# Expectation and Anticipation of Dynamic Visual Events by 3.5-Month-Old Babies

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HAITH, MARSHALL M , HAZAN, CINDY and GOODMAN, GAIL S *Expectation and Anticipation of Dynamic Visual Events by 3 5-Month-old Babies* CHILD DEVELOPMENT 1988, 59, 467–479 We report an investigation of the development of visual expectancies in 3 5-month-old infants One of the infant s eyes was videorecorded as the infant watched a series of slides that were presented noncontingent on behavior Babies were presented an alternating and an irregular series of 30 slides with a 700-msec onset duration separated by an interstimulus interval (ISI) The ISI for the alternating series was 1,100 msec, whereas the slides for the irregular series were separated by 900, 1,100, or 1,300 msec, randomly ordered One-half of the babies saw the irregular series first, and one-half saw the regular series first Babies in both groups provided evidence that they developed expectations for the visual events in the alternating series Their reaction times (RTs) declined significantly from 3–5 ' baseline' presentations, and their RTs were reliably faster during the alternating than the irregular series Additionally, babies in the alternating-late group had significantly more stimulus anticipations during the alternating than during the irregular series These findings indicate that 3 5-month-olds can detect regularity in a spatiotemporal series, will develop expectancies for events in the series, and will act on the basis of those expectancies even when those actions have no effect on the stimulus events We believe that infants are motivated to develop expectations for noncontrollable spatiotemporal events, because these expectations permit them to bring their visual behavior under partial internal control

There is strong current interest in developing a theory of infant cognition that will easily relate to theories of later cognitive functioning An important characteristic of cognitive/perceptual theories in childhood and adulthood is concern for future-oriented mental processes such as expectations for environmental events and planning of self-directed activities Modern characterizations of cognitive functioning, such as schema and frame theory, emphasize the role of expectation for spatial layouts and event sequences in facilitating a person's ongoing understanding of and memory for experience (Minsky, 1975, Schank & Abelson, 1977) as well as his or her scanning of scenes (Friedman, 1979, Goodman, Price, Cohen, & Haith, 1981) and recognition of items in these scenes (Friedman, 1979, Goodman, 1980)

However the study of future-oriented activities in early infancy has been virtually ignored Research and conceptualization concerning perceptual/cognitive processes in early infancy have traditionally focused on how the infant deals with currently available visual events, whether these events are new or familiar In a sense, then, the time frames of interest have been the present and the past Hebb's (1949) theoretical discussion over 3 decades ago of the role of expectancies in early infancy still stands as the only systematic treatment and enjoys only scattered empirical buttressing [1]

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[1] Kagan (1970) developed a motivational theory of attention and cognitive development around the notion of ' violation of expectancy" or discrepancy For Kagan, the concept refers to a structural schema of the object and an input match or mismatch In most cases the input is unchanging Thus Kagan s principal concern has been with the development of cognitive representations of objects rather than with how expectations contribute to the perceptual organization of the changing or dynamic events that concern us here

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Perhaps progress in studying expectations in early infancy has suffered partly from the absence of a suitable paradigm We will introduce a new approach to studying infant expectations and will present findings that demonstrate that young infants develop visual expectations rapidly and tend to organize their behavior around these expectations

Before proceeding, it may be useful to present various usages of the term "expectation" so that we can clarify what we will be discussing Use of the term by theorists has run the gamut from highly cognitive processes to relatively low-level sensorimotor processes At one extreme, for example, we speak of the expectation one person has for another's behavior in a social interaction (Markman, 1981) At the other extreme, we speak of the expectation a person has for the perceptual consequences of a motor command to move the eye (Helmholtz, 1925) The time domain of interest may be relatively short (as in the expectation for retinal stimulus change consequent to an eye movement) or relatively long (as when one expects course work to lead to a degree) Expectations may refer to psychological processes utilized in static or dynamic situations For example, we expect that objects will occupy particular locations in familiar static scenes (Biederman, Glass, & Stacy, 1973), and we expect that unimpeded moving objects will continue to move (Aslin, 1981) Finally, expectations may be involved in situations in which a person's action is irrelevant (the onset of a rainstorm), interactive (moving the hand to catch a ball), or the only matter of concern (the consequence of a motor command to move the arm) What all of these examples share is allusion to a psychological process or processes which is (are) future oriented We know of no theory that deals with all of these different types of expectancies Whether they involve similar or distinct processes is unknown Speculation about a sequence of development of various kinds of expectancies and their independence or interrelation could prove quite interesting It is essential, however, that we first develop a data base on future-oriented processes in early infancy

For this presentation, we are interested in perceptual expectations that are relatively short-term in nature, that involve dynamic events, and that reflect an interaction between organismic action and environmental change It seems likely that the earliest expectations would be more perceptual than cognitive in nature, would involve relatively limited time frames, and would depend on sensorimotor actions In contrast to traditional learning studies, the events we use are presented noncontingent on the infant's action We believe that babies must develop expectations in order to deal with the dynamic flow of perceptual events in their environment, over which they often have no control, and that this class of expectations is among the earliest to occur

We want to present some terminology for discussing future-oriented processes in order to distinguish our references to internal constructs from behavioral indices of those constructs The literature on expectancy and planning often fails to make this distinction The term "expectation" will be used as a cognitive/perceptual construct that refers to the infant's forecasting of a future event, the presence of an expectation will be indexed, behaviorally, by anticipation and response facilitation

"Anticipation" will refer to an action that is initiated prior to an event and is adaptive for it "Facilitation" will refer to enhancement of behavior after the actual event occurs (when, of course, there was no anticipation) As an illustration, consider a visual two-choice, reaction-time (RT) task A subject must move the eyes to the left or right as rapidly as possible, when a corresponding left or right light goes on Sometimes, a warning light flashes red or green first to indicate, respectively, that the left or right response will be relevant for that trial We know that the eye-movement response to the stimulus-light onset will be faster on trials preceded by the warning light Thus, the warning light "facilitates" the reaction, and we would infer that the facilitation reflects the presence of an expectation If the response actually occurred prior to the onset of the left or right light, we would say the response was "anticipatory," and we would also infer that an expectation had mediated the reaction Even though an anticipation would be in error for this task, there are related situations, such as the one we will describe, for which anticipation is quite appropriate

A few studies that are relevant to this example have been conducted on young infants, such as Aslin's careful observations of visual tracking in 10-week-old infants (Aslin, 1981) Aslin confirmed earlier reports that, prior to 10 weeks, infants typically track a moving object with jerky eye movements, repeatedly losing and then refixating the object through its flight After 10 weeks, infants become increasingly able to track the object smoothly Aslin speculated that, in part, the infant's newfound ability might reflect the formation of expectations about the objects' continuing path Because eye-movement latencies to the appearance of a visual target exceed 200 msec, ad hoc reactions to the object's new locations would generate a jerky rather than a smooth-tracking performance Haith, Kessen, and Collins (1969) presented to 2- and 4-month-old infants displays of sequentially illuminated lights and reported that the infants appeared to make erroneous fixations that reflected the infants' expectation that events would continue to follow a linear trajectory rather than to change direction Similarly, Nelson (1968) reported that infants, ranging in age from about 1 5 to 4 months, continued to move their eyes along a trajectory created by sequential illumination of discrete lights, even when intermediate onsets were deleted As another example, Anglin and Mundy-Castle (1969) presented infants from a few weeks to 8 months of age stimuli that alternately appeared in right and left windows, separated by 3 5 sec, they reported anticipatory fixations during this delay interval Unfortunately, the latter two reports did not provide comparative performance data during an unpredictable series, as we shall see, one can obtain behavior during a nonpredictable series that looks like anticipation and must be taken into account in inferring that an expectation has been established We know of no reports suggesting that expectations may facilitate infants' reactions to stimuli by enhancing their response time

The purpose of the present study was to establish whether 3 5-month-olds could form expectations for a series of predictable visual events that unfolded independent of their behavior We examined both anticipatory fixations and facilitated reactions to these events to provide evidence for the presence of expectations and compared these behaviors for relatively predictable and relatively unpredictable series

## Method

*Overview* —Each infant saw a sequence of projected slides that appeared to the left or right of visual center The pictures moved up and down while they were on (700 msec) For the alternating series, successive slides were separated by an interval of 1,100 msec and appeared in left-right alternation For the irregular series, slides were separated by ISIs (interstimulus intervals) of 900, 1,100, or 1,300 msec, arranged randomly The image of the baby's right eye was videotaped during this procedure We were especially interested to determine whether babies would detect the spatial and temporal predictability of the series and whether they would manifest this detection through anticipatory eye movements and enhanced reaction times to slide onsets

*Subjects* —Twelve 3 5-month-olds participated in this experiment (range 3 months, 8 days to 3 months, 19 days) Data from 10 other babies were not used because we encountered equipment problems ($N = 2$), insufficient data were obtained ($N = 4$), or the baby was inattentive ($N = 2$), had an abnormal iris ($N = 2$), or made excessive shifts between stimulus locations during the ISI for both conditions (>65%, $N = 1$)

*Stimuli* —The stimuli were 60 projected 35mm slides of checkerboards, bull's eyes, and schematic faces in various combinations of green, red, yellow, black, and white The baby viewed the projected slides by mirror reflection on a rear-projection screen that was 7 cm high × 15 2 cm wide, at a distance of 38 1 cm The stimuli were approximately 4 5° square and their centers were 5 7° to the left or right of the infant's visual center Each stimulus moved vertically at a rate of 4 4°/sec, completing one up-down cycle for each presentation, which lasted 700 msec The variations in stimulus objects and colors were combined with stimulus motion to maximize the infant's interest

*Apparatus* —The infant lay supine on a baby mattress and viewed the rear-projected stimuli by reflection from a visible-reflecting, infrared-transmitting mirror (mirror Y in Fig 1, Libby-Owens No 956) The image of the infant's right eye (in a camera field approximately 3 8 cm square) was videotaped by a TV camera that was equipped with an infrared video tube Light for televising this eye image was provided by an infrared source and collimator whose beam reflected from infrared-transmitting, visible-reflecting mirror Z (Fig 1, Libby-Owens No 956), which was in the same optical path as the recording video camera The eye image was transmitted through mirrors Y and Z and reflected from front-surface mirror X to the camera The collimator was fitted with optical filters (Corning 7-69, and Kodak Wratten 87c) to eliminate heat and to reduce visibility, because the collimated beam was directed toward infrared-transmitting mirror Z, only a small fraction of the light was reflected toward the infant's eye, from the infant's position, the light was virtually invisible This arrangement maximized the amount of light, reflected from the eye, that reached the TV camera (because

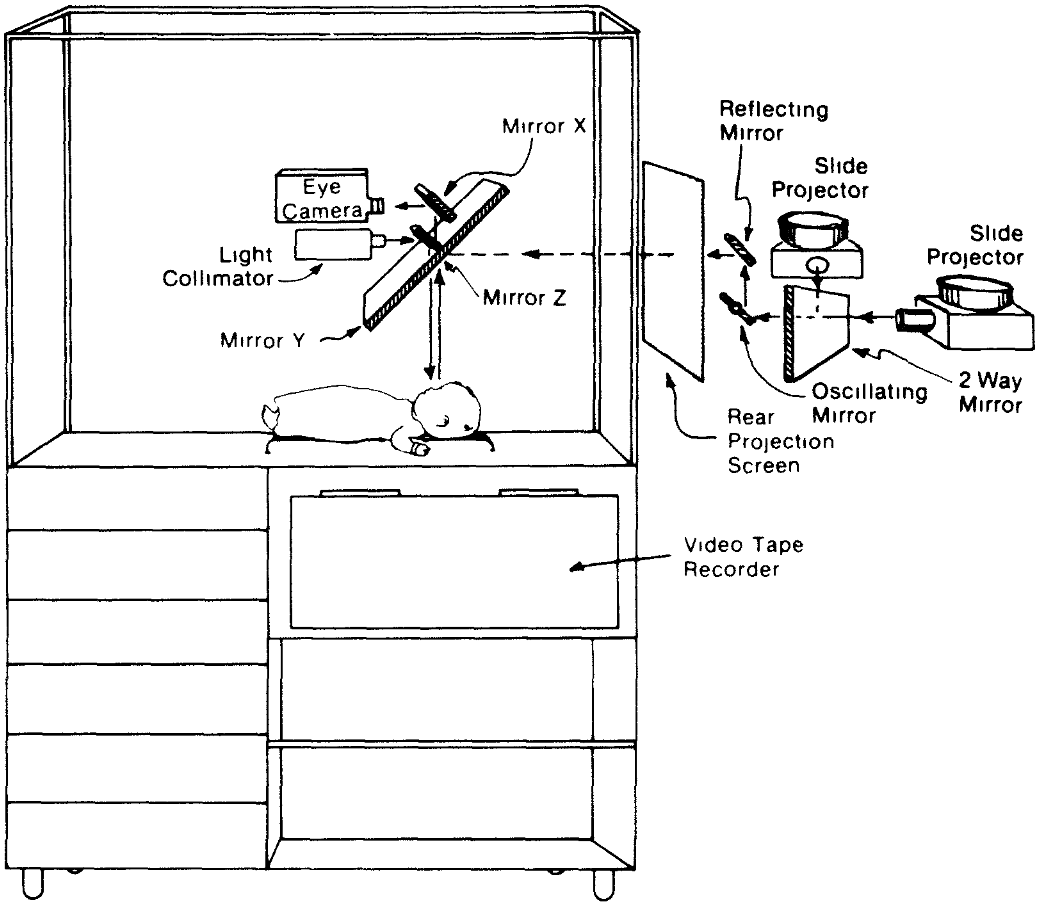


FIG 1 —Portrayal of the recording and stimulus-presentation arrangement used in the expectancy studies Stimuli were presented by the two projectors through computer-controlled tachistoscopic shutters The beam from one projector reflected from a two-way mirror, and the beam from the other was transmitted through the two-way mirror Both beams reflected from an oscillating mirror and a first-surface reflecting mirror before forming an image on the projection screen One projector presented stimuli positioned on the right, and the other presented stimuli positioned on the left The infant viewed the stimuli by reflection from mirror *Y* An infrared collimator illuminated the baby's eye by reflection from mirror *Z* and transmission through mirror *Y* The image of the baby's eye was recorded by the infrared TV camera after passing through mirrors *Y* and *Z* and reflecting from mirror *X*

mirrors *Y* and *Z* were infrared-transmitting in the eye-camera path) while preserving the optical alignment of the beam and camera This optical alignment created an image of a "back-lit pupil," produced by light reflected from the retina back through the pupil The video recording of this white pupil against the dark iris facilitated the experimenter's task in detecting eye movements, part of the source light was also reflected from the corneal surface of the eye and formed a small, bright, white spot that served as a reference point for the center of the visual field The eye image was combined with the output of a video time/date generator, which provided time increments of 1/10 sec for video recording

Two slide projectors were used to present the left and right stimuli These projectors were equipped with Lafayette tachistoscopic shutters The beam from one projector reflected from a two-way mirror angled at 45°, while that of the other passed through it To produce vertical motion of the projected stimuli, beams from these projectors were further intercepted by a small mirror that oscillated around its horizontal axis, driven by a small stepping motor (General Scanning drive and motors) In turn, the stepping motor was activated by a sine-wave output from a Heathkit Function Generator (IG1271), the resulting images oscillated vertically and smoothly, moving the image up and down a distance of

± 1.5° during the 700-msec presentation of each stimulus.

Through relays on a parallel I/O buffer, a PDP 11/04 computer controlled the advance of the slide projectors and the timing of stimulus presentation through the tachistoscopic shutters. The computer also controlled the presentation of one digit on the time/date recorder that was synchronized with the opening of the T-scope shutters; this digit displayed a "1" when the left stimulus appeared, and a "2" when the right stimulus appeared.

*Procedure.*—The infant was placed supine on an infant seat, positioned so that his or her head rested in a cloth sling, which tended to restrain head movement. A pacifier was offered to the infant as the TV eye camera was focused, and minor adjustments of the infant's head were made. During this time, both the left and right stimuli were shown continuously to hold the infant's interest. When focus and positioning were established, the experiment began.

Each baby saw 60 events; 30 of these appeared in a left-right alternating sequence, with an onset duration of 700 msec. The ISI for this alternating series was 1,100 msec. The remaining 30 events appeared in an irregular spatial sequence, randomly ordered within the constraints that no more than three successive slides appeared on the same side, and the number of slides appearing on each side was equal across each of the three 10-trial blocks. The ISIs for this sequence varied among the values of 900, 1,100, or 1,300 msec randomly sequenced, but balanced for frequency of occurrence. Thus, the duration of both series was 106.9 sec. The variable ISIs were used to augment the unpredictability of the irregular series. These two series were presented to six of the babies in an alternating-irregular sequence (alternating-early) and to the remaining six in an irregular-alternating series (alternating-late).

*Data reduction.*—One measure of interest was the latency of initiation of an appropriate eye movement following the onset of each slide that changed location. (For the irregular series, some slide onsets did not change location.) A second measure of interest was the frequency of shifts in fixation location during the anticipation interval (defined below). An observer played back the videotape on a Sony AVC-3650 at the slowest playback speed; this was calibrated on our machine to be a ratio of 1:15.7 real time to playback time. The observer pressed a button to start an electronic clock when the stimulus digit on the time/date display appeared and pressed a button to stop the clock when the eye began to move; if the eye moved to the opposite side during the ISI preceding a slide onset, this procedure was reversed. The clock provided a resolution of 1/10 sec, and a simple division of 15.7 recovered the estimated original latency of the eye movement.

Because the time sequence of event presentation was fixed, the scorer could not be uninformed about event onset, nor was it practical to keep the scorer blind about event location. However, the correctness of the direction of eye movement, well over 95% in any case, was not our concern; rather, latency was. Given our optical setup and the expanded image of the eye, refixations were quite easily discerned. We estimated that our procedure established the actual latency within ± 16.7 msec. This estimate was based on the fact that each video field, consuming 16.7 msec in real time, occupied 262 msec in playback time. Although some lag was produced by the scorer's RT to respond to the event-onset signal and to the initiation of an eye movement, these RTs should have cancelled one another, leaving only the variance in RT as potential error. This variability is typically around 50 msec, one-fifth of the 262 msec for a playback field or for the 16.7-msec real-time estimate we used. One subject's complete record was rescored by an experienced scorer after an interval of several weeks. The estimated RT values corresponded between ± 12.7 msec (real time) for 67% of the events and ± 19.1 msec for 88% of the events.

## Results

Mixed-model analyses of variance (ANOVAs) were carried out on the variables that will be reported, followed up by orthogonal comparisons for predicted differences. Except where noted, type (alternating or irregular) and sequence (alternating-early or alternating-late) were the main effects, with type as a within-subject variable and sequence as a between-subject variable in the 2 × 2 ANOVAs.

*Anticipation results.*—We predicted that infants would detect the spatiotemporal rule that governed the appearance of the slides in the alternating series and would develop expectations for their appearances. One index of these expectations is an anticipatory eye movement to the location of the next slide.

In defining anticipatory eye movements, there was no doubt about eye movements that changed sides prior to event onset However, because a response to stimulus onset takes time, it is possible that an eye movement that occurs soon after stimulus onset could be anticipatory, that is, if it begins earlier than the lower limit on RT An eye movement that occurs earlier than this lower limit, by inference, reflects a motor command that occurred prior to stimulus onset and should be considered an anticipation

The postonset limit for the anticipation interval was set at 200 msec, that is, appropriately directed eye movements that began prior to 200 msec after stimulus onset were considered anticipatory, and those occurring after 200 msec were considered event reactions Unfortunately, this decision had no direct data base, because we know of no published data on RTs for eye movements in 3 5-month-old infants However, several studies in the literature report that when adults are presented peripheral stimuli more than 4° from the current fixation point, their fastest RT is in the range of 180–200 msec (e g , Becker, 1972, Saslow, 1967) We confirmed these observations for our situation with two adults who lay in the apparatus, saw the series presented to the infants, and tried to respond to each event as rapidly as possible Their median RT was 255 msec and their fastest RT was 196 msec We know of no evidence that 3 5-month-old babies have faster RTs than adults, in fact, the evidence indicates that they are slower than adults One consideration is that the sensory transmission time from eye to brain is about 20 msec slower for infants than for adults for the type of stimuli we used here (Sokol, 1982) The most comparable RT data that do exist were collected from 2-month-olds by Aslin and Salapatek (1975) They reported a median value of 480 msec for a 10° movement in the situation most comparable to ours Thus, we conclude that a 200-msec boundary is reasonable, though possibly conservative at this age, and that eye movements that occurred prior to this time boundary reflect an eye-movement command that was initiated prior to stimulus onset

The percent of fixation shifts during the anticipation interval is shown separately for the early and late groups in Table 1 An eye movement was counted during the irregular series if it occurred in the anticipation interval (up to 200 msec following event onset), even if it was in error (i e , the following event did not change location) Combining across the early and late groups, there was a higher shift likelihood for the alternating than for the irregular series, 22% versus 11 1%, $F(1,10) = 4\ 5$, $p = \ 06$ However, an examination of Table 1 suggests that the advantage of the alternating series occurred only when that series appeared late, that is, for events 31–60 Babies in this series shifted their fixations in the anticipation interval for almost 34% of all events, reliably more than for their own irregular series, $t(10) = 2\ 65$, $p < \ 05$, or for the alternating-early group's alternating, $t(10) = 3\ 26$, $p < \ 01$, or irregular series, $t(10) = 3\ 59$, $p < \ 01$

*Facilitation results* —The adult RT literature suggested that if infants detected the predictability of the alternating sequence and

TABLE 1

MEDIAN REACTION TIMES AND PERCENT OF ANTICIPATIONS AND FAST, INTERMEDIATE, AND SLOW REACTIONS

| | SEQUENCE | | | |
|---|---|---|---|---|
| | Alternating Early | | Alternating Late | |
| | Alternating | Irregular | Alternating | Irregular |
| Reaction times | | | | |
| Baseline RT (median) | 475 (116) | | | 462 (126) |
| Median RT | 409 (67) | 445 (87) | 373 (34) | 478 (110) |
| Categories of reaction times (%) | | | | |
| Fast (200–300 msec) | 27 8 | 20 8 | 29 6 | 20 4 |
| Intermediate (300–450 msec) | 32 3 | 33 2 | 43 8 | 23 2 |
| Slow (> 450 msec) | 39 9 | 46 0 | 26 6 | 56 4 |
| Percent of anticipation | 10 4 | 7 4 | 33 7 | 14 8 |

NOTE —Standard deviations are in parentheses if they were developing expectations for those events, their speed of response to the onset of each slide would be enhanced Of course, a sensible analysis for this possibility required that anticipatory fixations be excluded Thus, the time values reported below are taken only for RTs that exceeded 200 msec following event onset RTs in excess of 700 msec were given values of 700 msec, the duration of stimulus onset

A baseline RT (median) was calculated for the first 3–5 alternating events, the specific number depending on how many scorable frames were obtained near the beginning of the series (Scorable frames varied because infants sometimes failed to look at one or more early events, or their head movement precluded recording of the eye ) This baseline was intended to serve as an individual reference value for RT, presumably before the infant had an opportunity to pick up the spatial and temporal regularity of the series

For the early and late groups combined, the postbaseline median RT for the irregular series was almost identical to the baseline, 462 msec versus 469 msec Thus, there is no indication from this experiment that RT declines with increasing familiarity with the experimental setting or the stimulus events, per se However, the combined postbaseline value for the alternating series was considerably lower than baseline, 391 msec versus 469 msec, this improvement represents about 29% of the total possible change, given a lower limit on RT of 200 msec An ANOVA on medians with condition (baseline, alternating postbaseline, and irregular postbaseline—469 msec, 391 msec, and 462 msec, respectively) as a within-subject factor, and sequence as a between-subject factor, yielded a significant condition effect, $F(2,20) = 3\ 91$, $p < 05$ Also, there were significant individual differences in RT, $F(10,20) = 2\ 86$, $p < 05$ The alternating-postbaseline median was significantly lower than that for the baseline, $t(20) = 2\ 53$, $p < 05$, or than that for the irregular postbaseline, $t(20) = 2\ 29$, $p < 05$ The slight difference between the irregular postbaseline and the baseline did not approach significance

Analyses were carried out on "fast" and "slow" RTs separately to determine whether RT differences were uniform No analysis was carried out on intermediate times as these were completely determined by percentages in the other categories An analysis of variance on the percent of fast postbaseline RTs (between 200–300 msec) produced a significant type main effect, with a higher percent for the alternating than for the irregular series, 28 7% versus 20 6%, respectively, $F(1,10) = 5\ 99$, $p < 05$ These values were quite similar for the two sequence conditions

An analysis of variance on the percent of slow RTs (longer than 450 msec) produced a significant main effect of type, $F(1,10) = 10\ 4$, $p < 01$, and a marginally stable type × sequence interaction, $F(1,10) = 4\ 54$, $p = 06$ Examination of Table 1 indicates a larger difference between the irregular and alternating series when the alternating series appeared late than when it appeared early For the late-alternation condition (events 31–60), there was a smaller percent of slow RTs than for the within-subject, irregular-series comparison (events 1–30), $t(10) = 3\ 79$, $p < 01$, or for the between-subject irregular series comparison (events 31–60), $t(10) = 2\ 46$, $p < 05$ A lower percentage of slow movements occurred for the alternating-late condition than for the alternating-early condition group, but the difference was only marginally stable, $t(10) = 1\ 69$, $10 < p < 15$

*Other behavior during the ISI*—Excluding anticipations, during the ISI, babies made only small refixations that did not significantly change the direction of their gaze on 83 2% of the events They looked down, up, or farther to the same side during the ISI after 16 8% of the events

*Two detailed examples of performance in the task*—Figure 2 displays the stimulus-by-stimulus RT data for two subjects who had different patterns of performance This figure is intended to give the reader a graphic feel for the performance of individual subjects in this task Both subjects received the irregular series (slides 1–30) prior to the alternating series (slides 31–60) The vertical axis represents reaction time, and the horizontal axis represents the slide number (slides 1–60) The horizontal dashed line is drawn at the 200-msec RT boundary that we used to define an anticipatory movement. The open circles represent reactions or anticipations of slides on the right side, and the filled circles represent reactions or anticipations to the left side Circles are connected when they represent adjacent trials Fewer circles appear for the irregular series, because there were fewer left-right shifts in location (resulting in fewer eye-fixation shifts for which a RT could be measured)

Both subjects had a higher percent of fixation shifts in the anticipation interval dur-

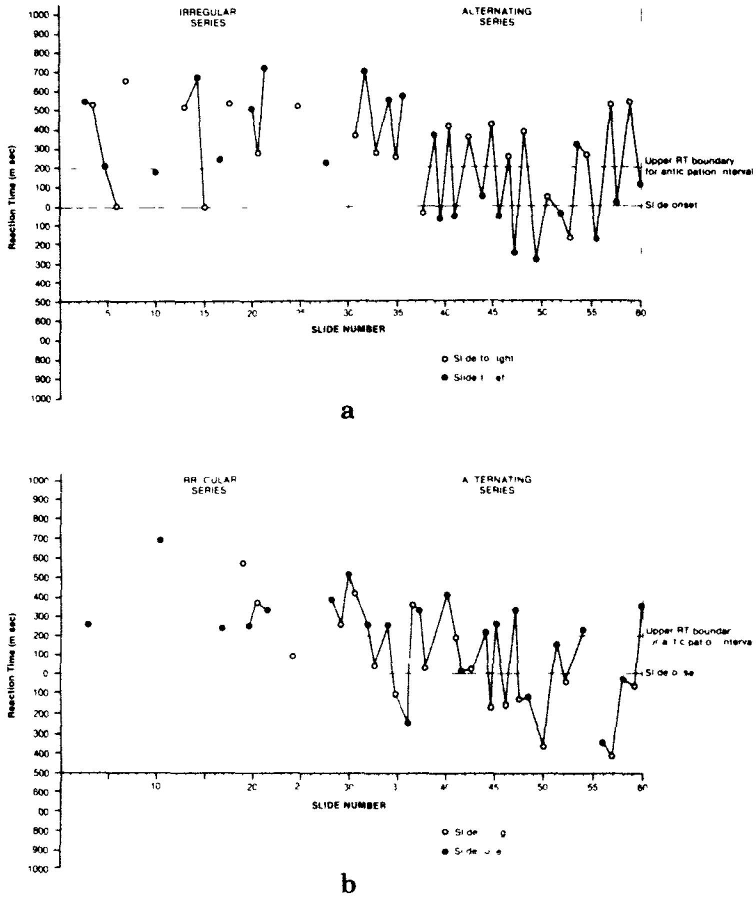


FIG 2 —Plot of reaction times against slide number for the 60-slide series The data for two subjects are shown (Figs 2*a* and 2*b*), both of whom received the irregular series first A vertical dashed line separates the irregular from the regular series The horizontal dashed line is drawn at the 200-msec boundary that separated what was defined as anticipatory movements from event reactions

ing the alternating than the irregular series, although some side shifting occurred in this interval for the irregular series also The subject shown in Figure 2*a* displayed many more left- than right-side anticipations, whereas the subject in Figure 2*b* had a more even side balance in anticipations and near anticipations The pattern of behavior essentially stabilized for both subjects within about 8–11 slides after the onset of the alternating series

## Discussion

Infants provided evidence that they can rapidly develop expectations for visual events even when they have no control over those events The evidence consisted of enhanced reaction times and more anticipatory fixations for a series of events that was predictable as opposed to a series that was less predictable The term "less predictable" is used advisedly In fact, the irregular series we used was reasonably predictable and therefore provided a very conservative estimate for comparison with the alternating series In the irregular series, events appeared in only one of two places, there was a 50% probability that the spatial location would change from one event occurrence to the next, and the time of event appearance varied around a fixed value by only ± 200 msec Thus, the comparison was between one condition that provided a strong base for developing expectations and a second condition that provided a weaker base for developing expectations

Still, the evidence for a facilitation effect was clear from the analyses of both the median RT data and the percent of fast movements This was true for both the alternating-early and alternating-late conditions (whether the comparison for the alternating condition was the baseline or the irregular series). Supporting evidence for the presence of expectations also came from the analyses of percent of visual anticipations and slow fixations, but here the outcomes were complicated somewhat by the superior performance during the alternating series of those subjects who received that series late (events 31–60). When the alternating series occurred early (events 1–30), performance was only slightly better for anticipations and slow fixations than for the irregular series.

We believe that performance on the alternating-late series was superior to that of the alternating-early series because of a "dazzle effect." A baby began this experiment by seeing the room lights darken, followed immediately by the appearance of little pictures that were colored, changed each second, shifted their location, moved up and down, and appeared and disappeared. It is unlikely that the infant had ever experienced anything like this before. The continual and rapid change in the stimulus array may have required some "getting used to" before the baby could attend to the higher-order spatial and temporal regularities that governed the sequence.

In a similar, prior study (Haith, Hazan, & Goodman, 1984)[2] we also found a significant decline in RT from baseline for alternating events. Here, we obtained no evidence that the effect can be attributed to familiarity as the median RTs for the irregular series were quite similar whether the series occurred for events 1–30 (478 msec) or 31–60 (445 msec). Moreover, these values were within 5% of the overall median baseline RT calculated on the first 3–5 events (469 msec). In both the prior and current study, the facilitation effect is most credibly attributed to infant's detection of the spatial-temporal predictability in the series. This conclusion is supported by the significantly lower RT for the alternating (predictable) series in the current study, whether it appeared early or late in the sequence.

The anticipation and facilitation phenomena fit naturally into a discussion of perceptual learning but with a somewhat unusual twist. The bulk of the developmental literature on perceptual learning concerns identification and discrimination, with action serving only as an index of the process. We see eye movements and sensory reception as integral and inseparable in the process of visual perception, at least in early infancy. This process seems most closely related to the type of correlative feed-forward and error-checking action models that have their roots in Helmholtz's early work and were developed by such people as von Holst (1954), with many additional refinements. In brief, we would argue that, as early as 3.5 months of age, the baby can create an action-based perceptual model of the situation he or she confronts, can generate short-term expectations from this model, and can support action, sometimes from these expectations (in the extreme case, anticipation), but more typically in orchestration with sensory input (in the case of facilitation). This modeling, expectation, and action sequence serves to maintain continuity in an ever-changing perceptual world where objects and the head frequently move continuously and the eyes, discontinuously.

Several other future-oriented, perception/action systems will unfold within the half year for the 3.5-month-old that will facilitate such behaviors as reaching and catching (von Hofsten, 1983) and infant locomotion (Benson, Welch, Campos, & Haith, 1985). These accomplishments share the component skills of detection of environmental regularities, implementation of controlled action, and prediction of their interrelation. It seems likely that the principles underlying the establishment of the eye-movement prediction system are similar to those skills required for these later accomplishments. In a similar vein, Piaget noted that ". . . this anticipatory function . . . is to be found over and over again at every level of the cognitive mechanisms and at the very heart of the most elementary habits, even of perception" (Piaget, 1971, p. 19). From Piagetian theory we might also expect that the early body-centered, future-oriented skills will eventually give rise to more cognitively based planning skills.

We are certain that some will feel that this characterization attributes too much cognitive capability to the infant. Perhaps. But it is also true that such expectations are realized a few months later (see, e.g., Moore, 1896,

[2] The present results confirm those of a similar study with nine 3.5-month-olds that did not contain complete data from an irregular-series control condition (paper presented at the ICIS meetings in New York, April 1984). The median RT for post baseline alternating events was 327 msec, significantly lower ($p < .05$) than the baseline median of 427 msec. Fast intermediate and slow reaction times (see Table 1 for definitions) occurred for 41.1%, 39.1%, and 19.8% of the nonanticipation trials. Anticipations occurred for 18.6% of the alternating events.

Piaget, 1954, Ripin, 1930) It is unlikely that they arise emergently, as Fischer (1980) has convincingly argued, skills appear earliest in those spheres for which the infant has the greatest opportunity for practice There is no voluntary motor system that is better practiced than the oculomotor system, nor is there any other motor system that so closely approximates the mature state in early infancy By conservative estimate, by 3 5 months of age, a baby has experienced 800 hours of alert wakefulness (Parmelee, Wenner, & Schulz, 1964) and during those hours has made 3–6 million eye movements That is a lot of practice Further, by this age the infant has encountered untold numbers of occasions of predictable object motion Thus, there is reason to believe that analogues to perception-action skills that emerge later will appear earliest in the sensory, perceptual-motor, and cognitive processes that comprise the visual system

We mentioned earlier the observations of anticipatory behavior by Haith et al (1969), the report by Anglin and Mundy-Castle (1969), and the formal study by Nelson (1968) For all of these studies, eye movements were under observation in a situation for which temporal and spatial rules governed visual sequence of events Only the Nelson study, however, has been published and contains adequate detail for critical evaluation of results relevant to the development of expectations Nelson presented babies with a series of sequentially flashing lights in a row Expectations were inferred when eye fixations continued as events were occasionally deleted and also when the eyes moved toward the front of the series after the last event While the data were suggestive, there was an inadequate baseline of comparison with behavior during an unpredictable sequence of events, the "anticipation" activities could have reflected a combination of continuation efforts (as the sequential stimuli moved in a straight line) and center-return tendencies (after the last event on the far side occurred) Our findings indicate that anticipation-like behavior can occur in an irregular series but is more probable with a regular series As far as we know, the present evidence for response facilitation in infants has no precedent, although the effect has been well documented in the adult literature (e g , Polidora, Ratoosh, & Westheimer, 1957, Stark, Vossius, & Young, 1962, Vaughan, 1983)

There are alternative interpretations to the behavioral phenomena we have observed and, certainly, different ways of thinking about them We shall discuss three of these the effects of familiarity, the role of entrainment, and the issue of infant learning The effect of familiarity might be raised as an issue in interpreting the stronger evidence for anticipation and facilitation (in fewer slow RTs) for the late- than early-alternation condition While we believe that familiarity can explain the difference between the late- and early-alternation performance (elimination of the "dazzle" effect), it cannot be argued that there is simply an increasing tendency with the passage of time for babies to switch sides in the anticipation interval or to yield faster RTs If this were the case, we should have obtained comparable data for the late-irregular condition (events 31–60)

The entrainment interpretation of anticipatory and facilitory behavior leans on evidence in the literature that the biological rhythms of babies tend to adjust to the rhythm of the environment One example is the developing sensitivity of infants to a diurnal rhythm around 2 months of age Another example involves thinking of the infant's eye-movement system as a kind of oscillator, driven by left and right stimulus "snap shots" We see no way that the entrainment interpretation could account for the difference we found between the alternating-early and alternating-late conditions While babies were engaged in the alternating series in the alternating-early condition (and fixated virtually every event), we saw evidence for expectancies only in the increased proportion of fast RTs (compared to the irregular series) What is more important, this interpretation implies a regularity in behavior that we did not observe Infants sometimes, for example, would anticipate several right events, in sequence, or respond very rapidly to those events, but would respond relatively slowly to left events (see Fig 2) In short, a careful look at our data indicated anything but the kind of lock-step response that, according to this interpretation, should mirror the fixed spatial-temporal sequence we presented

Have we simply provided another illustration of learning in infants? Of course, a kind of learning must be involved, in the sense that infants acquired information about the spatial and temporal properties of the visual sequence The question is whether standard classical or operant learning interpretations can accommodate the phenomena under analysis Perceptual learning processes have not typically rested easily in these traditions, but a specific action was integral to the learning examined here, so the fit might be somewhat better A complete analysis of the applicability of the traditional learning models for our observations would consume more space than is warranted We conclude, however, that they are unlikely to fit well for the following reasons For classical conditioning interpretations (*a*) although there are exceptions, classical conditioning analyses are typically applied to autonomic rather than skeletal responses, (*b*) left and right eye movements did not initially satisfy the fixed relation to the left- and right-picture onsets that one expects of unconditioned stimulus–unconditioned response relations, such as that between an air puff and eye blink The "stimulus-response" timing was highly variable, and sometimes the babies did not even fixate the first 2–3 slides, (*c*) some infants began to anticipate the two side events at the same time, which would seem a remarkable coincidence for two independent classical conditioning tasks, (*d*) the rapidity with which the skill was acquired in a setting that required two learning connections at once (or one while being distracted by another) flies in the face of the infant learning literature (Brackbill, Fitzgerald, & Lintz, 1967, Papousek, 1967) The average number of events on a side after which the first anticipation was made across all subjects (who had at least one anticipatory response), in both this and our earlier experiment was 5 4 trials on the left side and 5 5 trials on the right, that is, within about 16–17 sec of exposure to the alternating series

An operant analysis shares the coincidence problem in (*c*) above, and the rapidity of learning even one operant response so quickly is so out of line with the operant literature (see Olson & Sherman, 1983, Sameroff & Cavanaugh, 1979) that the problem of modeling the learning of two operants simultaneously seems beyond credibility It is also important to remember that, in contrast to operant paradigms, the series proceeded independently of the infant's responses Further, it would be difficult to argue that our procedure increased the likelihood of directionally appropriate responses, as required by an operant analysis, since the tendency to fixate a peripheral stimulus onset is strong even at birth (Harris & MacFarlane, 1974) Finally, neither model accommodates the facilitation effect that we observed

Our data demonstrate that babies as young as 3 5 months of age can rapidly detect spatial and temporal regularities that govern a visual sequence, develop expectations for the impending event in the series, and use those expectations to support adaptive action either in the absence of visual input (anticipation) or in orchestration with it (facilitation) However, we feel that an important point would be missed if these abilities were seen merely as additions to a taxonomic collection of infant perceptual skills We believe it is important to ask why a baby would gratuitously develop expectations for a series of events over which it has no control Why not simply respond on an ad hoc basis to each picture onset? We believe that infants are motivated to detect regularities in dynamic events and to develop expectations partly in order to bring their behavior under self-control, the alternative is to let their behavior be enslaved to external events, which, at least for the adult, requires substantially more effort Thus, in addition to demonstrating the young infant's abilities to detect regularity, to develop expectations, and to govern adaptive action based on expectations, these findings suggest a natural motivation in babies at a very early age to control their own perceptual activity

Apart from the interpretation of our results, the paradigm we have developed provides a window on the fast-paced and short-lived expectations that young infants generate for dealing with their dynamic visual world This paradigm generates many data points that are gathered quickly in a task that engages the infant, and data reduction is straightforward and relatively nontechnical However, we do not want to claim that we have seen merely the tip of the cognitive iceberg or to endow the infant of 3 5 months with excessive capacity for dealing with future events Rather, we believe that we have approximated an optimal situation for tapping into the expectation phenomenon—by employing highly interesting events, a highly skilled motor system, and temporal, spatial, and contingency parameters that demand as little of the baby as possible And we want to alert potential researchers in this area to the fact that this convergence of factors was not casually chosen In one form or another, one of us (M M H ) has worked on this problem for over 20 years The present paradigm is a distillation of many failures and partial successes How far such factors as the time and spatial parameters can be pushed without destroying the phenomena is open to question More interesting is how complications of the temporal and spatial contingencies will affect performance In part, these are questions not only about the paradigm but also about the cognitive complexity the infant possesses in the domain of expectations Most certainly, these are developmental questions that also hold promise for exploring individual differences in cognitive status

Given the fact that expectations occupy core status in cognitive theories, it is clear that a complete exposition of cognitive development requires an understanding of the earliest phases of future-oriented behavior The paradigm and results we have described provide a tool and a beginning for this understanding

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