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The Nature of Infants' Visual Expectations for Event Content

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Recent studies have revealed that young infants can form expectations for the spatial location of future visual events. Four experiments examined whether 3-month-old infants also form expectations for content features of events, defined as an invariant color combination. Infants viewed a spatially alternating (left–right) sequence of varying pictures in which pictures on one side (invariant colors) always appeared with the same color combination (e.g., red/green), while on the other side (varied colors) the pictures appeared with any of 4 possible color combinations. Results indicated that infants formed a content expectation for the invariant color combination on the invariant side, such that their anticipatory responding was disrupted by a novel color combination event and by a novel pattern event. A dissociation between reactive and anticipatory eye movements in their sensitivity to the content manipulation suggests that infants' expectations for spatial and content information engage somewhat different processes.

We obtain a measure of control over the environment by learning about and remembering patterns of events, then using that experience to plan goal-oriented activity. Such expectations guide our everyday behaviors, such as planning our driving based on expectations for traffic patterns, preparing for weather patterns,

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Supplementary materials to this article are available on the World Wide Web at http://www.infancyarchives.com.

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and guiding our social interactions. Presumably, because little of the environment is under the infant's direct physical control, such future-oriented thinking has been thought to be beyond their cognitive capabilities (for various discussions of this issue, see Haith, Benson, Roberts, & Pennington, 1994). Haith and his colleagues (Haith, Hazan, & Goodman, 1988; Haith & McCarty, 1990; Wentworth & Haith, 1992, 1998), however, have found that human infants form expectations for future events, an important component of future-oriented thinking, as early as eight weeks of age.

Specifically, Haith et al. (1988) demonstrated infants' expectations for events that were not perceptually available with a new paradigm called the *Visual Expectation Paradigm (VExP)*. In the prototypic procedure, infants view pictures that appear either in a predictable left–right alternating sequence or in an unpredictable irregular sequence. The primary index of the expectation construct is anticipatory behavior—eye movements programmed during the *interstimulus interval (ISI)* to locations where pictures will appear before their actual onset. When an anticipatory eye movement does not occur, response facilitation—the reduction in reaction time to make an eye movement after a picture is presented—also provides evidence for expectations. Typically, infants' anticipatory eye movements are more numerous, and the latency of their reactive eye movements after picture onset are faster, when the pictures appear in a predictable spatiotemporal sequence rather than in an unpredictable sequence (Haith et al., 1988). Such results demonstrate that infants form expectations for events that are not perceptually available and that rudimentary future-oriented processes are evident early in life (Haith, 1994). Subsequent studies have revealed that infants encode and form expectations for more complex, asymmetric (e.g., left–left–right) spatial sequences (Canfield & Haith, 1991) and for the temporal parameters of visual events (Adler & Haith, 1998; Lanthier, Arehart, & Haith, 1993; Wass, Lewis, & Haith, 1998).

Events, however, have content as well as spatial and temporal information. Over the years, content has been extensively shown to be a very salient cue in infants' processing of event information. For example, that infants discriminate very fine transformations in event content from initial familiarization to test (Cohen, 1972; Colombo, Mitchell, Coldren, Atwater, 1990; Fagan, 1970; Fantz, 1964; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982; Salapatek, 1975) and form long-term memories whose content is unique to the constituent attributes of the originally encoded event (Adler, Inslicht, Rovee-Collier, & Gerhardstein, 1998; Adler & Rovee-Collier, 1994; Greco, Rovee-Collier, Hayne, Griesler, & Earley, 1986; Rovee-Collier & Sullivan, 1980). Whether infants' expectations are similarly sensitive to encoded event content remains an open question.

A first attempt at investigating whether infants form expectations for specific event content was conducted by Wentworth and Haith (1992). Across three experiments, they displayed pictures in a spatially alternating left–right sequence, but the same picture was used for every stimulus presentation on one (invariant) side, whereas the picture content varied on the other side. Wentworth and Haith found that both 2- and 3-month-olds made significantly more anticipations to the invariant than to the varying content side. The latency of infants' reactive eye movements was shorter to the invariant content side than the varied side for 2-month-olds (for two out of the three experiments), but did not differ between the two sides for 3-month-olds. The anticipation result, in particular, suggested that infants encode the content of visual events as they form expectations, and that they use predictable content to enhance their expectations for future events. Tamis-LeMonda and McClure (1995) found that after familiarization to predictable content in an expectation paradigm, infants discriminated novel content in a novelty-preference paradigm, thus demonstrating that infants had encoded content information. Whether the predictable content affected infants' expectations, however, was not investigated.

Although Wentworth and Haith (1992) demonstrated that infants could form expectations for a single event, it is unclear whether they can form expectations for a general class of events that share particular feature content. People typically form expectations for a class of events rather than for a single, precise stimulus; therefore, the capacity to generalize an expectation across varied but related events must be an essential component of cognitive functioning. In particular, the ability to generalize across a set of different but related events is an inherent element of cognitive flexibility, which has, in turn, been theorized to be central to cognitive development. Recently, Siegler (1994) suggested that changes that occur in cognitive development reflect the flexibility by which the child applies available capacities to new and distinct, but related, situations. One focus of this study, therefore, was to determine whether infants could form an expectation for a set of events that share the same content.

Another focus of this study was to determine the nature of the content information that infants encode in their expectations and use in the behavioral manifestation of these expectations. In order to determine the nature of the stimulus information that infants have encoded, others have used contingency (e.g., Adler, 1997) and looking paradigms (e.g., Cohen, Gelber, & Lazar, 1971) which depend on infants' discrimination of novel from encoded information. In the Wentworth and Haith (1992) study, infants were not tested with novel content, so it is not possible to determine whether infants' expectations for the single, unchanging stimulus were specific to the content of that stimulus event. Perhaps infants simply encoded that the single picture on one side was constant, without necessarily forming an expectation for the content of the picture. To more fully determine the nature of the stimulus content information that infants encode in their expectations, we tested infants with pictures in which a stimulus feature was novel, while other features remained constant.

Specifically, we examined (a) whether infants can form a content expectation for a class of related but distinct event exemplars, and (b) the nature of the event content information encoded. We manipulated event content by defining it as an invariant color combination, as other parameters (e.g., shape and pattern) of the event varied. The ability to detect the invariant content of different stimulus exemplars has been well established as part of the perceptual and cognitive repertoire of the infant. For example, many studies have shown that infants can detect the invariance of the size or shape of an object even as it undergoes transformations (Caron, Caron, & Carlson, 1979; Day & McKenzie, 1981; Granrud, 1987; Slater, Mattock, & Brown, 1990), and are adept at detecting the invariance of the spatial relations between objects (Behl-Chadha & Eimas, 1995) and the underlying correlated attributes shared by objects (Younger, 1985, 1990, 1992). This ability to detect invariance has even been extended to information that crosses modalities (Bahrick, Netto, & Hernandez-Reif, 1998; Pickens & Bahrick, 1997). Finally, and most important for this study, infants can detect the invariance of the simple attribute of color across distinct stimuli (Bornstein & Korda, 1984; Catherwood, Crassini, & Freiberg, 1989).

By holding color information invariant among events that vary along other dimensions (e.g., shape and pattern), this study builds on the Wentworth and Haith (1992) study that demonstrated content expectations for a single unique stimulus event. Since the invariant color combination condition in this study included multiple exemplars, infants could not use expectations for the same specific event. Instead, infants had to generalize their expectations across events that differed from each other in their patterns or shapes, on the basis of their invariant color combination. In line with the findings of Wentworth and Haith, we expected that infants would exhibit better performance for the invariant color combination events even across multiple exemplars, indicating that infants' expectations can be generalized beyond a single unchanging event to a set of events that share a particular property, but otherwise differ.

The prediction for this study and the finding by Wentworth and Haith (1992) would seem to be contrary to numerous infant studies which suggest that repetitive stimulus information is *less likely* to attract processing resources. For example, studies of *inhibition of return (IOR)* in infants have shown that their saccadic responses took longer to a stimulus that was repeated in the same location as a preceding spatial cue as to a stimulus in a different spatial location as the cue (e.g., Hood, 1993). However, this finding requires that infants' attention be reoriented back to the fixation stimulus between the presentation of the cue and target. When this is not required, infants, in fact, show a facilitation in response latency to a stimulus repeated in the same location as a cue (e.g., Johnson, Posner, & Rothbart, 1991), a finding that is in concordance with our prediction of a facilitative effect of repetitive content information. Other infant studies, such as pop-out (Adler & Orprecio, 2002: Quinn & Bhatt, 1998; Sireteanu & Rieth, 1992) and habituation (Kaplan & Werner, 1986; Slater, Morison, & Rose, 1982) have indicated that infants respond to discrepant or novel information, and are less likely to respond to redundant information. Redundant information, however, is required for the exhibition of these effects in that pop-out occurs with homogenous (redundant) distractors, but not varied distractors (Bhatt, Bertin, & Gilbert, 1999), and, without habituation to a repetitively presented stimulus, there would be no demonstration of a novelty effect. That is, to exhibit a greater likelihood of responding to varied or novel information, encoding of the redundant information is necessary. What behavioral form the processing of redundant information takes depends on the paradigm and measure: in visual expectation studies, it is an increase in anticipatory eye movements; in habituation studies, it is a decrease in fixation time; and in pop-out studies, it is control of behavior by the pop-out stimulus. Regardless, all of these studies, including this one, are demonstrating behaviors that, at their core, rely on the processing of redundant information in the stimulus environment.

To preview the main finding from this study, 3-month-old infants' anticipatory behavior, but not the latency of their reactive eye movements, was superior for invariant color combination events, indicating that they formed expectations based on the invariant color combination. In follow-up experiments, novel content information, in the form of a completely novel color combination, and a novel pattern, was presented during a test phase in order to determine the nature of the event content information that infants encode to express their expectations.

EXPERIMENT 1: EXPECTATION FOR INVARIANT VERSUS VARIABLE EVENTS

In the first experiment, we wanted to establish whether 3-month-old infants could form expectations for a set of stimulus events by presenting exemplars that are invariant in one content attribute as they change in other attributes. As in previous VExP studies, infants viewed stimuli that appeared in a left–right alternating sequence. Similar to the Wentworth and Haith (1992) study, one side was designated as the invariant side and the other as the varied side. The invariant property that defined the invariant side was a color combination. If infants detect the invariant color combination and form an expectation for this information, then their anticipatory performance should be better to the more predictable invariant color combination side than to the side on which picture content is unpredictable.

Method

Participants. Infants and mothers who participated in the study were recruited through a standing arrangement with the Colorado Department of Health. Once names were provided, parents were sent a letter and self-addressed postcard to inquire about their interest in having their infant participate in studies at the University of Denver. If they returned the postcard, they were contacted by phone and participated, if they were interested in the study. The data from 16 infants (11 male, 5 female), who ranged in age from 90 to 98 days ($M = 94.3$ days, $SD = 2.2$)

were used for analyses. Infants in the sample were Caucasian (n = 14) and Hispanic (n = 2), were primarily drawn from middle to upper socioeconomic status (SES) families, were full-term at birth with no reported complications, and appeared in good health. An additional 17 infants (9 male, 8 female) participated, but insufficient data (i.e., data on less than 65% of the pictures) were collected from them because they cried (n = 6), were inattentive (i.e., disinterested, or looked at their hands, or other parts of the visual field; n = 9), or for a reason that the experimenter failed to record (n = 2). The high dropout rate in this and the subsequent experiments reflected a strict criterion for inclusion of an infants' data in the analyses. In all previous expectation studies (e.g., Haith et al., 1988), the criterion for inclusion of an infant's data was a requirement that they attend to 65% of all postbaseline pictures. In this study, because we were interested in infants' expectation to the invariant content side versus the varied content side, we required them to attend to 65% of the pictures on each side, rather than just 65% of pictures in the entire session. However, the dropout rates in the described experiments are well inline with the dropout rates reported in other visual expectation studies (e.g., Haith et al., 1988; Haith & McCarty, 1990; Wentworth & Haith, 1992).

Stimuli. The stimuli were computer-generated graphic images of checkerboards, vertical stripes, concentric circles, and diamond-in-square shapes in various combinations of green, red, yellow, and blue (color images of the stimuli can be viewed at the Infancy web archives at http://www.infancyarchives.com). The infant viewed the images by mirror reflection on a Sony color monitor (model 1302) that was 20.3 cm high × 25.4 cm wide, at a distance of 40 cm. The stimuli were approximately 4.5° squares, 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. An ISI of 1000 msec preceded each picture, during which infants had the opportunity to make anticipatory eye movements in the absence of any visual stimuli (i.e., the monitor screen was blank).

A total of 100 pictures were presented to each infant, with the first 10 constituting a baseline period during which the pictures were randomly presented on the two sides and infants' eye movement activity prior to learning was assessed. The remaining 90 pictures constituted the experimental phase during which every picture on one side of the video monitor appeared in the same color combination (red/green, red/blue, yellow/green, or blue/yellow), while the color combination for the pictures on the other side of the video monitor varied randomly among the four color combinations.

Apparatus. The infant lay supine on a mattress and viewed the stimuli by reflection from a visible-reflecting, infrared-transmitting mirror (Libby-Owens No. 956; see Haith, Hazan, & Goodman, 1988, for details). The image of the infant's right eye (in a camera field approximately 3.8 cm) was videotaped by a Panasonic CCD TV camera (model WV-CD20) from which the infrared lens filter was removed. (Unfiltered CCD elements are quite sensitive to near infrared light.) Light for televising this eye image was provided by an infrared source and collimator whose beam reflected from an infrared-transmitting, visible-reflecting mirror that was in the same optical path as the recording video camera (for a schematic of the apparatus, see Haith, Wentworth, & Canfield, 1993). The eye image was transmitted through these mirrors to the camera. The collimator was fitted with optical filters (Corning 7-69 and Kodak Wratten 87c) to eliminate heat and reduce visibility; from the infant's position, the light was virtually invisible. The optical alignment of the beam and camera created an image of a backlit 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 1/100 sec for video recording.

A Zenith 8086 computer controlled the sequencing and the timing of stimulus presentation. The computer also controlled the presentation of one digit on the time/date recorder that was synchronized with the presentation of pictures; the digit was a "1" when the left-stimulus appeared, a "2" when the right-stimulus appeared, and a "0" during the ISI.

Procedure. A pacifier was offered to the infant as the TV eye camera was focused and minor adjustments to the position of the infant's head were made. During this time, the monitor screen displayed a magenta solid circle that moved in a circular path to hold the infant's interest. When camera focus and positioning of the infant were established, the experiment began.

Initially, infants saw 10 pictures that were presented in an irregular spatial sequence and whose color content was random, constituting a baseline phase during which infants' reaction time (RT) and anticipation levels were assessed before expectations were formed. The infants then saw a L–R, alternating sequence, of 90 pictures (45 on each side) in which the pictures on one side (e.g., left) were comprised of an unchanging color combination while the pictures on the other side (e.g., right) varied in their color combination content. On the invariant content side, four different picture patterns (stripes, bullseye, checkerboard, and diamond-in-square) appeared randomly, but in one of four color combinations (red/green, red/blue, yellow/green, or blue/yellow). Which of the four color combinations comprised the invariant content side and which side was designated the invariant content side were counterbalanced across infants. On the varied content side, the same picture patterns appeared randomly in any of the four color combinations.

Data reduction. To determine the eye movement locations from the videotape, an eye-tracking computer program completed multiple runs on a given infant's video record to average out machine and tape noise in the detection of the pupil and corneal reflection. This system produced an eye movement timing resolution of 16.6 msec. Specially developed software displayed eye-location data as a graph representing the horizontal and vertical locations of the infant's eye for each 16.6 msec sample and the video fields on which pictures were on and off.

A secondary computer program then identified which eye movements belonged to which of two measurement categories that were used to reflect what we have referred to as *anticipation and facilitation* (Haith et al., 1988). Anticipation refers to an appropriate eye movement that is triggered prior to a visual event, whereas facilitation refers to the latency of an eye movement following the event and to what degree that latency is reduced, presumably by knowledge about it (spatial location and/or timing). An eye movement was categorized as an anticipation if it occurred during the ISI preceding an event, or within 167 msec following its onset (i.e., faster than the lower limit of RT), and if the movement was directionally appropriate. A percent of anticipation measure was computed by the formula:

$$\frac{\text{Number of Anticipation Trials}}{\text{Number of Anticipation Trials} + \text{Number of RT Trials}}$$

with the denominator reflecting the total number of pictures for which the scorer judged the infant to be looking. In Experiment 1, infants responded on an average of 89% of the baseline trials and 82% of the experimental trials.

For those occasions on which the infant did not anticipate the event, but did make a directionally appropriate eye movement 168 msec or later, an RT was recorded. Reliability in identifying the critical saccades, both anticipatory and reactive eye movements, by the eye tracking and reduction programs was identified by additionally double coding 20% of the participants in this study with a conventional manual, frame-by-frame, reduction method. To determine reliability, the percentage of eye movements selected by both coding methods that were within one frame (+/– 33.3 msec) was calculated. Reliability across all experiments between manual, frame-by-frame coding by the first author and the computer coding system was 93.5%.

Results

Preliminary analyses. Since the invariant content for this experiment was drawn from four possible color combinations, and 3-month-old infants have been shown to have differential sensitivity to various colors (Adams, Maurer, & Davis, 1986; Peeples & Teller, 1975; Teller, Peeples, & Sekel, 1978), it was first necessary to determine whether each of the color combinations yielded equivalent expectancy performance across infants. To this end, 4×2 repeated measures analyses of variance (ANOVA) were conducted on percent anticipations and RT, with color combination (green/red, red/blue, green/yellow, yellow/blue) as the between factor and content side (invariant, varied) as the within, repeating factor. For percent anticipations, this analysis yielded a nonsignificant effect of the particular color combination, $F(3, 12) = 1.35$, $p = .30$, indicating that infants' anticipatory performance did not differ reliably across the possible color combinations. There was a significant effect of the content side, which will be discussed in more detail later in this article. Further, a nonsignificant interaction between color combination and content side indicated that the difference in anticipations between the two sides did not reliably differ for the four color combinations used on the invariant side. For RTs, an identical analysis yielded no significant main effects of color combination ($p = .83$) or content side and no significant interaction effect between the two ($p = .34$).

These preliminary analyses indicate that, regardless of the specific color combination that served as the invariant content, infants' performance was consistent. This pattern of results was the same across the other three experiments in this study, and, therefore, will not be discussed further. As a result of these analyses, in each experiment, data were collapsed across infants who viewed different color combinations as the invariant content.

Anticipation results. A repeated-measures, one-way ANOVA was performed on percent anticipations comparing infants' performance across the conditions of the baseline phase, invariant color combination side, and varied color combination side. All fixation shifts were included as anticipations for the baseline phase. There was a significant main effect of conditions, $F(2, 30) = 7.56$, $p < .003$. Because of the results obtained by Wentworth and Haith (1992) and our a priori experimental interest in the relative effects on eye movements of the invariant content side versus the varied content side, and both of these versus responding during baseline, in this, and subsequent experiments, we conducted planned comparisons of these contrasts. Using planned comparisons, as opposed to post-hoc comparisons, provided our analysis with a number of advantages, particularly that planned comparisons contain more power and they do not require significant effects in an omnibus ANOVA (Saville, 1990; Wilson, 1962).

The planned pairwise comparisons of means revealed that infants' anticipations were significantly more likely to the invariant colors side ($M = 18.8\%$, $SE = 2.8$) than to the varied colors side ($M = 9.5\%$, $SE = 1.5$), $F(1, 30) = 10.91$, $p < .003$, or during the baseline period ($M = 9.1\%$, $SE = 2.9$), $F(1, 30) = 11.76$, $p < .0025$ (see Figure 1)[1]. Anticipatory performance to the varied side, however,

[1]The level of anticipatory responding to the invariant and varied content sides in this and subsequent experiments was consistent with the level of responding in the Wentworth and Haith (1992) study in which infants had approximately 22% anticipations to the unchanging (invariant) picture and 12% to the changing (varied) picture.

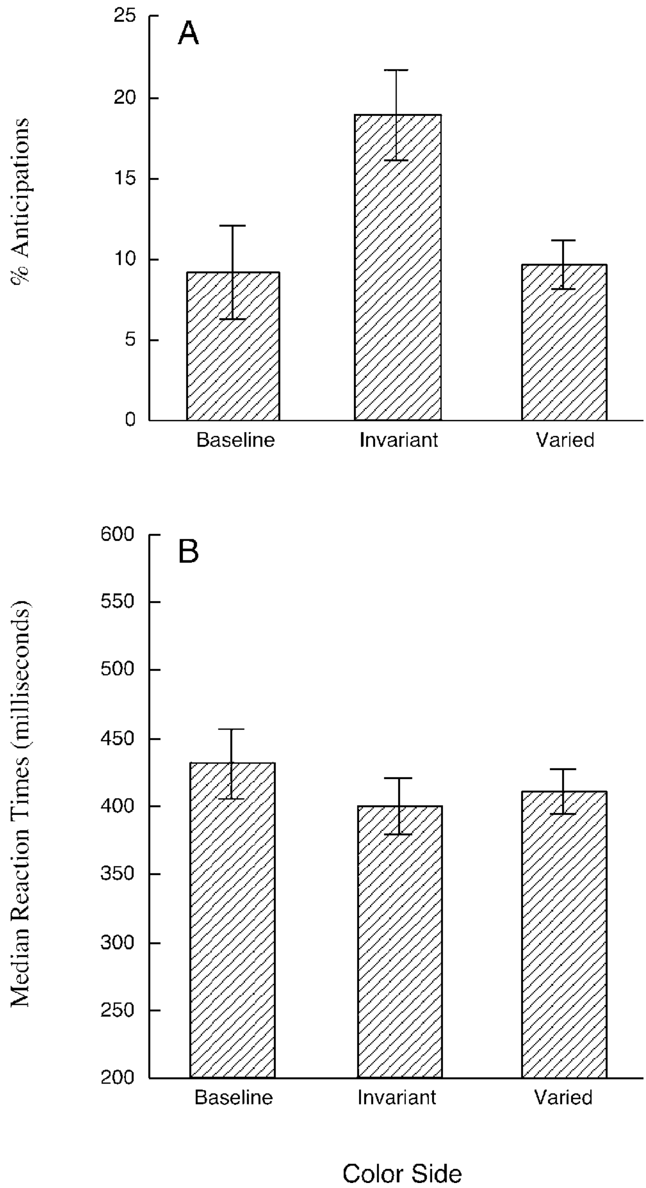

FIGURE 1 Percentage of anticipations (A) and median reaction times (B) as a function of baseline and content side (invariant and varied) in Experiment 1. Vertical error bars indicate +/– *SE*.

did not significantly differ from baseline ($p > .90$). These results suggest that infants were able to detect the invariant color information from the multiple pattern exemplars on the invariant colors side and form a content expectation for that color combination. In accord with the Wentworth and Haith (1992) findings, infants made anticipatory fixations more frequently when some of the content features were predictable than when they were not.

Reaction time results. On those trials on which infants' eye movements did not anticipate picture onset, median RTs after picture onset for each infant were calculated.[2] These RTs were then subjected to a repeated-measures one-way ANOVA comparing their level across the conditions of the baseline phase, invariant color combination side, and varied color combination side. Surprisingly, this analysis yielded no significant effect of conditions, $F(2, 30) = 1.36$, *ns*, indicating that the color combination manipulation failed to influence the speed with which infants visually oriented to the pictures on the two sides. This finding was confirmed by the results of the planned comparisons, which indicated that the RT to the invariant colors side ($M = 398.9$ msec, $SE = 20.8$) did not significantly differ from the RT to the varied colors side ($M = 410.4$ msec, $SE = 16.4$), $F(1, 30) = .36$, *ns*, or from the baseline period ($M = 430.2$ msec, $SE = 25.7$), $F(1, 30) = 2.66$, *ns*. In addition, RT to the varied color combination side did not differ from baseline, $F(1, 30) = 1.07$, *ns*. The failure to find an effect of the content manipulation on infants' RTs is consistent with the finding of Wentworth and Haith (1992). Nevertheless, that RTs were unaffected by the content manipulation is surprising because both anticipatory performance and reaction times have previously been hypothesized to represent the same underlying cognitive construct of expectations (Haith et al., 1993). A possible explanation for the absence of an RT effect is described later.

Discussion

The findings from this experiment confirm the findings from Wentworth and Haith (1992) that infants form expectations, not only for the spatial location of visual events, but also for their content information. Infants anticipated events whose content was predictable about twice as frequently as events whose content was unpredictable. Extending the Wentworth and Haith findings, this experiment demonstrated that infants' established a content expectation for the invariant color combination shared by exemplars that differed in shape, as manifested in more frequent anticipation for the side on which the color combination was predictable.

[2]Medians are used because infants' eye movement latencies tend to be skewed and, therefore, means do not provide an accurate measure of the central tendency.

Thus, this experiment reveals that infants not only form expectations for a single event, but also for a set of events that share the same content.

In contrast to the anticipation results, but consistent with the findings of Wentworth and Haith (1992), the latency of infants' reactive saccades after picture onset did not differ between the invariant and varied color combination sides. The reason for the lack of a reaction time difference was not discussed by Wentworth and Haith, and is not presently clear. Subsequent experiments build on these findings and attempt to establish the level of specificity of infants' content expectations for the invariant color information and their capacity to generalize the content expectation to novel events.

EXPERIMENT 2: EFFECT OF A NOVEL COLOR COMBINATION

Experiment 2 was designed to further support the contention that infants also form expectations for the content of visual events by introducing a completely novel invariant color combination on both the invariant and varied content sides. If infants form an expectation for the specific color combination on the invariant side, then they should discriminate a novel color combination because it does not match the expected color combination. On the varied content side, for which infants presumably do not form an expectation for a particular color combination, the novel color combination should not affect infants' behavior.

Infants discrimination of the novel color information could be exhibited in their expectancy behavior in one of two ways. Grossberg (1995) proposes that the violation of an expectation by novel event information results in an increased allocation of attentional resources in order to integrate the novel information into the existing expectation. Accordingly, we might expect that presentation of novel color information would result in infants allocating additional attentional resources. In conjunction with the well established link in adults (Adler, Bala, & Krauzlis, 2002; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995) and infants (Hood & Atkinson, 1993; Johnson, Posner, & Rothbart, 1994; Matsuzawa & Shimojo, 1997) between attentional allocation and the initiation of saccadic eye movements, the increase in infants' attentional allocation should yield a concordant increase in anticipations. On the other hand, in infant memory studies where task performance improves with training, presentation of novel information results in a decrease in performance and a return to pre-training levels (e.g., Adler & Rovee-Collier, 1994). In the present case, in which infants' anticipatory performance also increases with training, one might expect that presentation of novel color information would decrease infants' anticipatory performance and return it to pre-training levels. Regardless of which disruption scenario is exhibited by infants, a change in performance to the invariant content side, and not to the varied content side, would provide converging evidence that infants formed a content expectation for the specific invariant color combination.

Method

Participants. Infants were recruited as in Experiment 1. The data from 16 infants (8 male, 8 female), who ranged in age from 90 to 99 days (M = 94.3 days, SD = 2.9) were used for analyses. Infants in the sample were Caucasian (n = 14), Native American (n = 1), and Other (n = 1); were primarily drawn from middle to upper SES families; were full-term at birth with no reported complications; and appeared in good health. An additional 23 infants (12 male, 11 female) participated, but insufficient data (i.e., data on less than 65% of the pictures) were collected from them because they cried (n = 8), were inattentive (n = 12), fell asleep during the experimental session (n = 1), or experimenter error in videotape recording (n = 2).

Stimuli and apparatus. The stimuli and apparatus were identical to Experiment 1, except that a fifth color combination, magenta and white, was used as novel color content during the novel test phase.

Procedure. The procedure was essentially the same as in Experiment 1, except that in this experiment, after viewing pictures that spatially alternated between an invariant content side and a varied content side, infants received a novel test phase in which a familiar picture pattern occasionally appeared with completely novel colors. The infants received a baseline period of ten random pictures, followed by a *training phase* in which they saw a L–R alternating sequence of 60 pictures (30 on each side). One location (e.g., left) constituted an invariant color combination side and the other location (e.g., right) constituted a varied color combination side. Subsequent to the training phase, infants received a 30-picture *novel test phase,* during which the pictures continued to appear in a L–R alternating sequence, but, on five occurrences on each side, the picture appeared with completely novel colors (magenta/white). In this second experiment, infants responded on an average of 83% of the baseline trials, 81% of the training phase trials, and 75% of the novel test phase trials.

Presentation of the novel colors and other types of novel content adhered to two criteria: (a) The novel content could not occur on consecutive trials across sides, and (b) the novel content could not occur on consecutive trials on the same side. As a consequence of these criteria and the limited number of trials in the novel test phase, the novel content was presented every third trial, but its first presentation was counterbalanced across the first three trials of the novel phase. A schematic of a sample portion of the novel test phase is presented in Figure 2 (a color image of this Figure can be viewed at the Infancy web archives, http://www.infancyarchives.com).

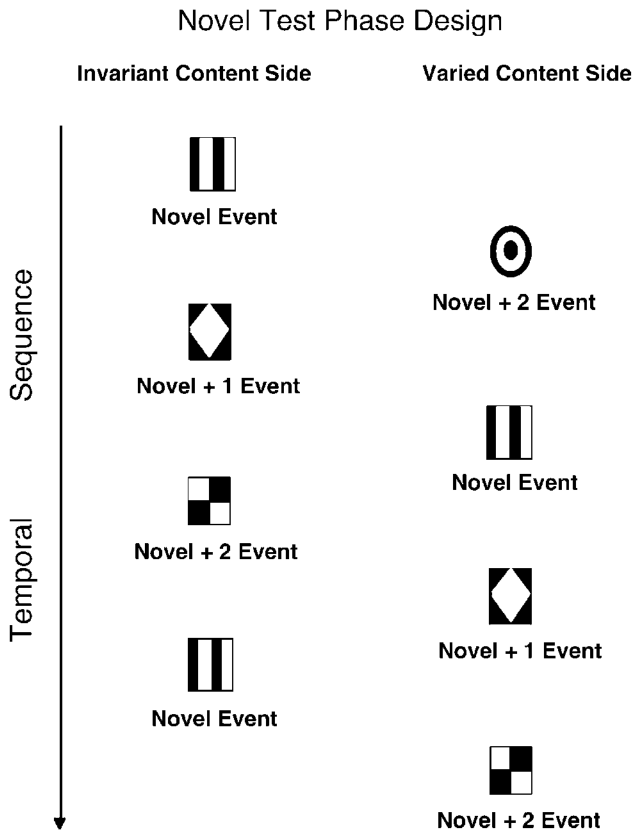

FIGURE 2 Schematic of a portion of the novel test phase presented to infants in Experiments 2 and 3. Shown for each content side (invariant and varied) are the novel events, novel + 1 events, and novel + 2 events. The first novel event could occur on any of the first five during the test phase, and was counterbalanced across infants. In Experiment 2, the novel event was a novel color combination, whereas, in Experiment 3, the novel event was a novel pattern.

Results

Training Phase

Anticipation results. A repeated-measures, one-way ANOVA was performed comparing infants' performance across the condition levels of the baseline period, invariant content side, and varied content side. Results of this analysis indicated a significant main effect of conditions, $F(2, 30) = 3.74$, $p < .04$. Planned comparisons again revealed that the number of anticipations was significantly greater on the invariant side (M = 18.7%, SE = 1.8) than the varied side (M = 10.4%, *SE* = 2.5), $F(1, 30) = 5.43$, $p < .03$, and during the baseline period (*M* = 10.2%, *SE* = 2.5), $F(1, 30) = 5.77$, $p < .03$. Anticipatory performance to the varied content side did not differ from baseline, $F(1, 30) = .005$, *ns*. These results replicate those from Experiment 1.

Reaction time results. RTs were also subjected to a repeated-measures, one-way ANOVA comparing their level across the condition levels of the baseline period, invariant content side, and varied content side. As in Experiment 1, this analysis failed to yield a significant effect of conditions, $F(2, 30) = 0.82$, *ns*, indicating that the color combination manipulation failed to differentially influence the speed at which infants visually oriented to the pictures on the two sides. This finding was confirmed by the result of a planned comparison which indicated that the RT to the invariant colors side (*M* = 447.9 msec, *SE* = 19.1) did not significantly differ from the varied side (*M* = 468.7 msec, *SE* = 17.3), $F(1, 30) = 0.70$, *ns*, or from the baseline period (*M* = 479.1 msec, *SE* = 26.6), $F(1, 30) = 1.58$, *ns*. Reactive responding to the varied side also did not differ from the baseline period, $F(1, 30) = 0.18$, *ns*. Again, there was no stable influence of the content manipulation on infants' reactive eye movements to the onset of a visual event. The replication of this dissociation of the content manipulation on anticipations and RTs strongly suggests that it is due to some underlying information processing differences in how anticipations and RTs are related to the cognitive construct of expectations. The assumption of Haith et al. (1993) that anticipations and RTs reflect the same expectation mechanism is not supported by the current anticipation/RT dissociation.

Novel Test Phase

In the novel test phase, in addition to comparing performance between the invariant side and the varied sides, the data were also analyzed according to the type of event. It seemed likely that the novel color combination would affect responding to succeeding events (i.e., novel + 1, novel + 2), and that this effect would be side-specific. The reason why it seemed likely that the effect of the novel stimulus would be side-specific was because the previous experiment indicated that infants' anticipatory performance was side-specific. Because of our a priori supposition that the effect of the novel stimulus might be side- and event-type-specific, planned pairwise comparisons were conducted to compare performance for each type of event separately for the invariant and varied sides. That is, separately for each side, performance was compared among the novel events, the events on the same side that immediately followed novel events (novel + 1), and the second events that followed the novel events on that same side (novel + 2; see Figure 2). Finally, to further assess the effect of the introduction of novel information on infants' existing content expectation, planned pairwise comparisons were conducted to compare anticipatory and RT performance to the different types of events during the test phase to performance during the training phase.

Anticipation results. A repeated-measures, two-way ANOVA was performed comparing infants' performance across conditions (invariant and varied sides) and across event type (training, novel, novel + 1, and novel + 2). A significant main effect of conditions, $F(1, 15) = 13.50$, $p < .003$ was found, indicating that across all trials, infants made more anticipations to the invariant side ($M = 19.2\%$, $SE = 2.1$) than to the varied side ($M = 11.6\%$, $SE = 2.1$). The main effect of event type was not significant, $F(3, 45) = 1.84$, *ns*. Planned pairwise comparisons, however, revealed that infants overall made more anticipations on novel + 1 events ($M = 20.5\%$, $SE = 3.8$) than on novel trials ($M = 10.4\%$, $SE = 2.4$), $F(1, 30) = 5.35$, $p < .03$, for which responding was depressed. All other comparisons were not significant. This result suggests that overall, and regardless of content side, the novel content produced a decrease in infants' anticipatory responding to novel events relative to immediately subsequent, novel + 1 events. Whether this result was specific to a particular content side was addressed by the interaction of condition and event type.

The interaction of condition and event type yielded a nonsignificant result, $F(3, 45) = 1.13$, *ns*, suggesting that the greater anticipation level to novel + 1 events than to novel events did not differ between the invariant and varied sides. Planned pairwise comparisons of the different event types on a given content side [e.g., novel trials (invariant) versus novel + 1 trials (invariant)] and of a given event type across content sides [e.g., novel trials (invariant) versus novel trials (varied)], however, yielded a different conclusion (see Figure 3). These comparisons revealed that the number of anticipations on the invariant color combination side were unusually high to the novel + 1 events ($M = 27.8\%$, $SE = 5.3$). They were significantly higher than to novel events ($M = 11.8\%$, $SE = 3.1$), $F(1, 30) = 10.88$, $p < .002$, and were also nearly significantly higher than to novel + 2 events ($M = 18.6\%$, $SE = 5.0$), $F(1, 30) = 3.55$, $p < .07$, and to training events ($M = 18.7\%$, $SE = 1.8$), $F(1, 30) = 3.53$, $p < .07$, (see Figure 3). In contrast, on the varied side, none of the event types was significantly different from any other ($p > .10$). The percent of anticipations to the novel + 1 events on the invariant side was significantly higher than to novel + 1 events on the varied side, $F(1, 30) = 8.99$, $p < .005$.

These results reveal an increase in the level of anticipatory responding by the infants on trials on the invariant side that immediately followed a novel content trial on the invariant side. On novel trials on the invariant side, a general but nonsignificant decrement in anticipatory performance was exhibited. Presumably, on the invariant side, infants had formed an expectation for the appearance of a particular color combination that was violated by the appearance of the novel color content. Note that this is the first published study that used the VExP to demonstrate a disruption of infants' behavior as a result of a violation of an expectation.

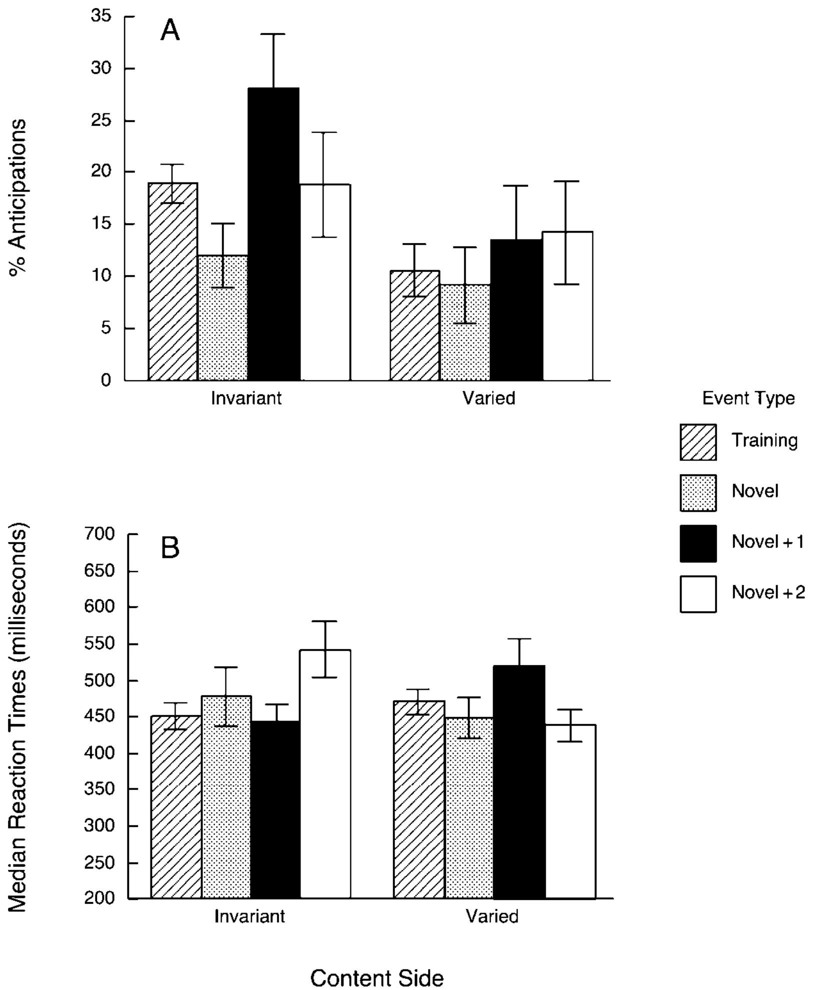

FIGURE 3 Percentage of anticipations (A) and median reaction times (B) as a function of the content side (invariant and varied) and event type (training events, novel events, novel + 1 events, and novel + 2 events) in Experiment 2. Vertical error bars indicate +/– *SE*.

Reaction time results. A repeated-measures, two-way (condition × event type) ANOVA on the means of the infants' median RTs of eye movements yielded nonsignificant main effects of condition, $F(1, 15) = 0.34$, *ns* and of event type, $F(3, 45) = 0.61$, *ns*, indicating that the RT on the invariant and varied content sides, irrespective of event type, were relatively equivalent. A significant condition × event type interaction, however, was obtained, $F(3, 45) = 4.39$, $p < .009$. Planned comparisons revealed that, on the invariant side, RTs on novel + 2 trials

(M = 539.5 msec, SE = 37.6) were significantly longer than during training (M = 447.9 msec, SE = 19.1), $F(1, 30) = 6.26$, $p < .02$. The RTs on novel + 2 trials on the invariant side was also found to be significantly longer than on novel + 1 trials (M = 438.8 msec, SE = 22.7), $F(1, 30) = 7.27$, $p < .01$ (see Figure 3). On the varied side, novel + 2 trials had significantly shorter RTs than on novel + 1 trials (M = 517.7 msec, SE = 37.4), $F(1, 30) = 5.04$, $p < .03$. Finally, one significant difference was found between the invariant and varied content sides, RTs on novel + 2 trials were longer on the invariant side than on the varied side (M = 435.4 msec, SE = 21.9), $F(1, 30) = 8.08$, $p < .007$. This significant difference on novel + 2 trials between the invariant and varied sides, however, was not replicated in the succeeding experiment. It is therefore unclear at this time whether this difference is indicating an essential aspect of infants' expectation behavior and how to interpret it.

Linear trend analysis. To determine the nature of the relation between infants' performance across the novel + 1, novel + 2, and novel events on a particular side, anticipations and RTs were converted using orthogonal polynomials, and a linear trend analysis was conducted. These analyses uncovered only one significant trend: A significant decreasing linear trend was exhibited in infants' anticipatory performance on the invariant side, $F(1, 44) = 5.56$, $p < .025$, indicating that anticipations linearly decreased from the novel + 1 event to the novel + 2 event and then the novel events. No significant linear trends were exhibited for anticipations on the varied content side or for RTs on either side. Further, no significant quadratic trends were exhibited in any of the analyses.

Discussion

The effects during both the training and the novel test phases, both on anticipatory performance and the latency of reactive saccades, support the notion that infants formed content expectations for events on the invariant color-combination side but not for those on the varied colors side. As a consequence of their expectation for the color combination, infants' expectancy behavior was affected by the violation of that expectation when novel color content was presented on the invariant side. In contrast, expectancy behavior to the varied side, to which infants could not form a color content expectation during training, was relatively unaffected by the presentation of novel content. Further, the finding that the presentation of novel colors influenced anticipatory performance only to the invariant content side indicates that infants encoded the invariant color information in their expectation representation, thereby resulting in their discrimination of the novel events.

How is it that a forthcoming novel event can affect anticipatory behavior on the invariant content side before the infant perceives the event? The answer lies in the design of the novel test sequence for which each third event on each side consisted of a novel color combination. The small number of trials intervening between novel exposures made it possible for carry-over effects to occur for the forthcoming novel event from the prior novel event. The observed effect can be understood within the framework of Grossberg's (1995) attention model. Grossberg proposes that expectations guide one's attentional allocation, and that the violation of an expectation by novel event information stimulates an increase in the allocation of attentional resources for the purpose of integrating the novel information into the existing expectation. In this case, the increase in anticipations to novel + 1 events on the invariant color-combination side apparently reflected a heightened level of attentional processing that was allocated in order to assimilate the incongruent content information that was presented on the prior novel event. The increased allocation of attentional resources then gradually subsides, leading to the decreasing levels of anticipatory performance on novel + 2 events, and on the following novel event. Support for this attentional effect is provided by the linear trend analysis in which a significant decreasing linear trend was exhibited for anticipations on the invariant side. This attentional enhancement is similar to the effect of response recovery that occurs when novel information is presented to infants in habituation or novelty-preference studies (Berlyne, 1958; Cohen, 1972; Fantz, 1958; Quinn & Eimas, 1986; Salapatek, 1975).

EXPERIMENT 3: EFFECT OF A NOVEL PATTERN

The findings from the previous two experiments indicate that infants' encode in their expectations the specific colors that are invariant across a class of related but distinct event exemplars. However, the stimulus events in this study had pattern content as well. Studies have demonstrated that color and shape/pattern information in stimulus events may not be initially encoded equivalently by young infants (Catherwood, 1994; Rose & Slater, 1983). Catherwood (1994), for example, demonstrated with a familiarization paradigm that 5-month-old infants exhibit recognition of color information, but not shape information, after very brief exposures. If infants encode color information more easily or at a faster rate than shape/pattern information (Catherwood, Skoien, Green, & Holt, 1996), then perhaps in the first two experiments infants failed to discriminate the variation in patterns, and only encoded the specific color content.

Alternatively, if the level of attentional allocation and the level of anticipatory responding are linked as has been hypothesized (Grossberg, 1995), then infants' high level of anticipations to the invariant color side might have also resulted in the encoding of the specific pattern exemplars. That is, due to anticipating, infants have additional time to view the stimuli on the invariant side. As a result of this additional viewing time, infants might have sufficient exposure to the stimuli to process and encode the stimulus patterns, as well as the invariant color combination. Previous studies have indicated a link between exposure time and amount of stimulus information that is processed and encoded by infants (e.g., Colombo, Mitchell, Coldren, & Freeseman, 1991). If this is the case, then presentation of a novel pattern would not match the pattern information in their content expectation. Consequently, infants would discriminate the novel pattern, and their anticipatory responding would be disrupted to the invariant color side. To determine the nature of the effect of presentation of novel pattern content, the novel visual event consisted of a new stimulus pattern—triangles—presented with the familiar, invariant color combination.

Method

Participants. Infants were recruited as before. The data from 16 infants (12 male, 4 female), who ranged in age from 91 to 98 days (M = 92.6 days, SD = 2.1) were used for analyses. Infants in the sample were Caucasian (n = 14), African American (n = 1), and Native American (n = 1); were primarily drawn from middle to upper SES families; were full-term at birth with no reported complications; and appeared in good health. An additional nine infants (4 male, 5 female) participated, but insufficient data (i.e., data on less than 65% of the pictures) were collected from them because they cried (n = 2), were inattentive (n = 6), or exhibited general fussiness (n = 1). It is unclear as to why the dropout rate was lower in this experiment than in the previous experiment (Experiment 2) in which 23 infants were excluded. The only noticeable difference between the subject pools of the two experiments was the time of year that they participated in the study. This experiment was run during the spring months, whereas the Experiment 2 was run during the winter months. Perhaps, infants who participate during the winter are less attentive and cooperative because of the poorer weather conditions. Regardless, the results from the two experiments were remarkably similar, so the different dropout rates did not differentially effect the data collected in the two experiments.

Stimuli and apparatus. The stimuli and apparatus were identical to the previous experiments, except that a fifth stimulus pattern, nine small triangles arranged in a pyramid structure—one small triangle on top, three in the next row, and five on the bottom—forming a larger triangle, was used as novel content during the novel test phase.

Procedure. The procedure was identical to Experiment 2, except that during the novel test phase, instead of presenting infants (n = 16) with novel color content (i.e., completely novel colors in a familiar stimulus pattern), they were presented with novel pattern content (i.e., a completely novel pattern presented with the familiar color combination). In this experiment, infants responding on an average of 74% of the baseline trials, 78% of the training phase trials, and 82% of the novel test phase trials contributed to the calculation of the mean percent anticipations.

Results

Training Phase

Anticipation results. A repeated-measures, one-way ANOVA was performed on infants' anticipatory performance during the training phase. Results of this analysis once again indicated a significant main effect of conditions, $F(2, 30) = 4.39, p < .03$. Planned comparisons again revealed that the number of infants' anticipations was significantly greater on the invariant side ($M = 21.7\%$, $SE = 3.4$) than on the varied side ($M = 13.2\%$, $SE = 1.9$), $F(1, 30) = 4.50, p < .05$, and during the baseline period ($M = 10.6\%$, $SE = 3.4$), $F(1, 30) = 8.14, p < .01$. Anticipatory performance on the varied content side did not differ from baseline.

Reaction time results. As before, a repeated-measures, one-way ANOVA failed to yield a significant effect of conditions, $F(2, 30) = 0.77$, *ns*. Further, none of the pairwise planned comparisons was significant, indicating that yet again there was no influence of the content manipulation on infants' reactive eye movements to the onset of a visual event.

Novel Test Phase

Anticipation results. A repeated-measures, two-way (conditions × event type) ANOVA was performed on infants' anticipatory performance during the novel test phase. The main effect of conditions was not significant, $F(1, 15) = 0.01$, *ns*, indicating that across all trials, infants made an approximately equal number of anticipations to the invariant ($M = 16.6\%$, $SE = 2.5$) and the varied sides ($M = 16.1\%$, $SE = 2.3$). The main effect of event type was significant, $F(3, 45) = 3.72, p < .02$, with planned pairwise comparisons revealing that infants overall made fewer anticipations for novel events ($M = 8.3\%$, $SE = 3.2$) than for training ($M = 17.1\%$, $SE = 2.1$), $F(1, 30) = 4.40, p < .05$, for novel + 1 events ($M = 18.0\%$, $SE = 4.0$), $F(1, 30) = 5.26, p < .03$, and for novel + 2 events ($M = 21.9\%$, $SE = 3.6$), $F(1, 30) = 10.43, p < .003$. These results indicate that, overall, the novel content produced a decrease in infants' anticipatory responding on novel events relative to all other events during the test phase.

The interaction of condition and event type yielded a nonsignificant result, $F(3, 45) = 1.66$, *ns*. Planned pairwise comparisons, however, revealed that the number of infants' anticipations on the invariant color combination side were significantly fewer on the novel trials (M = 5.6%, SE = 2.5) than during training (M = 21.7%, SE = 3.4), $F(1, 30) = 6.68$, $p < .02$, on novel + 1 events (M = 21.1%, SE = 6.5), $F(1, 30) = 6.77$, $p < .02$, and on novel + 2 events (M = 18.4%, SE = 5.6), $F(1, 30) = 4.62$, $p < .04$ (see Figure 4). On the varied content side, anticipatory level

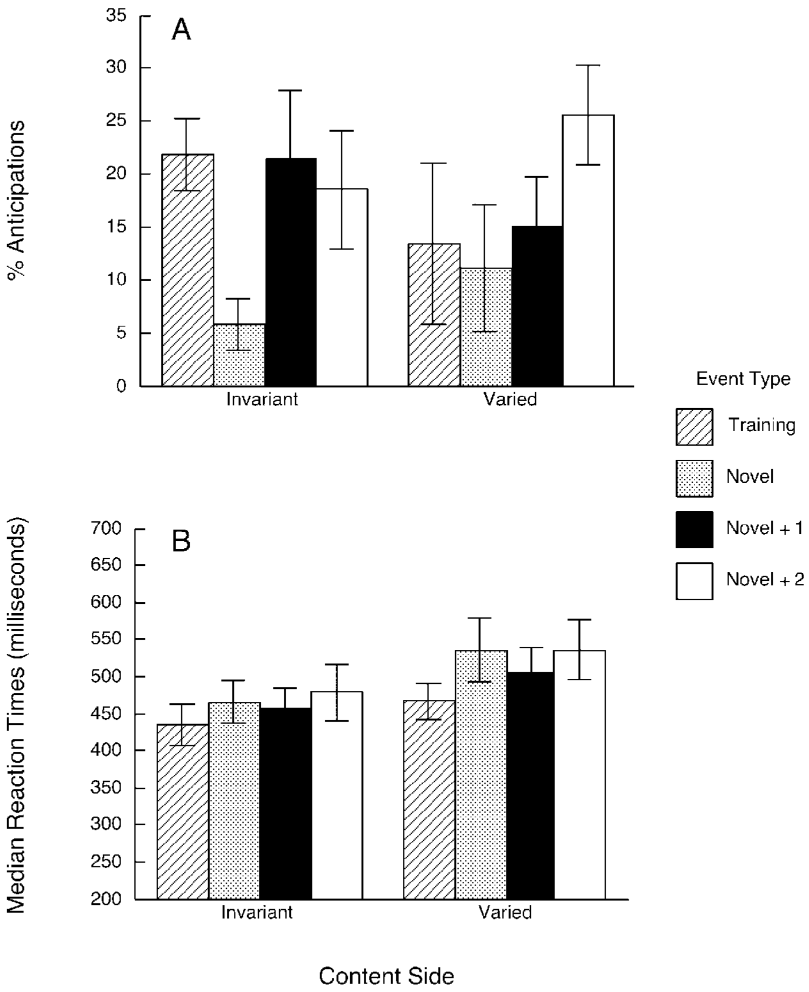

FIGURE 4 Percentage of anticipations (A) and median reaction times (B) as a function of content side (invariant and varied) and event type (training events, novel events, novel + 1 events, and novel + 2 events) in Experiment 3. Vertical error bars indicate +/– *SE*.

was significantly greater to novel + 2 events (M = 25.4%, SE = 4.6) than during training (M = 13.2%, SE = 1.9), $F(1, 30) = 4.16$, $p < .05$, and on novel events (M = 10.9%, SE = 6.0), $F(1, 30) = 5.89$, $p < .02$. Finally, none of the pairwise tests was significant for particular novel event types when compared across content sides.

Reaction time results. A repeated-measures, two-way (Condition × Event Type) ANOVA was conducted on the means of the infants' median RTs. This analysis yielded nonsignificant main effects of condition, $F(1, 15) = 3.52$, *ns*, and event type, $F(3, 45) = 1.98$, *ns*, and a nonsignificant Condition × Event Type interaction, $F(3, 45) = 0.17$, *ns*. Planned pairwise comparisons of the different levels of event type revealed that RTs to novel + 2 events (M = 504.8 msec, SE = 27.3) were significantly longer than during training (M = 448.9 msec, SE = 17.4), $F(1, 30) = 4.90$, $p < .04$. Planned comparisons of the interaction, however, yielded no significant differences, suggesting that the presentation of the novel pattern content had no influence on the latency of infants' reactive eye movements (see Figure 4).

Linear trend analysis. As in Experiment 2, a significant decreasing linear trend was exhibited in infants' anticipatory performance on the invariant side, $F(1, 44) = 7.01$, $p < .015$, indicating that anticipations again linearly decreased from the novel + 1 event to the novel + 2 and then to novel events. No significant linear trends were exhibited for anticipations on the varied content side or for RTs on either side. Further, no significant quadratic trends were exhibited in any of the analyses.

Thus, though the individual planned comparisons yielded different patterns of significance between Experiments 2 and 3, this analysis reveals that the overall trend in anticipatory performance due to presentation of the novel stimulus was consistent between the two experiments. In this experiment, in which the novel content was a novel pattern, a significant decrement in anticipatory performance was exhibited on novel events on the invariant content side. Presumably, this decrement was produced by an attentional mechanism similar to that discussed to explain the results in Experiment 2. That is, infants formed an expectation for the appearance of not only a particular color combination, but also for that color combination to appear in particular patterns, which was subsequently violated by the presentation of the novel pattern content.

Discussion

Presentation of novel pattern content yielded similar results to presentation of novel color content in that anticipatory performance decreased on novel events on the invariant color combination side but not on the varied side. Presumably, infants allocated more attentional resources to the invariant content side after a discrepant pattern appeared, but not the varied side, because only on the invariant side did they experience a violated expectation (Grossberg, 1995; Jones & Boltz, 1989; Rothbart, Rundman, Gerardi, & Posner, 1995). This differential attentional allocation to the two sides, and the increased processing time engendered by increased anticipatory responding, enabled the encoding of the specific pattern exemplars in infants' content expectations. Consequently, the novel pattern did not match the pattern information in their content expectations, resulting in the disruption of infants' expectancy behavior on the invariant side. That is, similar to Experiment 2, upon the initial presentation of the novel pattern, attentional resources were further increased for the purpose of assimilating the incongruent content information into the existing expectation (Grossberg, 1995). The increased allocation of attentional resources then decreased over novel + 1 and novel + 2 events, leading to the significantly decreased levels of anticipatory performance on the next event which consisted of a novel stimulus.

The findings from this experiment once again replicate the main finding that infants form expectations for event content, even when multiple exemplars appear, and are not limited to a single event (e.g., Wentworth & Haith, 1992). Additionally, the findings from this experiment are inconsistent with a claim that perhaps the infants noticed only a single color combination versus varying color combinations, without noticing the variations in pattern among the stimulus events. That infants' anticipations were disrupted by the novel pattern, however, indicates that they must have encoded pattern information at least on the invariant color combination side. Disruption of anticipatory responding by the novel pattern only on the invariant color side indicates that the encoding of the multiple pattern exemplars was facilitated by the invariant color combination. Perhaps, having already initially encoded the invariant color information, additional processing time was then available for encoding pattern information on subsequent pictures on the invariant color side. In contrast, on the varied color side, where there were multiple color combinations, this additional processing time was not available for the subsequent processing of the pattern content. Such a processing account would be consistent with the Catherwood (1994; Catherwood et al., 1996) finding that color information has priority in processing over shape information.

GENERAL DISCUSSION

This set of experiments addressed two primary questions: (a) Can infants form a visual expectation for a set of events that share the same content, and (b) what is the nature of the content information that infants encode in their expectation representation and use in the behavioral manifestation of this expectation? The answer to the first question is yes. Repeatedly, across all four experiments in this study, infants anticipated a set of distinct events in which the content constituted a predictable color combination at a greater rate than events whose color content was unpredictable (see Figure 5). One might argue that infants' anticipations were not directed by the content predictability of the visual events, but were based on the spatial or temporal predictability of event occurrence. If so, then infants would have exhibited equal levels of anticipations to invariant color combination and varied color combination events, because they were equally predictable in the spatial and temporal domains. That infants' anticipatory levels were higher to the invariant than varied sides indicates that they had formed a content expectation for the invariant color combination.

Previously, Haith (1993) speculated that, without the ability to form expectations, infants would be required to react to each event after its initiation, which would hinder efficient processing of that event and all of its components. Thus, the motivation for infants' expectation formation is that it permits internal control of actions and functions to increase the efficacy of information processing. In order for expectations to truly increase the efficiency of infant's processing of event information, infants must be able to distinguish between events that match their underlying expectation representation and those that do not. This will ensure that the novel information in those events is appropriately encoded and integrated, either into existing cognitive structures or into new cognitive structures. Additionally, it will ensure that behavioral manifestation of the expectation is expressed to events for which it is appropriate. Finally, being able to distinguish between events that do and do not match the underlying expectation representation

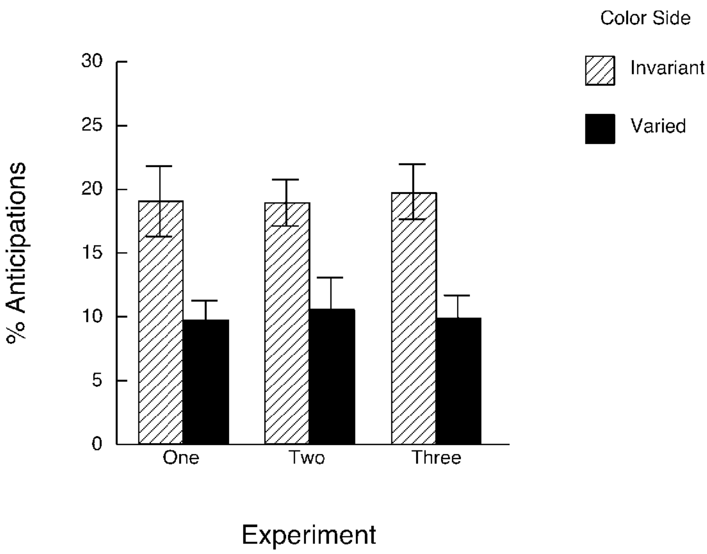

FIGURE 5 Percentage of anticipations as a function of the content side (invariant and varied) in Experiment 1, and the training events of Experiments 2 and 3. Vertical error bars indicate +/– *SE*.

would indicate the nature of the specific information infants encode in their expectation representation.

All previous expectation studies have indicated that infants form expectations for the spatial (Canfield & Haith, 1991; Haith et al., 1988), temporal (Adler & Haith, 1998; Wass, Lewis, & Haith, 1998), and content (Wentworth & Haith, 1992) parameters of events. However, in the latter study, infants were presented with a single exemplar and never with a novel event, so there is a question about what infants encoded in their expectation representation. Infants may simply have encoded the constancy of the single picture on one side versus the variety of pictures on the other side, without necessarily encoding the content of the invariant pictures.

In this set of experiments, events with novel content were presented to infants and the effect of such a violation of their content expectation was assessed to determine the nature and specificity of the content information infants encode during expectation formation. Across this set of experiments, infants discriminated events in which the colors or the stimulus pattern did not match the comparable information (Experiments 2 and 3) of the pictures on the invariant content side. Due to this discrimination, infants' overt expectancy behavior was disrupted. Nevertheless, the present study, in terms of our second question, provides ample evidence that infants do encode the specific content of events into their expectation representation and that their anticipatory behavior is based on that expected content.

The disruption in infants' anticipatory behavior by novel events in Experiments 2 and 3 supports Grossberg's (1995) information-processing account of expectations and anticipations. Having incorporated expectations into his attention model, Grossberg hypothesized that encountering novel event information stimulates an increase in the allocation of attentional resources for the purpose of integrating this novel information into the existing expectation. Applying this aspect of the model to the present work, the increase in anticipations on novel + 1 events on the invariant side (Experiment 2 and 3) reflected an increased level of attentional allocation that was generated by the preceding novel, incongruent event on the invariant side. The increased allocation of attentional resources gradually subsided over events, leading to decreased levels of anticipatory performance on novel + 2 events and the following novel event. If Grossberg is correct, then the increased level of anticipation generated by the novel content events serves to allocate processing resources for integrating novel information into infants' content expectation. In short, anticipations, which are overt behavioral indications of infants' underlying cognitive expectations (Haith et al., 1988), serve to distribute resources for the more efficient processing of event information.

The preceding discussion focused on infants' anticipatory behavior as evidence for the formation of a content expectation and of the information-processing function of expectations. However, infants' performance on the second dependent measure, namely, the facilitation of their latency of reactive eye movements (RTs) was also assessed. This second measure, like anticipations, has been presumed to be a behavioral index of expectations (Haith, 1993). In this study, as in the Wentworth and Haith (1992) study, a comparison of infants' performance between the invariant and the varied content sides revealed no difference in RTs. If expectations are expressed in facilitated RTs, as well as increased anticipations, as has been hypothesized, then infants should have exhibited shorter latencies of reactive saccades to visual events on the invariant content side as compared to the varied content side. The failure to find a difference in RTs as a function of content predictability, whereas a difference was found in anticipations, suggests that the two measures are differentially sensitive to expected event content.

Eye movement reaction times are reactive to sensory input and, therefore, may be sensitive to relatively primitive properties of the input, such as the predictability of spatial location or the timing of events, and less sensitive to content manipulations that result in either more or less anticipatory responding. This possibility would account for why RT measures did not differentiate performance, because spatial and temporal parameters did not vary between the two content sides. In contrast, anticipations occur prior to sensory input and involve top-down cognitive forecasting of events that are not perceptually available. Because the two content sides differed in their content predictability, differences in anticipations to the two sides may reflect the relative amount of cognitive processing of event's color (and pattern) content. The proposal that content information is processed separately, and to different levels than spatial or temporal information, is not a new one, but has been suggested by many behavioral studies (e.g., Biederman & Cooper, 1992; Craik & Lockhart, 1972; Treisman & Gelade, 1980) Further, other studies of infants' information processing, such as their immediate perceptual discrimination (Colombo, Mitchell, Coldren, & Freeseman, 1991) and long-term memory (Adler, Gerhardstein, & Rovee-Collier, 1998), have similarly indicated that informational parameters of events are processed to different cognitive levels.

The discrete processing of spatial and content (color or pattern) parameters is also supported by neurophysiological evidence (Ferrera & Lisberger, 1995; Schiller, 1985; Schiller & Logothetis,1990). Research has indicated that the processing of spatio-temporal information flows through the dorsal stream whereas the processing of color, shape, and object information flows through the ventral stream (Farah, 2000; Reid, 1999; Schiller, 1995). The dorsal stream includes the superior colliculus, which represents a spatial map of possible stimulus locations (Robinson & Kertzman, 1995; Schiller, 1995), and is involved in guiding spatial attention and the generation of reactive eye movements to those spatial locations (Krauzlis, Basso, & Wurtz, 2000; Krauzlis & Dill, 2002; Kustov & Robinson, 1996). The ventral stream includes the primary visual cortex, which is involved in the processing of object attributes such as color, shape, and size (e.g., Ungerleider & Mishkin, 1982). Furthermore, the ventral stream has projections to the frontal eye fields, which have been implicated in the generation of predictive and anticipatory eye movements (Hanes, Patterson, & Schall, 1998; Keating, 1991). Developmentally, Johnson (1990) has suggested that these two processing streams have different rates of maturation that results in the dorsal stream reaching functional maturity prior to the ventral stream, though both are fully functioning by the age of the infants tested in the current study. Thus, the sensitivity of anticipations to the color content manipulation may reflect the functioning of the ventral processing stream, whereas reactive eye movements' insensitivity to the color content manipulation, but previously demonstrated sensitivity to spatial manipulations, may reflect the functioning of the dorsal processing stream.

That a number of different experimental paradigms lead to similar conclusions suggests that levels of processing of event information permeates much of infants' neural and cognitive processing, and, therefore, may play an important role in infants' cognitive development. Future studies will need to investigate the validity and makeup of the distinct and differential processing of event information, and its precise function in cognitive development.

In conclusion, this series of experiments consistently documented that 3-month-old infants encode event content during expectation formation. In addition, evidence was obtained that infants can form a content expectation for a set of events rather than a single repeating event, and that their expectations are specific to the content information encoded from the original events. As a result, violating their content expectation by presenting novel content disrupted expectancy behavior, particularly anticipations. This is the first study to investigate the effect of a content violation of an expectation—demonstrating a disruption in infants' anticipatory behavior in a manner that indicated an increase in attentional allocation due to the violation. This set of experiments also revealed a dissociation between anticipatory eye movements and reactive eye movements in their sensitivity to the content manipulation, suggesting a differential sensitivity to and processing of event parameters. Further studies will need to confirm these findings without some of limitations of the present investigation, such as the limited number of novel trials, and their predictable presentation at regular trial intervals. Nevertheless, this study has extended our understanding of infants' cognitive expectations and demonstrated the usefulness of the Visual Expectation Paradigm in rendering unique insights into infants' cognitive development.

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