses were also of a different form from those observed in the younger infants. Unfortunately, because the television camera was situated at an angle which optimized visibility of the fingers, this angle made it impossible to quantify the movements of the arms. While it was possible to record whether or not an arm movement took place, the amount and direction of movement could not be specified. However, qualitative appraisal indicated that the younger infants responded primarily with discrete movements of only the fingers, while the older infants extended their entire arms during trials, alternately extending and flexing their fingers while the arms remained extended. Thus, the younger and older infants seemed to be responding not only to different aspects of the stimulus situation, but with different responses as well.

Although a relationship was not directly established in this study, early intensity-determined patterns of responding may provide the basis for later patterns such as observed in the older infants.

The Transition from Lower to Higher Levels of Organization. It has been noted that while early extension of the arms appears to be reflex-like, movements that are visually-guided and accurate begin to appear at about twenty weeks of age (White, 1970; Piaget, 1952). In this study, visually-guided reaching such as that described by Piaget (1952), White (1970) and others (Halverson, 1931; Castner, 1932), in which the infant extends his arms accurately toward an object, makes contact, grasps and then brings it in toward the body, was not observed even at 20-25 weeks of age. This was possibly because the stimuli were beyond reach, even in the near position.

The arm and finger movements of the older infants in this study seem quite similar to those described by Cruikshank (1941) and Bower (1974) for infants of roughly the same ages who were exposed to stimuli that were beyond reach. Cruikshank considered these responses to be "reaching responses" that indicated lack of distance discrimination. Bower suggested that these movements in five month old infants might be "indicator gestures" meant to affect the behavior of nearby adults. Because it does not seem necessary to assume that these infants are acting purposively in attempting to gain objects directly or to influence nearby adults to get them, it does not seem appropriate to call these movements either "reaching" or "indicator gestures" on the part of the infants.

In the course of this study, such extension movements were observed both in the absence of visible adults and in their presence. There are a variety of possible interpretations of this behavior, including the possibility that these were conditioned patterns of responding which had been reinforced in the past, when out-of-reach objects were handed over by willing adults who interpreted their infants' movements as "begging." That they serve as indicator gestures to nearby adults illustrates the adaptive value of this behavior pattern. Persistent "indicator gestures" accompanied by "pleading vocalizations" are very effective in shaping the behavior of many adults, whether or not the infant understands this relationship.

Clearly, neither in terms of the appearance of the responses, nor in terms of the bases for responding, is there a "reaching response" characteristic of all stages of development. In this study, the extension movements of the younger infants are understandable in terms of low-level, sensory-motor processes that are responsive to quantitative rather than qualitative stimulus properties. This low level pattern of responding precedes patterns based upon perceptual-motor integration, leading to questions of how higher-level response patterns develop. It is possible that the sensory-motor mode of responding provides a necessary basis upon which later perceptual-motor responsiveness is built, that the two ways of responding develop independently at different rates, or that they interact during development.

Although analysis of the development of voluntary movement is beyond the scope of this investigation, a suggestion about the way in which the transition from lower to higher levels of processing may occur does follow from the findings of this study. While many investigators have pointed to the importance of visual regard of the hand for visual-motor development (Held & Bauer, 1975; Twitchell, 1970; White, 1970), there has been relatively little concern for how the hand enters the visual field. However, in a discussion following his paper "Reflex mechanisms and the development of prehension" (1970), Twitchell asked "What is the mechanism for first getting the hand into the visual field?" (p.40) and speculated that neck and labyrinthine reflexes might play a role. He also mentioned (1970) that he had observed adult encephalopathic patients who reacted to an object entering the visual field by extending the hand toward the object without attempting contact with it. Twitchell suggested that "If such a reaction occurred during early development in the infant, it would provide a mechanism for getting the hand into the visual field" (p.40).

The findings of the present study suggest that factors in keeping with the approach-withdrawal intensity hypothesis may be responsible for first getting the hand into the visual field and then keeping it there long enough for intersensory associations to take place: Early extension of the limbs, determined by the effective intensity of environmental stimulation, increase the chances that the hand will enter the visual field. Once the hand enters the visual field, it becomes an effective stimulus for looking; and more importantly, the visual stimulation the hand provides is now available for integration into previously non-visually guided patterns of movement. This sequence may provide the basis upon which visually directed behavior patterns later develop.

In this investigation of visual-motor development, behavior at different ages was considered to reflect different levels of organization. The lower level was characterized by mechanisms responsive to intensity of stimulation rather than quality, while the higher level was characterized as involving more complex mechanisms that remain to be analyzed. Recent evidence suggests that the two levels suggested here for visual-motor behavior may be related to two processes that govern visual behavior, and that they may be under the control of different central mechanisms. For example, Schneider (1967) has found that pattern recognition in the hamster is dependent upon cortical functioning independent of sub-cortical processes, while orientation in space toward visual targets is dependent upon sub-cortical regions of the superior colliculus. Specifically, he found that hamsters with tectal lesions could discriminate between patterns, but could not perform oriented movements toward visually presented targets. On the other hand, hamsters with cortical lesions had well-oriented movements, but no pattern recognition. Thus, vision in the hamster is not a unitary process--visually-guided orienting behavior is controlled by a separate process from that which controls pattern recognition and analysis of form.

A two-process theory of visual behavior has also been suggested for kittens (Held, 1968), with pattern discrimination attributed to a different process than visual-motor orienting behavior. This suggestion is based upon evidence that visual-motor behavior can be dissociated between the two eyes, while pattern discrimination cannot. Although it has been found (Meyers and McCleary, 1964) that pattern discrimination can be transferred from a trained to an untrained eye, the visual guidance of motor behavior in kittens reared under monocular deprivation does not transfer from the experienced to the deprived eye (Hein, Held and Gower, 1970). Further, there is no interocular transfer of visual-motor tasks such as paw guidance to the edge of a crenelated surface. Pattern discrimination in similarly deprived animals is not lost, however, as long as visual-motor control is not required in the test situation (Meyers and McCleary, 1964).

Riesen, Kurke and Mellinger's (1953) finding that pattern-deprived kittens lack pattern discrimination ability, has been attributed to their testing situation (Held, 1968), which required visual-motor coordination in order for subjects to indicate their choices. When similarly deprived kittens were tested in a situation in which visual-motor responses were not required, they displayed pattern discrimination equal to normal animals and interocular transfer of learned discriminations (Meyers and McCleary, 1964).

There are also indications in the literature that pattern discrimination and visual-motor coordination in primates may be under the control of different central mechanisms. There are several reports (*e.g.* Kluver, 1937, 1941) that animals with cortical lesions lose the ability to discriminate patterns, but retain the ability to discriminate differences in contrast and luminosity. There are no indications, however, that such animals retain pattern vision, but lose the ability to respond to contrast and luminosity. These findings suggest that while pattern discrimination is higher-level and dependent upon perceptual or cognitive processes, responses to changes in contrast and luminosity are intensity-determined and lower-level.

On the basis of findings such as described above, and the results of studies of split-brain animals (Trevarthen, 1968) and humans subjected to visual rearrangement (Held, 1968), investigators are beginning to view visual functioning in terms of two distinct processes: Trevarthen (1968) separates fine motor control and visual analysis from body-centered orientation; while Held (1968) refers to a visual-motor orienting system which is separate from and more plastic than the pattern-analysing system. Finally, although he does not relate his suggestion to visual-motor development, Bronson (1974) has suggested that there are two visual systems in human infants, one based upon peripherally-stimulated, and the other upon centrally-stimulated retinal elements. He suggests that, in early infancy, visual processing is predominantly controlled by peripheral retinal elements, and does not respond to shape and pattern, but that later in development vision is dominantly foveal and capable of attending to the kinds of details that make pattern discrimination possible. In this way, he accounts for the pattern preferences of older infants as opposed to the size preferences of younger ones.

The levels approach in this study led to the observation that very young infants' visual-motor responses are related to the quantitative rather than the qualitative aspects of visual stimulation. A two-process view of visual functioning is also compatible with this view. Sub-cortical mechanisms such as observed by Schneider (1967) may control the intensity-determined movements of the younger infants in this study (cf. McGraw's early suggestion that infant reaching is reflexive and probably sub-cortically controlled), and it is possible that these movements are in response to a peripherally-dominated retina as suggested by Trevarthen (1968) and Bronson (1974).

In this view, low-level visual-motor responses may be described as sub-cortically controlled responses that occur as the result of stimulation of peripheral retinal elements. These responses may be determined by the intensity of visual stimuli, and are considered to be lower-level than cortically-controlled movements that are perceptually-determined and dependent upon foveal stimulation. These lower-level responses precede responses that involve pattern analysis, and may provide the basis upon which such higher-level capacities develop. It is possible that the two systems develop independently or that they interact during development. All of these suggestions are now open to investigation. So far, the evidence seems to suggest that a levels approach is not only useful for organizing the information already available, but for suggesting guidelines for further investigations that may lead to a better understanding of the bases of behavior in early infancy.

Appendix A

Finger Response Distributions, All Subjects

Subject	Total Trials	Extensions	Flexions	No Response	Unscorable
01	43	24	9	10	0
02	38	23	11	1	3
03*	40	14	14	9	3
04	37	13	13	7	4
05	74	23	28	21	2
06	41	34	3	2	2
07	39	21	13	3	2
08	60	33	15	11	1
09	66	35	26	3	2
10	44	24	13	6	1
11	41	24	12	5	0
12	52	29	15	5	3
13*	40	36	4	0	0
14	52	34	7	8	3
15	61	49	9	1	2

* Same subject tested at different ages

Appendix B

Correlations Between Age and Extension Ratio Scores for each Stimulus Condition

Stimulus Condition	N	R	Probability
NLB	15	.68	$p < .01$
NLD	13	.29	N.S.
NSB	15	.03	N.S.
NSD	15	.50	$p < .05$
FLB	15	.10	N.S.
FLD	14	.57	$p < .05$
FSB	15	.53	$p < .05$
FSD	15	-.30	N.S.

N = near
F = far
L = large
S = small
B = bright
D = dim

Appendix C

Mean Extension Ratio Scores

Infants 10-15 Weeks

Subject	Mean	D	SD from Mean
1	.656	.003	.33
2	.700	.107	.56
3	.375	.218	1.15
4	.469	.124	.65
5	.432	.161	.85
6	.927	.334	1.76
7	.590	.003	.02

Group Mean = .593 S.E. = .08

Infants 20-25 Weeks

Subject	Mean	D	SD from Mean
8	.659	.106	1.06
9	.655	.110	1.10
10	.716	.049	.49
11	.896	.131	1.31
12	.790	.025	.25
13	.871	.106	1.06

Group Mean = .765 S.E. = .04

Appendix D

Analysis of Variance Summary Table

for Finger Extension Ratios

Infants 10-15 Weeks

Source	df	SS	MS	F
Distance	1	.875	.875	.002
Distance x Subjects	6	2214.25	369.04	
Size	1	4029.02	4029.02	10.80*
Size x Subjects	6	2238.6	373.10	
Illumination	1	1370.16	1370.16	1.18
Illumination x Subjects	6	6995.96	1165.99	
Distance x Size	1	33.02	33.02	.07
Dist x Size x Subjects	6	2827.11	471.19	
Distance x Illumination	1	1020.02	1020.02	1.05
Distance x Ill x Subjects	6	5805.11	967.60	
Size x Illumination	1	5.16	5.16	.007
Size x Illum x Subjects	6	4215.97	702.66	
D x Size x Ill x Subj	1	3075.45	3075.45	10.54*
Subjects	6	1751.17	291.86	

* = $p < .025$

Appendix E

Analysis of Variance Summary Table

For Finger Extension Ratios

Infants 10-15 Weeks
(Omitting Subject 06)

Source	df	SS	MS	F
Distance	1	4.6875	4.6875	.01
Distance x Subjects	5	2202.4425	440.4885	
Size	1	4860.1875	4860.1875	17.365**
Size x Subject	5	1399.443	279.8886	
Illumination	1	2338.0208	2338.0208	2.08
Illumination x Subject	5	5607.61	1121.522	
Distance x Size	1	212.5208	212.5208	.477
Dist x Size x Subjects	5	2227.0997	445.4199	
Distance x Illumination	1	1111.6875	1111.6875	.974
Distance x Ill x Subjects	5	5705.934	1141.1869	
Size x Illumination	1	13.0208	13.0208	.016
Size x Illum x Subjects	5	4200.100	840.02	
Dist x Size x Illum	1	2655.1875	2655.1875	7.58*
D x Size x Ill x Subj	5	1750.944	350.1889	
Subjects	5	7028.94	1405.788	

* = $p < .05$
** = $p < .01$

Appendix F

Analysis of Variance Summary Table
for Finger Extension Ratios
Infants 20-25 Weeks

Source	df	SS	MS	F
Distance	1	266.02	266.02	.379
Distance x Subjects	5	3510.63	702.13	
Size	1	450.19	450.19	40.23**
Size x Subjects	5	55.96	11.19	
Illumination	1	67.69	67.69	.247
Illumination x Subjects	5	1372.46	274.49	
Distance x Size	1	652.69	652.69	.351
Distance x Size x Subj.	5	2761.41	552.28	
Distance x Illumination	1	150.52	150.52	.856
Distance x Ill x Subj	5	879.56	175.91	
Size x Illumination	1	475.02	475.02	.800
Size x Illum x Subjects	5	2967.60	593.52	
Dist x Size x Illum	1	1938.02	1938.02	13.35*
D x Size x Ill x Subj.	5	725.61	145.12	
Subjects	5	3849.60	1539.84	

* = $p < .025$
** = $p < .005$

Appendix G

Mean Extension Ratios for Age, Size and Illumination

Factor	Mean Extension Ratios All Subjects	Mean Extension Ratios 10-15 Weeks	20-25 Weeks
Grand Mean	.651		
Age*		.537	.765
Distance			
Near	.666	.543	.790
Far	.635	.531	.739
Size*			
Large	.587	.439	.732
Small	.716	.635	.797
Illumination**			
Bright	.623	.465	.782
Dim	.678	.610	.747

*Significant effects. See Table VIII for mean squares, *F* values, *df* and probabilities. For size, there was also a significant age x size interaction (See text, page 85 and Figure 5, page 86).

**Althought there was not a statistically significant age x illumination interaction, the difference between the means for the younger infants was in the predicted direction.

Appendix H

Mean Extension Ratios for Stimulus Dimension Combinations of Intermediate Intensity

Stimulus Dimensions	Stimuli[1]	Mean Extension Ratios	
		10-15 Weeks	20-25 Weeks
Size and Illumination	Large-Dim	.509	.744
	Small-Bright	.560	.844
Size and Distance	Far-Large	.452	.672
	Near-Small	.659	.787
Distance and Illumination	Far-Bright	.413	.741
	Near-Dim	.570	.757
Distance, Size and Illumination[2]	NBS	.707	.785
	NDS	.611	.790
	NDL	.528	.723
	FBS	.413	.903
	FBL	.413	.578
	FDL	.490	.765

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[1] The ordering of these stimuli is completely arbitrary, as the effects of combining dimensions were not known.

[2] N = Near, F = Far, L = Large, S = Small, B = Bright, D = Dim

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