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VISUAL SCANNING DURING INFORMATION PROCESSING IN INFANCY

by

SHARON J. KRINSKY-McHALE

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

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Abstract

VISUAL SCANNING DURING INFORMATION PROCESSING IN INFANCY

by

Sharon J. Krinsky-McHale

Advisor: Professor Louise Hainline

This study examined the relationship between visual scanning and information processing in 32 two- and three-month-old infants. Eye movements were recorded using a computer-based infrared corneal reflection monitoring system while subjects participated in an infant-controlled habituation task. This method provided detailed information regarding both the duration and spatial distribution of fixations as an infant become familiarized with a stimulus and upon the presentation of novel stimuli. The results of the study demonstrated that visual scanning is related to information processing in 2-and 3-month olds; the eye-mind relationship is applicable in infants. However, we did not find a developmental trend in the limited age range tested. Infants scanned longer and made more fixations on the stimulus and more thoroughly and extensively scanned the stimulus during the baseline trials compared to the criterion trials. Individual differences between infants who were categorized as "short" and "long" lookers, based on their average fixation duration, engaged in both qualitatively and quantitatively different patterns of scanning during the baseline trials.

Differences between short and long lookers were also evident during the trial of the peak look and there were no differences between them during either the trial preceding or succeeding the peak trial. We consistently found that long lookers spent more time and made more fixations to a limited number of stimulus zones than short lookers. It appears that rather than progressively or incrementally processing the stimulus, infants encode simple stimuli, in basically one presentation (i.e., the peak trial). Furthermore, consistent with extant studies, we did not find evidence to support the serial processing hypothesis.

Upon the presentation of novel stimuli, we found differences in scanning behaviors between infants who did and did not demonstrated a preference for novelty. However, contrary to other studies we did not find differences between short and long lookers in terms of their qualitative or quantitative parameters of scanning novel stimuli.

Taken together, the results clearly reveal that analyzing eye movements is a more molecular and precise method of analysis and therefore the variables that are derived from such an analysis are useful adjuncts to the traditional global measures of attention.

Acknowledgments

The completion of this dissertation project was a long and at times arduous process, one that could not have been accomplished without the encouragement and assistance from many wonderful people. Firstly, I would like to thank my mentor, Dr. Louise Hainline. As my defense date approached I often reflected back on my time working with Louise and I tried to decide whether her being my mentor, friend, or role model was most instrumental to my work, career, and to me as a person. I reached the conclusion that it was the combination of all three that enriched my time at the Brooklyn College Infant Study Center. As my mentor she provided me with unlimited use of her laboratory, exposure to all sorts of experiences, and with challenges which sometimes made me wonder whether I could live up to her expectations. As my friend, she listened to my assortment of problems over the years, provided me with "big sister" advise, and simply hugged me when I felt completely overwhelmed by the task of completing a dissertation. As my role model, she demonstrated first-hand that a women can be assertive, talented, accomplished, and caring; that there are no limitations to who we are and who we can become simply because we were born one sex or the other. All this is to say that I feel very lucky to have had Louise as my mentor.

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I consider myself extremely lucky to have Sandye and Sy as my parents. My dad not only told me that a girl could do anything that a boy could do, but he also demonstrated his belief by providing me with an abundance of enriching experiences that many of my friends never had the opportunity to share with their dads. My mother and I have shared a very special relationship all these years, we are not just mother and daughter, but we are good friends as well. She has always encouraged me to pursue my dreams and gave me probably one of the most valuable gifts a parent could give her child, the love of reading.

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Ultimately, it was Kevin R. McHale, my husband, my best friend, my most ardent supporter, that made the completion of this dissertation possible, "I'm having feelings like I've never had before, and all I want is more...."[1]I feel genuinely blessed that you are sharing life with me. Also, thank-you for the many hours of discussing "stories," they've enriched our life together and have kept me grounded. More importantly, I want to keep creating many, many more stories with you...at least for the next 57 years, so at least we tie the Grandparents Siepmanns' record for martial bless.

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[1] From "I Just Want To Love You" by Delbert McClinton, from I'm With You, 1990 Curb Records. On May 27, 1990 this was the song to which we danced our first as wife and husband.

In memory of my grandmothers, Sally Horowitz Kipness, Lillian Hirschson Krinsky and my aunt, Thelma Kipness Stuppler.
Three women who taught me about love and made me feel extremely special.

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INTRODUCTION

Visual scanning involves the active, selective, and sequential acquiring of information about the environment. Eye position at each successive fixation therefore reflects higher cognitive processes (Neiser, 1976; Noton & Stark, 1971; Yarbus, 1967). This view is sometimes termed the “eye-mind” hypothesis (Just & Carpenter, 1976a; 1976b). Extant research with adult subjects has shown that visual scanning is in fact related to information processing. Moreover, changes in the quality of visual scanning (i.e., in the extensiveness, timing, and the patterns) are related to perceptual and cognitive development. There is an extensive body of literature demonstrating that as the demand of a visual task increases, so does the duration of fixations (Fisher, Monty, & Senders, 1981; Gould, 1973; Groner, Menz, Fisher, & Monty, 1983; Johnson & Pirozzolo, 1981; Pirozzolo, 1979; Senders, Fisher, Monty, 1978). Johnston and Pirozzolo (1981) found this relationship between verbal-cognitive ability, as measured by the Peabody Picture Vocabulary Test[1] (PPVT; Dunn & Dunn, 1981), and oculomotor performance such that, incorrect responses on this test were associated with fixations of longer duration than correct responses. Noton and Stark (1971) identified "scanpaths" when adults were freely viewing a pattern that is, a fixed pattern of fixation locations was characteristic of a given subject. They further suggested that the presence of scanpaths indicates that the viewer is forming an internal representation or memory of the stimulus being viewed, "That the subject follows a fixed path from feature to feature suggests that the eye movement motor components involved in perception are not merely involved in moving the pattern over the retina, but are an integral part of the memories on which recognition is based" (p. 310). Therefore, while visual scanning is a perceptual-motor behavior, it can also be viewed as a cognitively-based process (Day, 1975).

While eye movements have been used to study visual information processing since the 19th century, it is only during the last two decades with the development of sophisticated eye tracking devices, that the "eye-mind" relationships have been investigated in infants (Siegler, 1983). Since the pioneering work of Robert Fantz (1964), a major assumption underlying the research on infant visual perception is that perception can be inferred from how an infant fixates a stimulus; the direction toward which a baby looks indicates visual selectivity and information processing (Day, 1975; Kessen, Salapatek, & Haith, 1972; Noton & Stark, 1971; Yarbus, 1967). We do not know however, if the "eye-

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[1] The Peabody Picture Vocabulary Test is a vocabulary test which provides a basal and ceiling measure of verbal ability, as well as an overall verbal IQ score.

mind" hypothesis is applicable in infancy (Vurpillot, 1968). If it is, it follows that the capacity of infants to control their eye movements must reasonably set limits to the amount of information they can extract from their environmental surroundings (Hainline, 1985). From their work on infant visual development, Hainline and Abramov (1992) insightfully and with a touch of humor stated, "While infants may not, indeed, see as well as adults do, they normally see well enough to function effectively in their roles as infants" (p.41).

1.1 Infant Oculomotor Systems

Research devoted to infant oculomotor systems have focused on comparing their systems to those of adults, in order to understand infant competencies and limitations. Hainline and Abramov (1992) have stated, "poor control of eye movements could adversely influence functional vision and therefore perception" (p. 71). The oculomotor behaviors that are germane to this presentation are the profiles of saccades and the properties of fixations.

1.1.1 Infant Saccades. Saccadic eye movements reorient the high resolution fovea on successive fixations. It is also the type of eye movement which the eye uses to correct its position in viewing a point of interest as a target moves. Research on the saccadic system has explored its various parameters such as the accuracy at "capturing" a target of interest, the relationship between peak velocity and amplitude of the movement (also known as the ***main sequence***[2]), and the latency to make a saccade. Each of these parameters will be discussed in succession.

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[2] The main sequence relates the highest velocity achieved during a given saccade to the amplitude of the movement.

There have been conflicting reports on the accuracy of infant saccades. Typically, a single peripheral target elicits a saccade from an adult. This saccade is generally a single large saccade, which may be followed by a smaller corrective saccade, if the first one was inaccurate. Several studies have shown that when infants localize a small target their saccades do not take this form. Rather they locate a target with a series of small saccadic "steps" (Ashmead, 1984; Aslin & Salapatek, 1975; Salapatek, Aslin, Simonson, & Pulos, 1980; Roucoux, Culee, & Roucoux, 1983). Ashmead (1984) further found a predominance of multiple-step saccades in younger infants compared to older infants (for instance, one-month versus three-month-olds) and for larger target shifts compared to smaller target shifts (for instance, 10 versus 20 degrees). Bronson (1990b) further found that between 3½ and 8 weeks of age, there is no significant measurable change in saccadic accuracy. However, after 8-weeks of age, saccadic accuracy gradually and steadily improves. In contrast, Hainline, Turkel, Abramov, Lemerise, & Harris (1984) found that when infants viewed more interesting highly textured patterns single saccades were generally the rule and multiple saccades an infrequent exception.

Several other studies concluded that there are other parameters of infant saccades that are in fact, "adult-like" (Ashmead, 1984; Hainline et al., 1984). Ashmead (1984) found a consistent relation between saccadic parameters in both infants and adults such that, as saccadic amplitude increased, saccadic duration increased and saccadic velocity decreased. In the Hainline et al. (1984) study, infants between the ages of two-weeks and 5-months and adults viewed both simple geometric forms and more complex richly textured patterns. Infant saccades were similar to adult saccades in both their main sequences and in the mean and distribution of their saccadic amplitudes. For one analysis, they plotted main sequences for each of the subjects and tested whether a linear regression would fit the data; all the adults and many of the infants had significant regressions. However, they occasionally and usually under very specific conditions, observed two unusual properties in the infant saccadic system that were not found in the adult saccadic system; low velocity saccades and oscillations (back-to-back saccades, with significantly shorter inter-saccadic intervals). There were no developmental changes in either the slope of the main sequence or the speed of the saccade. However, they did observe differences in several saccadic properties which were dependent on the stimulus being viewed. They noted a diminished occurrence of oscillations with the textured patterns and an increased occurrence with form stimuli. The slopes of the main sequence were shallower (i.e., lower velocity saccades) for the form patterns than for the textured patterns.

It is therefore apparent that the type of stimuli used to study infant visual perception significantly influences the results, and therefore, the evaluation of maturities and immaturities in these capabilities. Studies which found that the form of infant saccades are largely immature, typically used either simple geometric forms like circles, triangles, and squares, or a row of horizontal lights, possibly uninteresting stimuli for eliciting attention. Studies which used more interesting and attention eliciting stimuli found the saccadic system to be surprisingly mature. This finding has interesting implications for the interpretation of the previously mentioned studies and for future research on infant visual perception. Researchers working in this area have largely ignored the ramifications of the stimuli they use with infants, perhaps erroneously concluding limitations when competencies truly exist.

Saccadic latency has not been extensively studied in infants. However, there is indication that saccadic latencies increase with target eccentricity and decrease with age (Regal, Ashmead, & Salapatek, 1983).

1.1.2 Infant Fixations. Saccades are usually followed by fixations. It is during periods of fixations, when the eye is relatively stationary, that information is acquired and processed. Three parameters of infant fixations have been investigated and compared with adults; fixation duration, fixation control/stability, and the retinal location of fixations. These will be discussed in succession.

Due to their immaturities, infants have been portrayed as being "captured" by a stimulus, therefore long fixations would be the expected norm (Salapatek & Kessen, 1966). There is however, much variability in the mean duration of fixations. Harris, Hainline, Abramov, Lemerise, and Camenzuli (1988) examined a large number of fixations in infants and naive adults as they viewed a variety of different types of stimuli. While there was no developmental trend in the duration of fixations in infants between the ages they studied (14-256 days), infant fixation durations were generally shorter than adults for all stimuli. They also found that the mean duration of fixation is stimulus dependent; the more salient or complex the stimulus, the longer the fixation. This finding is consistent with studies on adults and with the "eye-mind" hypothesis.

Harris and colleagues (Harris and Hainline, 1987; Harris, Hainline, Lemerise, and Abramov, 1985) have extensively studied fixational control in infants and adults. They found that adults are able to fixate steadily when they are instructed or if they are given sufficient practice to do so (Hainline, 1988). In addition, they found that young infants have fairly good control of fixations. This is especially true when their performance is compared to that of uninstructed adults. In both groups, fixational drift[3] is dependent on the duration of the fixation such that the longer the fixation, the more drift is exhibited. Similar to the saccadic system, fixational control may also depend on the infant's attentional status. However, young infants exhibit more drift and jitter in their fixations than do older infants and adults. Hainline (1988) concluded that, "Despite their foveal immaturity, fixational control in infants seems adequate for effective vision, and is probably not the limiting factor in visual sensitivity" (p. 47).

Studies have demonstrated that the fovea of the young infant is immature; cone density is much lower and there is no foveal pit (Abramov, Gordon, Hendrickson, Hainline, Dobson, & LaBossiere, 1982; Hendrickson & Yuodelis, 1984). This has led researchers to query whether infants are using a consistent retinal locus of regard when directing their fixations. The answer has implications for how we interpret the findings of eye movement studies when we are interested in determining where on a given stimulus an infant is looking. For instance, a researcher who observed different eye positions on the same stimulus for different trials, might erroneously conclude that the infant was looking at different points on the stimulus, when in fact, the infant was actually looking at the same point on the stimulus but doing so using different retinal regions. Hainline and colleagues (Hainline & Harris, 1990; Hainline, Harris, and Krinsky, 1990) investigated

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[3] Fixational drift is one of three types of small eye movements which occur when subjects attempt to maintain an image of the target on the fovea.

quantitatively, the consistency of refixations of a small target in infants and found that while the scatter of refixations extended beyond the boundaries of the target shown, it was not as large as the degree of central retina immaturity that has previously been reported in infants. Moreover, there were no age differences in degree of scatter. They also found that uninstructed adults exhibited extensive scatter, in some cases even more so than some of the infant subjects. They hypothesized that attentional factors limit the scatter of refixations more than either sensory or oculomotor immaturities. The pattern of results suggests, that even young infants use a reasonably small consistent retinal locus to direct fixations.

In summary, researchers have hypothesized, and have often found the infants' oculomotor systems are immature relative to the adult's. This was the expected outcome given the studies which have demonstrated immaturities in the infant's retina, specifically the fovea. Hainline, Abramov, and colleagues have to the contrary shown that when tested under conditions which support optimal attention and arousal, the oculomotor systems in infancy have a high degree of functional maturity. Hainline and Abramov (1992) summarized the findings on infant eye movements by stating, "...infants come generally equipped with well-developed oculomotor systems--the problem is to "persuade" them to entrain these systems" (p.80).

1.1.3 Infant Visual Scanning. While little information is obtained during saccadic eye movements, the sequencing of saccades and fixations is linked to the processing of information. As previously stated, it has been proposed that infants younger than 2 months are reflexively "controlled" or even "captured" by the features of the stimulus and that information processing is limited by this tendency of stimulus features to capture attention (Bronson, 1990; Leahy, 1976; Nelson & Kessen, 1969; Salapatek, 1975; Salapatek & Kessen, 1966). Interestingly, it was also thought that little information processing was actually taking place in infants of this age due to immaturities in the visual and nervous system (Bronson, 1980). These immaturities have the effect of limiting infants' ability to store visual memories even in the short-term. By two months of age infants are observed to scan more extensively. It was hypothesized that at this time the infant's nervous system is somewhat more mature and therefore capable of complex perceptual processing. The work of Salapatek and his colleagues (Salapatek, 1968; Salapatek & Kessen, 1966) and Haith (1980) detailed the extent of infants' visual inspection of the world in the first two months of life. They demonstrated that even neonates actively scan their environment as much as two times per second and selectively attend to different parts of a visual display. One-month-olds however, tended to scan in a limited fashion, fixating on high contrast edges, repeatedly crossing over them with eye movements. Visual scanning at this age was shown to be confined to a very narrow area and frequently limited to one stimulus feature. Bronson (1990b) studied the changes in visual scanning of infants between the ages of 2 and 14 weeks. He described the scanning of younger infants as "unguided" that is, their saccades were not directed toward the stimulus. Older infants exhibited more "contour-directed" scanning that is, their saccades were directed toward the stimulus. They were also more likely to scan between different stimulus features. He also observed that stimulus characteristics influence scanning style such that, infants of all ages engaged in more contour-directed scanning when the stimulus moved or was of high luminance. Bronson (1994) also defined two other measures to characterize infant visual information processing. One measure is the duration of a given fixation preceding a saccade and the other measure is the fixation duration on one stimulus element before attention shifts to another stimulus element. Using these two measures he discriminated between "salience-guided" scanning versus "volitional-controlled" scanning. Characteristics associated with "salience-guided" scanning included prolonged fixations and long inspection times, especially when a fixation was located on or near a contour. Whereas characteristics associated with "volitional-controlled" scanning included brief, "adult-like" fixations and shorter inspection episodes. Bronson (1994) found that with age "salience-guided" scanning is replaced with "volitional-controlled" scanning. Moreover, brief fixations and short inspection times are highly correlated with one another such that, infants who engage in brief fixations also scan more rapidly over the stimulus features.

Maurer & Salapatek (1976) observed that in general one-month-olds looked less at faces than 2-month-olds and when they did look at a face, the fixation was directed to a limited region. In contrast, two-month-olds looked longer and at a greater number of different features than one-month-olds. In addition, Harris (1973) observed that 6-month-olds shifted their attention from one stimulus to a second, adjacent stimulus more frequently than 3-month-olds when the two stimuli were different. Performance however, was similar for both age groups when the stimuli were the same. He therefore concluded that this developmental trend occurs because older infants seek out stimulus novelty. Taken together, these studies seem to support the view that scanning is qualitatively different in younger infants than in older infants.

More recent investigations using improved recording methods and procedures found no evidence of developmental differences in scanning (Hainline & Lemerise, 1982). Hainline and Lemerise (1982) tested infants between the ages of 1 and 3 months with a series of geometric shapes of three different sizes. Infants appropriately adjusted their scanning patterns to adapt to the size of the stimulus they were viewing, such that scanning was more "extensive" for larger shapes than for smaller ones. This was true whether scanning was measured by the variability of fixations from their central tendency or by the number of subareas on the stimulus inspected. They concluded that, "...there are few data that unequivocally support the claimed developmental change in scanning extensiveness in early infancy," (p. 229).

In addition to foveal immaturities, researchers have shown that the retino-cortical visual pathways and the striate cortex are relatively immature at birth and subsequently undergo much progressive development over the first 3 or 4 months of age (Abramov, Gordon, Hendrickson, Hainline, Dobson, & LaBossiere, 1982; Banks & Salapatek, 1983; Hainline, Lemerise, Abramov, & Turkel, 1984; Hendrickson & Youdelis, 1984). Acuity is also reported to be poor in early infancy (Dobson & Teller, 1978; but cf. Norcia & Tyler, 1985). If central vision and therefore resolution is highly limited during the first months of life, we must explore the possibility that eye movements serve very different functions at different ages. Although we now know that infants' oculomotor systems are fairly well developed and that they scan more broadly than was previously believed, there is not sufficient evidence to warrant the conclusion that anything about the stimulus is being processed on any particular fixation.

1.2 Infant Habituation

In addition to visual scanning techniques, measures of visual attention have also been widely used in studies of information processing. McCall (1971) posited that there may be a "common mechanism" accounting for both what captures an infant's attention and what facilitates cognitive development. Two measures of attention that have been particularly useful are habituation (Bornstein, 1985; Bornstein & Ruddy, 1983; Clifton & Nelson, 1976; Cohen, 1976; Friedman, 1972; Jeffrey & Cohen, 1971; Miller, 1972; Ruddy & Bornstein, 1982) and novelty preference (Fagan & Singer, 1983; Lewis & Brooks-Gunn, 1981; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982). At the introduction of a novel stimulus an infant will typically orient and attend to its presence. If, however, the stimulus is repeatedly presented or continuously available the infants' attention will eventually diminish. This decrement has been traditionally termed ***habituation*** and is considered a reflection of the infant's construction of an internal mental representation or schema of an external stimulus and the subsequent comparison of the new stimulation to that representation (Bornstein, 1985; Cohen & Gelber, 1975; Lewis & Baldini, 1979; Lewis, Goldberg, & Campbell, 1969; McCall & McGhee, 1971; Olson, 1976; Sokolov, 1963). With repeated exposure, the schema becomes more complete and progressively matches the external stimulus, attention therefore decreases.

Following a familiarization phase, infants are typically presented with a novel stimulus, usually paired with the familiar stimulus. ***Novelty preference*** is the difference in time spent looking at the novel stimulus in comparison to the familiar stimulus and is taken as a measure of visual recognition. It indicates the durability, quality, and fidelity of the mental representation and is evidence for perceptual learning and memory. A preference for novelty indicates that the infant has remembered or retained something about the familiar stimulus and discriminated the familiar from the novel stimulus.

These measures are also assumed to be the partial analogs of information processing and have been useful tools for investigating the ontogeny of memory. Though they focus on infants' perceptual responses, inherent to each is the strong suggestion that infants construct and use mental representations. The study of the process of developing mental representations is compelling because they are basic and pervasive in everyday information processing. Mental representations are fundamental to such higher order mental processes as language proficiency and concept formation (Bornstein & Ruddy, 1984; Bornstein & Sigman, 1986; Miller, Ryan, Aberger, McGuire, Short, & Kenny, 1979; Miller, Ryan, Short, Ries, McGuire, & Culler, 1977; Miller, Sinnott, Short, & Hains, 1976; Miller, Spiridigliozzi, Ryan, Callan, & McLaughlin, 1980; Rose, Slater, & Perry, 1986; Slater, 1985; Slater, Cooper, Rose, & Perry, 1985).

1.2.1 Models of Habituation. There are several theoretical accounts which discuss the deployment of attention during the habituation process. The theoretical account most widely accepted is known as the ***comparator model of habituation*** proposed by Sokolov (1963). This model proposes changes in an orienting response (OR) with stimulus familiarization such that the introduction of a novel stimulus invokes an orienting response (i.e., a fixation of large duration) and the construction of a mental representation of the stimulus. During each stimulus presentation this mental representation is compared with the visual input. With repeated presentations, the orienting response decreases (i.e., looking time decreases) as the fidelity of the mental representation compared to the original stimulus increases.

The ***serial model of habituation*** (Miller, 1972; Miller, Ryan, Sinnott, & Wilson, 1976; Jeffrey & Cohen, 1971; Olson, 1976) refined the comparator model by proposing that infants focus on "component features of a form" which are ordered in terms of their saliency at invoking attention (also discussed in the literature as an orienting response). Infants initially attend to the feature that is most salient. When the orienting response to this cue declines (i.e., is habituated to), infants then direct their attention to the next most salient feature and this process continues until infants have processed all of the stimulus features.

Other researchers believing models such as those discussed above inadequately explained the habituation process, proposed a ***dual process model of habituation*** (Bashinski, Werner, & Rudy 1985; Cohen, 1972; 1973; Groves & Thompson, 1976; Kaplan, Werner, Rudy, Groves & Thompson, 1970; Kaplan & Werner, 1986, 1987; Thompson & Glanzman, 1976). In the dual process model the habituation response is <u>not</u> simply response decrement, but is best represented as two independent, yet interactive response tendencies. One response tendency stimulates responsiveness (i.e., sensitization) and the other inhibits responsiveness (i.e., habituation). The behavior of the infant is thought to be a summation of these two processes. The magnitude of activation of these two processes is stimulus dependent. Moreover, these two processes decay at different rates over time.

Each of these models have both strengths and weaknesses in explaining the distribution of attention. One of their commonalities, and the reason for their popularity, lies in their interpretation of infant habituation as an essentially cognitive process. Non-cognitive explanations for the habituation process have been offered by Bronson (1974; 1982) and Dannemiller and Banks (1983). Bronson (1974; 1982) proposed that infants below the age of two months are "subcortical" or reflexively responsive to stimulation. Dannemiller and Banks (1983) argued that habituation in infants below 4-months can be adequately explained as sensory adaptation of feature-selective cortical neurons. These two theories have largely been disconfirmed (Antell & Keating, 1985; Bushell, McCutcheon, Sinclair, & Tweedlee, 1974; Slater, 1984; Slater & Morison, 1985; Slater, Morison, & Rose, 1982;1983; 1984) and most habituation researchers now prefer the cognitive models.

1.2.2 Habituation Paradigms. As habituation studies flourished, several procedural paradigms were developed to evaluate and measure the process, each of these have different and significant consequences (for a more detailed summary see Bornstein, 1985; Colombo, 1993; Colombo & Mitchell, 1990). Early habituation studies utilized the ***fixed-trials procedure*** (Fantz, 1964) which presented infants with a fixed number of trials of predetermined duration. While the data were easily analyzable, the major limitation of this paradigm is that the number and duration of stimulus presentations were set by the experimenter. The implications being that some infants are not allotted sufficient time with the stimulus to habituate, while others habituate quickly and must endure further presentations of the stimulus.

With the ***fixed-level procedure*** (McCall, Hogarty, Hamilton, & Vincent, 1973) a number of trials of fixed duration is presented until the infant reaches a predetermined low level of looking. This is similar to the fixed-trials procedure in that the duration of each trial is determined by the experimenter. However, it is considered a methodological refinement in that infants must reach a certain level of looking as opposed to terminating presentations after a fixed number of trials. A shortcoming of this procedure is that this low-level of looking is experimenter-determined.

Another variation is the ***free-looking procedure*** (Bornstein, Ferdinansen, & Gross, 1981; Bornstein & Krinsky 1985; Bornstein, Krinsky, & Benasich, 1986) where a stimulus is continuously available for viewing for a predetermined duration. This lengthy presentation is then subsequently divided into smaller segments of equal duration. The criticisms leveled at the other two paradigms discussed are applicable here.

The ***infant-controlled procedure*** represented a major methodological improvement (Horowitz, Paden, Bhana, & Self, 1972). In this paradigm stimulus onset, stimulus offset, and the ultimate duration of the study are controlled by each individual infant. Conducting an infant-controlled session is necessarily more complex as it requires the determination of the duration of looking "on-line," with a rapid calculation of a baseline score, and the continuous comparison of each trial to this baseline until the infant reaches a predetermined habituation criterion. An advantage of this paradigm is that researchers are better able to assess and track individual differences in infant looking behavior and subject loss is reportedly lower (Colombo & Horowitz, 1985; Horowitz et al., 1972) . However, a disadvantage is that there are a number of parameters which are defined by each individual researcher and these tend to vary from study to study, making comparisons among studies difficult. These parameters include the number and selection of trials to be included in the baseline calculation, the minimum amount of fixation time infants must accumulate for a given trial to be counted, the minimum amount of time infants must look away from the stimulus in order to end its presentation, the habituation criterion (that is, the level that looking must decline compared to the baseline score), and the number of consecutive trials which must fall below this criterion, signaling that habituation has occurred. Today the infant-controlled procedure is the preferred paradigm as the advantages significantly outweigh the procedural difficulties.

1.2.3 Quantitative Measures of Habituation. There are many quantitative measures, both observed and derived, which characterize an infant's habituation performance and there is much debate over which measures are most useful (Colombo, 1993). Researchers have been interested in assessing several parameters such as how quickly, efficiently, and completely infants habituate. For instance, the number of trials or exposures to the stimulus an infant requires before reaching criterion indicates how quickly an infant habituates. So presumably, the fewer trials needed to reach the habituation criterion, the faster the rate of habituation. The amount of accumulated looking time an infant exhibits before reaching criterion also indicates how quickly an infant habituates. Both the number of trials to criterion and accumulated looking time must be examined however, in evaluating the rate of habituation because, for instance, two infants may have habituated in four trials but infant A accumulated 50 s of looking time whereas infant B accumulated 150 s. Therefore, even though both infants habituated in four trials, infant A was the faster habituator. Efficient processing can be inferred if, during the course of habituation, we observe a long initial look followed by a rapid decline to criterion. We can quantify this by calculating the slope of the habituation function by regressing the ordinal trial number on the duration of looking during each trial. The result of this calculation should be a negative number; the larger this number, the more efficiently and rapidly processing occurred. How completely an infant habituates can be indexed by a comparison of the amount of looking in the final levels of habituation to the amount in the initial levels. Efficient information processing is also indicated by greater amounts of looking at a novel stimulus with reciprocally lesser amounts of looking at the familiar stimulus.

1.2.4 Short-term and Long-term Reliability and Stability in Habituation Performance. A large body of research has been conducted on the short and long-term stability and reliability of measures of habituation performance. The interest in stability of habituation performance was spurred by the continuity versus discontinuity debate in developmental psychology. If habituation/dishabituation performance is reliable in that infants perform similarly from one assessment to the next, then we can safely conclude that the habituation task is tapping in to a specific behavior in infants and that information processing is a stable entity.

Studies investigating short-term reliability have typically looked at within-age consistency or consistency between test-retest assessments of short periods. A positive correlation of measures between these assessments is indicative of stability. Many studies have demonstrated significant short-term reliability when the inter-test interval was shorter than one-month, specifically on the duration measures of habituation (Bornstein & Benasich, 1986; Fenson, Sapper, & Minner (1974); Colombo, Mitchell, O'Brien, & Horowitz, 1987a,b; Miller, Ryan, Sinnott, & Wilson 1976; Mitchell & Steiner, 1984; Pêcheux & Lécuyer, 1983; Pomerleau, Maître, & Malcuit, 1989). Measures of the rate of habituation, such as the number of trials needed to reach criterion, have generally proven unreliable (Malcuit, et al., 1989; Colombo et al., 1987) Bornstein and Benasich (1986) assessed the short-term reliability of habituation in infants between two assessments, shortly after their 5th month birthday and 10-days later. Several quantitative indices of habituation were significantly reliable: baseline looking, slope of the habituation function, and percent decrement. Colombo et al. (1987a) in an elaborate cross-sectional/ longitudinal study investigated both the short- and long-term reliability of habituation and dishabituation performance. They tested a total of 186 infants twice, at 3, 4, 7, and 9 months of age; a subsample was followed longitudinally at each age. In the short-term, they found that most of the duration-based (e.g., peak fixation, first fixation, average fixation) and the magnitude measures were the most reliable. However, none of the dishabituation measures (either their presence or magnitude) proved reliable across the short-term. The qualitative habituation patterns were also relatively stable over the short-term (Bornstein & Benasich, 1986; Colombo et al., 1987a; Mayes & Kessen, 1989). Also, importantly, these stability levels prevail despite several potential sources of variance including procedural variations, stimuli shown, and the length of the test-retest interval. Mayes and Kessen (1989) presented corroborating evidence of significant short-term reliability in terms of peak fixation, duration of baseline, accumulated looking time, and rate of decline in infants between 3- and 4-months of age. However, after 4-months of age, no measure showed significant individual stability. Colombo (1993) compiled and summarized the estimates of test-retest reliabilities of infant fixation duration measures from extant studies and determined the median reliability to be +.53.

Other studies with longer intervals between test and retest have found stability, although the magnitude of this stability is somewhat diminished (Colombo et al., 1987a,1988). Colombo (1993) compiled the limited number of studies addressing this issue and found the median reliability to be between +.20 and +.30, after a 6-month interval, significantly lower than those found in shorter term test-retest intervals. In their longitudinal study, Colombo and colleagues (1987a) demonstrated that the duration measures had the most consistency over the long term. This was specifically true of the duration of the peak fixation and the magnitude of habituation (Colombo, et al. 1987a, 1987b, 1988). None of the non-duration measures showed any stability over longer test-retest periods.

Interestingly, Colombo et al., (1987a) tested whether the observed stability in duration measures is primarily attributable to the duration of the peak. They reasoned that this was a possibility because the duration variables are not independent of one another; rather peak fixation duration is a component in all of these variables. By 4 months of age, duration measures were shown to have short-term test-retest reliability even after the duration of the peak fixation was partialled out. However, when peak fixation was excluded from the analyses of the magnitude of habituation measures, results were no longer reliable. Therefore, the reliabilities observed on the magnitude variables, within an age group, were attributed primarily to the influence of peak fixation. For the longitudinal data, when peak fixation was partialled out of the duration and magnitude habituation measures, a significant correlation was observed only between the 7- and 9-month testings. They stated, "These findings suggest some stabilization in more aspects of infants' visual habituation in the second half of the first year" (p. 484).

1.2.5 Individual differences in Habituation Performance. A related issue to the discussion of stability and reliability in information processing performance is whether infants demonstrate systematic and stable differences in their habituation style. The study of individual differences is not only academically interesting, but as Horowitz (1987) suggested, if we are to have a comprehensive understanding of the processes of development, an understanding of individual variation in performance is imperative. She stated, "The study of individual differences involves looking for stabilities across time, stabilities that persist in the face of change, characteristics that endure as constants even as the rules governing change may vary over time" (p. 3).

Most habituation research examined group performances such as how 5-month-olds perform in comparison to 3-month-olds. Group performance gives us interesting information on what the average infant is doing, but research on other aspects of behavior in infants has demonstrated significant individual differences in terms of for instance, temperament. It therefore seems intuitive that there be individual differences in terms of early cognitive performance. It has in fact been observed that infants demonstrate both quantitative and qualitative variations in the processes they use as they habituate. They distribute themselves for instance, on the number of trials and the amount of looking time they accumulate before reaching habituation (Bornstein & Benasich, 1986; Bornstein & Ruddy, 1984; Colombo et al., 1987a, b; Colombo 1990; Colombo & Mitchell, 1988; DeLoache, 1976; McCall, 1979). For example, DeLoache (1976) observed that it took different

4-month-olds between 4 and 24 trials to habituate to a geometric pattern. It thus appears that some infants habituate quickly while others require longer exposure times.

Infants have subsequently been trichotomized into "rapid habituators," "slow habituators," and "idiosyncratic types" by McCall and Kagan (1970) or "fast habituators," "slow habituators," or "non-habituators" by Cohen, DeLoache, and Pearl, (1977). Infants' qualitative patterns of habituation have been classified as "exponential-decrease," "increase-decrease," and "fluctuating" by Bornstein and Benasich (1986). They have also been simply dichotomized as "short-lookers" and "long-lookers" by Colombo and Mitchell, 1988, 1990; Colombo, Mitchell, Coldren, & Freeseman, 1991). Colombo et al., (1991) used a median split of the average fixation duration and then categorized infants depending on whether their individual average fixation duration score fell above or below the median. Another way to identify short and long lookers is to determine whether infants fall above or below the mean of the total amount of accumulated looking time (Krinsky-McHale, 1994).

Colombo et al. (1991) stated, "it is still uncertain as to what particular component or aspect of information processing is represented by fixation duration" (p. 1248). Riksen-Walraven (1978) hypothesized that slower habituators repeatedly focus on the most salient cue(s) in the stimulus and may therefore take longer to form a schema. This explanation is evocative of the earlier claims for scanning "captured" by the salient stimulus dimensions. It has also been argued that infants who habituate quickly are forming mental representations more quickly and efficiently than infants who habituate more slowly (Colombo et al,. 1991; Lewis, et al., 1969; McCall, 1971, Mitchell, 1990). Colombo et al. (1991; 1993) and

Colombo and Mitchell (1990) reasoned that the speed of processing hypothesis is congruous with the Sokovolovian comparator model of habituation.

While slower habituators, when given sufficient time, eventually form as accurate and complete a schema as fast habituators, the style each infant brings to information processing seems to have significant consequences in other areas of development such as cognitive and perceptual development (Lewis, et al., 1969; McCall, Hogarty, Hamilton, & Vincent, 1973; DeLoache, 1976). This has been demonstrated in concurrent relationships between habituation measures and other aspects of infant behavior (concurrent prediction) (Colombo, 1988; Colombo et al., 1987b; Greenberg, O'Donnell, & Crawford, 1973; Lamarre & Pomerleau, 1985; Pêcheux & Lécuyer, 1983) and between habituation measures in infancy and other early childhood measures (lagged prediction) (Krinsky, 1988; Lewis & Brooks-Gunn, 1981; Miller et al., 1977; Ruddy & Bornstein, 1982; Tamis-LeMonda & Bornstein, 1989). Information processing during infancy also foreshadows childhood cognitive performance. Relatively quicker declines, greater decrements, shorter fixation duration, and greater magnitude of novelty preference are generally considered to be more efficient and mature styles of information processing in infancy and are related to better intellectual performance in childhood. For example in demonstrating lagged predictability, Krinsky (1988) found that habituation performance measures of 5-month-olds predicted language comprehension and production in the two year old as measured by a standardized language test (Reynell Developmental Language Scales, RDLS.; Reynell, 1982[4]). Bornstein and

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[4] The Reynell Developmental Language Scales provide a detailed and comprehensive assessment of a child's language abilities. It provides a verbal comprehension and an expressive language scale.

Tamis-LeMonda (1988) found 5-month habituation scores predicted play sophistication.

1.2.6 Developmental Changes in Measures of Habituation. A tangential issue to the stability of habituation measures and individual differences in habituation performance is the developmental changes that occur in the process. Infants may be ranked similarly on a variety of habituation measures over time, but this does not preclude that habituation performance changes with age. Researchers have subsequently documented the developmental changes in habituation performance, the assumption being that older infants are "better" at habituating that is, they are possibly quicker, more efficient, and habituate more completely than younger infants. In general, researchers have found that fixation duration decreases with age; older infants take less time to habituate to a stimulus than younger infants (Bornstein, Pêcheux, and Lécuyer, 1988; Colombo & Mitchell, 1990; Colombo et al., 1988; Mayes & Kessen, 1989; Mitchell & Horowitz, 1988; Rose, Slater, & Perry, 1986)

Mayes and Kessen (1989) studied 38 infants between the ages of 3 and 6 months and noted maturational changes in the habituation response. The quantitative measures investigated included 4 observed measures: duration of longest look, accumulated looking time, length of the second criterion look, and the number of looks to criterion; and 3 derived measures: duration of baseline, amount of habituation, and rate of decline in looking. Duration of baseline, length of longest look, and the duration of the second criterion look all decreased with age. There was no similar developmental progression with habituation amount or the number of looks to criterion. They also discovered that the rate of decline in looking increased. Therefore, infants required less time to habituate, but they habituated in the same number of trials/looks (Colombo & Mitchell, 1990). Other developmental findings from this and other extant studies include the observation that the slope of the habituation curve becomes shallower (Colombo & Mitchell, 1990; Mayes & Kessen, 1989) and the peak fixation appears later during the progression toward habituation (McCall, 1979). The preceding cited studies used the infant-controlled paradigm. Developmental studies using the fixed-trials paradigm also found steeper decrements (i.e., older infants habituate more completely than younger infants) (Cohen, 1969; Lewis, 1969). It has been proposed that the etiology of the developmental shift in habituation performance, to a more efficient form of processing is a complex interaction between the maturity of the infants' nervous system and their increased experience with pictures, events, and objects in their environment (Bornstein, 1985).

1.3 The Relationship Between Visual Scanning and Habituation

The relationship between visual scanning and cognitive processing during habituation has been subject to investigations by Coles and Sigman (1987) and Bronson (1990,1991). Details of these studies are presented because they are relevant to the present discussion of the methodologies used and the data analyses conducted in these studies. In general, these researchers have demonstrated that there is a relationship between oculomotor behavior and underlying cognitive activity.

Coles and Sigman (1987) recorded the eye movements of infants between the ages of 4 and 6 months during habituation and dishabituation. Some of the global aspects of infant scanning showed that over two-thirds of the fixations fell within the central stimulus area, with the majority of these located in the zones that contained stimulus elements. They noted that scanning changed during the progression toward habituation and upon the presentation of the novel stimulus; during the last few trials of habituation, infants gave the stimulus pattern only brief inspections and during dishabituation, they once again actively scanned the novel stimulus. However, because the form and arrangement of stimulus elements varied between habituation and dishabituation, they could not determine the basis for the discrimination. This study suggested that at least by the age of 4 months, there is a relationship between oculomotor behavior and underlying cognitive activity. In addition, they did not observe significant age differences in either scanning or habituation. Their study also attempted to address some questions arising from hypothesized serial processing model of infant habituation: that is, during the course of habituation infants proceed from exploring the most salient features of a stimulus to progressively scanning the less salient features. They did not find evidence in support of this model. Rather, exploration was highly repetitive with a few locations being inspected repeatedly. They hypothesized that perhaps repeated exploration is a form of "rehearsal with the gradual build-up of expectations about the consequences of making a given eye movement" (p. 350). While their findings are highly provocative, there are a number of limitations which warrant further studies to unravel the complex relationships that exist between scanning and visual information processing. First, young infants (under four months) were not tested in this study. Therefore, we do not know if information processing and scanning would be qualitatively different at younger ages. Other research has strongly suggested that they could be. As previously discussed this relationship may not hold for the younger infants because of the immaturity of the visual pathways at the beginning of life and the subsequent maturation during the first few months. Second, since the stimuli varied both in overall configuration and form of the stimulus elements between habituation and dishabituation, it was impossible to determine the basis for the observed discrimination between the familiar and novel patterns. Third, while Coles and Sigman examined scanning over the course of habituation and dishabituation, they never explicitly correlated the various habituation measures with scanning properties nor did they investigate the role of individual differences in scanning and habituation. Finally, in order to facilitate the presentation of group statistics Coles and Sigman, believing that infants' performance was equated once infants reached the habituation criterion, divided the habituation data into 5 segments of equal duration. This unorthodox treatment of the habituation data raises the question of whether in fact infants' performance can be equated solely because they reached the habituation criterion. The infant-controlled paradigm has been the preferred method because it has been shown to tap into individual differences in information processing. It seems intuitive that dividing the session up in this manner would not preserve and may even obscure some of the individual differences observed with the infant-controlled procedure, therefore limiting the relations that can be found.

Bronson (1991) furthered the research paradigm by analyzing individual differences in the quality of visual scanning and the rate of encoding in a sample of 2- and 12-week-old infants. In general, rapidly-encoding 12-week-old infants were found to scan extensively, engage in shorter intervals in continuous inspection of one part of the stimulus, and engage in brief fixations. In addition, Bronson found significant age differences in the nature and style of scanning such that 12-week-olds who were slow encoders resembled the 2-week-olds in scanning style. Moreover, he found that there was a developmental advancement toward the characteristics found to be associated with rapid encoding. The "advanced scanner" exhibited a relative absence of long intervals of inspection and a relatively low incidence of prolonged fixations. Bronson found that while 2-week-old infants spent only 25% of the time in advanced scanning (29% of the time spent in brief fixations and 21% in short inspections), 12-week-olds spent 50% of the time in advanced scanning (45% of the time spent in brief fixations and 48% of the time spent in short inspections). He therefore concluded that rapidly-encoding infants are relatively advanced in their scanning style.

There are several methodological choices that were made in this study which need to be considered if we are to determine its merit. First, the 12-week-olds participated in a "modified" infant controlled procedure. Trial duration was determined by infant looking behavior as is customary in this paradigm. However, instead of allowing trials to continue until the infant reached a criterion, the session ended after the infant received seven trials. Presetting the number of stimulus presentations might take one infant past the criterion point while truncating looking for another infant.

Secondly, Bronson made comparisons between the scanning of 12-week-olds and 2-week-olds using different procedures for the two groups; while 12-week-olds participated in the "modified" infant controlled procedure, 2-week-olds were subject to a fixed-trials procedure, receiving 7 trials which were 30 seconds in duration. The performance between the two age groups is therefore not readily comparable. No data on encoding rates nor their relations to scanning were derived for the 2-week-olds. This fact limited the conclusions that could be made regarding developmental trends.

Third, Bronson's corneal reflection monitoring system collected eye position data at a much slower rate (4 Hz) than most systems employed today in measuring eye movements (typically around 60 Hz). Hainline and Lemerise (1985) pointed out that since information about change in eye position over time is of interest, one must be concerned with the characteristics of the recording instrument that limit the bandwidth. They stated that low sampling rates make it impossible to consider eye position as a continuous variable. With higher temporal bandwidths, it is possible to isolate fixations and saccades. Also they discovered characteristics of infant eye movements that led them to question whether methods with slow sampling rates are adequate to determine the spatial location of infants' actual fixations. For example, when looking at relatively uninteresting stimuli (such as the ubiquitous geometric stimuli), infants' saccades are slower than those of adults and these might actually be coded as fixations with slower bandwidth recording systems (see Hainline & Lemerise, 1985 for a complete discussion).

Fourth, Bronson's eye tracking system uses a dark pupil method; eye position may have been estimated from drowsy or inattentive infants. Fifth, Bronson never related scanning to specific pattern features. Finally, he derived summary variables that were averaged across the trials for each infant. While this examines average infant performance and is the type of data analysis common to studies investigating the global aspects of habituation, using average variables in a scanning study seems to defeat the original goal of this research, which is to detail the deployment of attention over time. Although the level of detail achieved in analyzing the scanning measures was not much better than can be achieved from the global measures, this study did add to our knowledge of early infant scanning behavior.

1.4 Summary of the Infant Oculomotor System and Infant Habituation

Eye movement researchers have contributed significantly to our understanding of infant oculomotor systems. They have admitted however, that a major gap in their work is in how oculomotor behaviors reflect cognitive processes. Johnston and Pirozzolo (1981) felt that compared to documenting the physical characteristics of eye movements, "It is a much greater challenge to determine how higher cognitive processes are related to the manner in which humans inspect the visual environment for information" (p. 623).

The habituation paradigm has enlightened researchers significantly about infant competencies. It has advanced our knowledge about detection, discrimination, categorization, and memory in infants. It has also highlighted important individual differences in infant perceptual abilities. However, researchers using the habituation paradigm have admitted that there is much we don't know about the process. Slater and Morison (1985) stated, "Even though habituation procedures have been an essential method of investigation of infant vision and memory for over 20 years, the habituation process is still little understood" (p. 102). Further, Mitchell (1990) stated, "cognitive researchers in infancy do not yet understand the underlying processes during habituation that influence the occurrence or failure of dishabituation" (p. 28). The gradual construction of an internal representation is thought to occur upon repeated exposure to a stimulus.

However, the concept of mental representation has been an elusive one. Questions involving the process by which these representations are acquired have not been adequately addressed. If we do not have a thorough account of the information which infants are actually using to achieve an understanding of the objects and events around them, then our hypothetical models of information processing are surely incomplete.

Given this paradigm's popularity and usefulness in exploring the capabilities and limitations of early information processing, it is essential that we investigate more thoroughly the mechanisms of habituation. The extant studies have shown that there are changes in scanning during the process of habituation; that early scanning is not merely a reflexive activity but is rather purposeful. However, further work is needed to delineate more precisely what is it we are measuring when an infant habituates.

The work presented in the following chapters was motivated by the same questions that were the focus of the Coles and Sigman (1986) and the Bronson (1991) studies. While a single study cannot address all the questions we have, or provide definitive answers on this issue, investigating visual scanning during habituation and upon the presentation of a novel stimulus will advance our knowledge of early information processing. This study was conducted to further delineate the precise function of oculomotor behavior in infant visual perception and information processing, how different processes of habituation are used by infants of different ages, and to determine whether scanning measures are useful adjuncts to the traditional global measures. During the first year of life both oculomotor activity and information processing abilities undergo significant development.

Examination of how these are interrelated, both within a habituation session and between ages, will contribute to our understanding of how infants actively construct knowledge about their environment.

[2]

EXPERIMENTAL DESIGN AND METHODS

2.1 Subjects

Subjects were 32 infants in two groups: 18 2-month-olds, 7 females and 11 males (M= 67.78 days, ± 8.64 days) and 14 3-month-olds, 9 females and 5 males (M=103.88 days, ± 16.71 days). All infants were full-term and free of any known neurological or visual abnormalities. Infants were screened for refractive errors and astigmatism using the techniques of photorefraction and photokeratometry, respectively. The infants were drawn from patient populations of cooperating pediatric and obstetrical groups in the Brooklyn College area. A total of 115 infants were seen in order to collect at least the minimal amount of data required for inclusion in the study and to obtain the required 32 subjects.[1]

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[1] Fifty-one infants were not tested because they cried before the experimental session began; 25 infants did not complete the habituation phase of the experiment because they cried excessively or became very fussy during the experimental session; 2 infants fell asleep during the experimental session, thereby making their scanning data noisy and unscoreable; and the data from 5 infants were unscoreable due to mechanical or experimenter error. Excluding the infants who were too fussy before the experiment commenced, the experimental drop-out rate was 50 percent.

As a check on the apparatus and for calibration purposes, 10 adults were asked to deliberately and steadily fixate on a number of calibration points (see section 2.6.1 on Adult Calibration Methods for more detail).

2.2 Stimuli

The stimuli consisted of geometric patterns previously used by Bornstein, Ferdinandsen, and Gross (1981) and Bornstein and Krinsky (1985) and were constructed using the Dr. Halo III™ computer graphics software package.[2] One vertically symmetrical, one horizontally symmetrical, and one asymmetrical pattern were constructed out of three pairs of amorphous shapes (see Figure 1). The vertical stimulus is the one shown on the top; components on the left and right of the vertical meridian are mirror image reflections. The horizontal stimulus is the one shown in the middle and is a 90° counterclockwise rotation of the vertical pattern. The asymmetrical stimulus is the one shown on the bottom and is composed of the same three shapes as the others but in an asymmetric arrangement. Because the stimuli were constructed from identical components,

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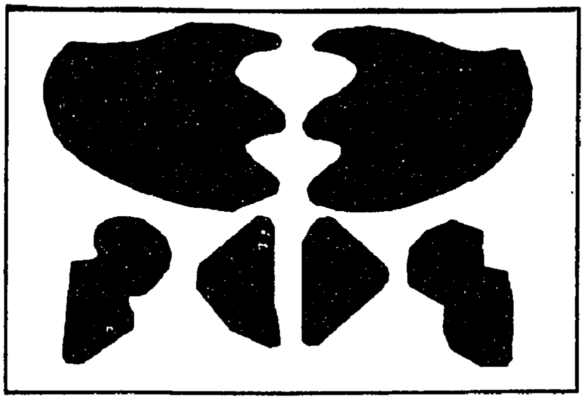
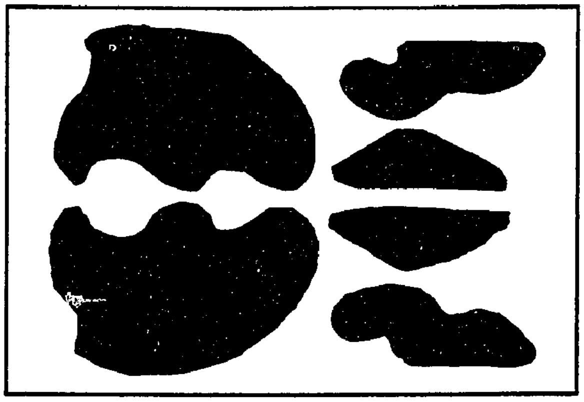
[2] These stimuli were selected because it was known from the Bornstein et al. (1981) and Bornstein and Krinsky (1985) studies, that 4-month-old babies would rapidly habituate to these stimuli. A stimulus which infants could quickly habituate to was needed because of the difficulties inherent to the procedure. In both studies, infants were continuously exposed to one of the patterns for 240 sec. For data analysis purposes, this was then divided into 24 10-second segments. Baseline was equal to the mean of the first three segments, and looking during each segment was converted to a percentage of baseline. The habituation criterion was set at three consecutive segments in which looking time as $\leq$ 50% of baseline. In the Bornstein et al. (1981) study, the mean number of 10-sec segments required for infants to reach criterion was 8.9 for the vertically symmetrical pattern [it took infants an average of 6.8 segments in the Bornstein and Krinsky (1985) study], 15.8 segments for the horizontally symmetrical pattern, and 15.7 segments for the asymmetrical pattern. Additionally, infants did not preferentially look at any of these three patterns during the first 30 seconds of stimulus presentation. For example, in the Bornstein et al. (1981) study, babies looked at the vertically symmetrical pattern an average of 21.37 seconds [18.57 seconds in the Bornstein and Krinsky (1985) study]; at the horizontally symmetrical pattern an average of 18.71 seconds; and at the asymmetrical pattern an average of 18.23 seconds. The differences were not significant (multiple t's(17) $\leq$ 1.74).

Figure 1

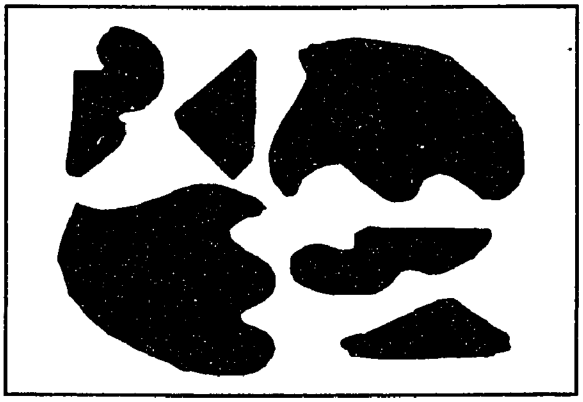
Habituation and test phase stimuli.



Vertical Symmetry



Horizontal Symmetry



Asymmetry

Figure 1

they were identical in perimeter contour and in area. The stimuli were located 57 cm from the infant and were red on a black background (with a mean luminance of 4.5 cd/m^2; dominant λ= 605 nm; purity = 90%)[3] and subtended 14.6° x 11.4° of visual angle[4]. In addition, there was a separation of 2-3° between the components of the stimuli which allowed for the resolution of scanning of each of these components. Infants also saw an altogether different geometric stimulus (a circle with a star in its center) as a pretest and posttest. This was done as an assessment of habituation per se (to rule out fatigue or other state changes) and for calibration purposes (for positioning the experimental stimuli on infants' scanning patterns). Before the experiment began and in order to properly set the controls of the instrument recording the eye, infants saw a picture of "Mickey Mouse" to attract their attention.

2.3 Eye Movement Recording System and Procedures for Measuring Eye Movements

Eye movements and fixations were recorded using a computer-based infrared corneal reflection monitoring system (Applied Science Laboratory Model 1994) which was extensively modified for use with infants (see Hainline, 1981). The principle elements of this system are shown in Figure 2. Light from a collimated, completely invisible infrared illuminator reaches the subject's eyes after being

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[3] Luminance was measured using the Photo Research PR-703A Spot Spectra Scan, Fast Spectral Scanner.

[4] The visual angle is a measure of the size of the retinal image. It can easily be computed when the size of the stimulus and the distance of the stimulus from the subject is known. The stimuli here were 57 cm from the subject and the size of the stimulus measured 11.3 cm, horizontally and 14.8 cm vertically. Tangent of visual angle, vertically = size/distance therefore, $\tan \alpha = 14.8/57 = .26$. Thus, α is approximately 14.6°. (At 57 cm, 1 cm of image size = 1° of visual angle).

Figure 2

A schematic representation of the essential elements and principles of operation of a television-based infrared eye movement recording system. The lower portion of the figure illustrates the differential movement of the corneal reflection with respect to the pupil during eye movements.
(From: Hainline, L., 1981.)

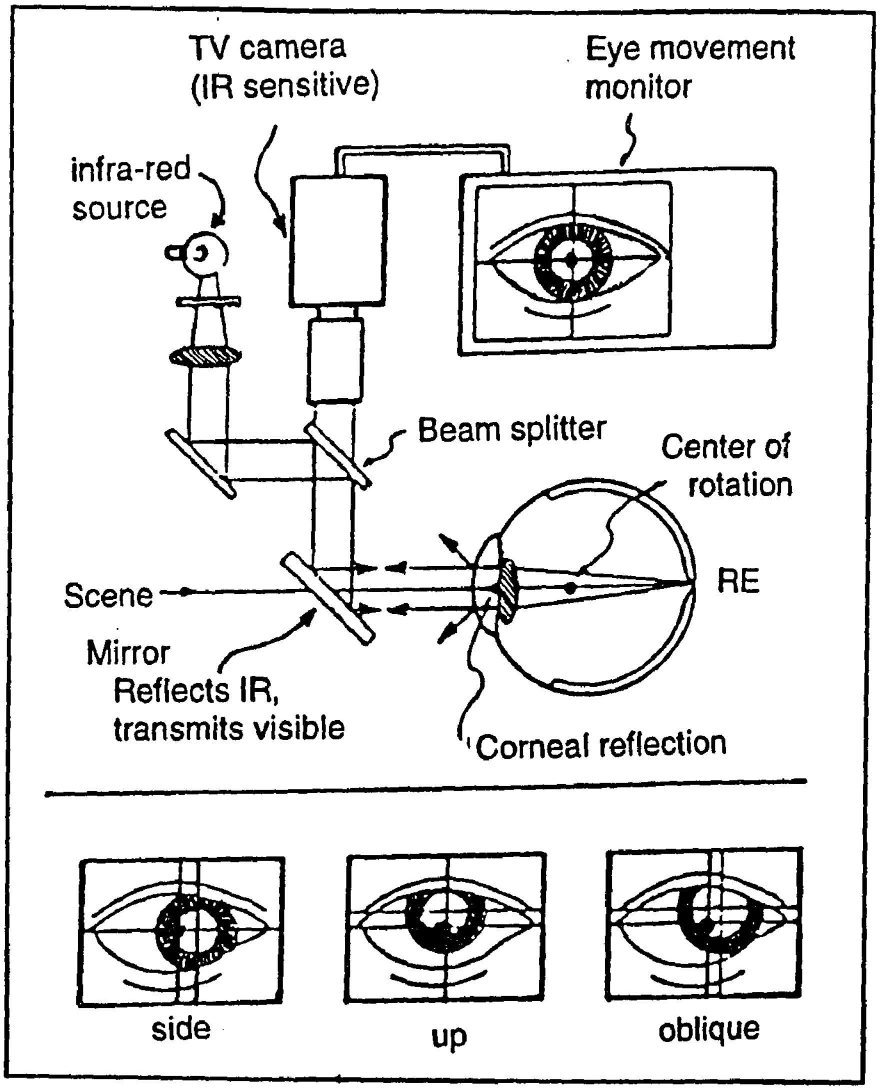
TV camera
(IR sensitive)
Eye movement
monitor
infra-red
source
Beam splitter
Center of
rotation
Scene
RE
Mirror
Reflects IR,
transmits visible
Corneal reflection
side
up
oblique

Figure 2

reflected by an infrared-reflecting, visible transmitting dichroic mirror. A small amount of light which enters the pupil is reflected back out by the retina, through the pupil, and eventually reaches an infrared sensitive television camera. This camera provides an enlarged image of the right eye with a bright pupil as well as the corneal reflection (or the first Purkinje image) of the light source superimposed on the pupil. The resulting picture of the eye is displayed on a television monitor. When the eye moves to look at a point in the visual scene, the corneal reflection moves differentially with respect to the pupil (see the bottom of Figure 2). However, when the entire head moves, the pupil and the corneal reflection move together. This means that if the position of the head is relatively stable, the direction of regard can be accurately specified by analyzing the shifts of the center of the corneal reflection, relative to the center of the pupil. The small field view of the camera (a volume of about 1 cm x 1 cm x 1 cm) controls for artifacts from large head movements, simply because no data can be collected if the head moves more than about a degree from the central position of the camera's view. The focusing adjustment of the camera lens is at a preset distance and the infants are moved until their eye is in focus at that constant distance. Additionally, the eye tracker comes equipped with head movement compensation circuitry which adjusts for smaller head movements. Therefore, eye position is relatively independent of head position as long as the pupil image is maintained within the field of view of the camera. This also means that nothing needs to be attached to the infant's head and testing is accomplished relatively unobtrusively. The system has a resolution of about a half a degree and a calibrated accuracy of about a degree of visual angle.

Figure 3 shows the entire eye movement recording system as used with infants. The infant looked through the beam splitter at the stimulus display (a NEC Multisynch XL Color Computer Monitor, screen dimensions 16″ x 12″). An experimenter, whose back was to the stimulus monitor (and therefore could not see the stimuli), maintained the infant's head position by observing a television monitor which showed the infant's eye. The experimenter corrected the positioning by moving her/his body, and that of the infant until the infant's eye was aligned properly for recording. Information from the "eye" camera was fed into the eye movement recorder at a rate of 60 Hz; this rate of data collection allowed the estimation of both the temporal and spatial characteristics of infants' oculomotor behavior (Hainline, 1981). Special recognition circuits detected the location of the pupil relative to the brighter corneal reflection and provided real-time estimates of the x and y coordinates of the point of regard, as well as pupil diameter (which is indicative of arousal and interest). The position of the horizontal crosshair, as measured by the number of scan lines (1 to 255) from the top of the screen to the present location of the crosshair and the vertical crosshair, as measured by the number of scan lines (1-255) from the left edge of the screen were stored digitally by a NEC Powermate II computer, which provided on-line analysis and mass storage for off-line analysis. A "scene" camera imaged the stimulus being viewed by the subject on another television monitor. This monitor displayed the stimulus together with vertical and horizontal crosshairs, which indicated the infant's point of regard. In an adjacent room, a second Powermate II computer collected the looks towards and the looks away from the stimulus, as judged by an observer, calculated the current status of looking relative to a baseline score and to the habituation

Figure 3

A systematic representation of an eye movement recording system designed for the use with infants.
(From: Hainline, 1981)

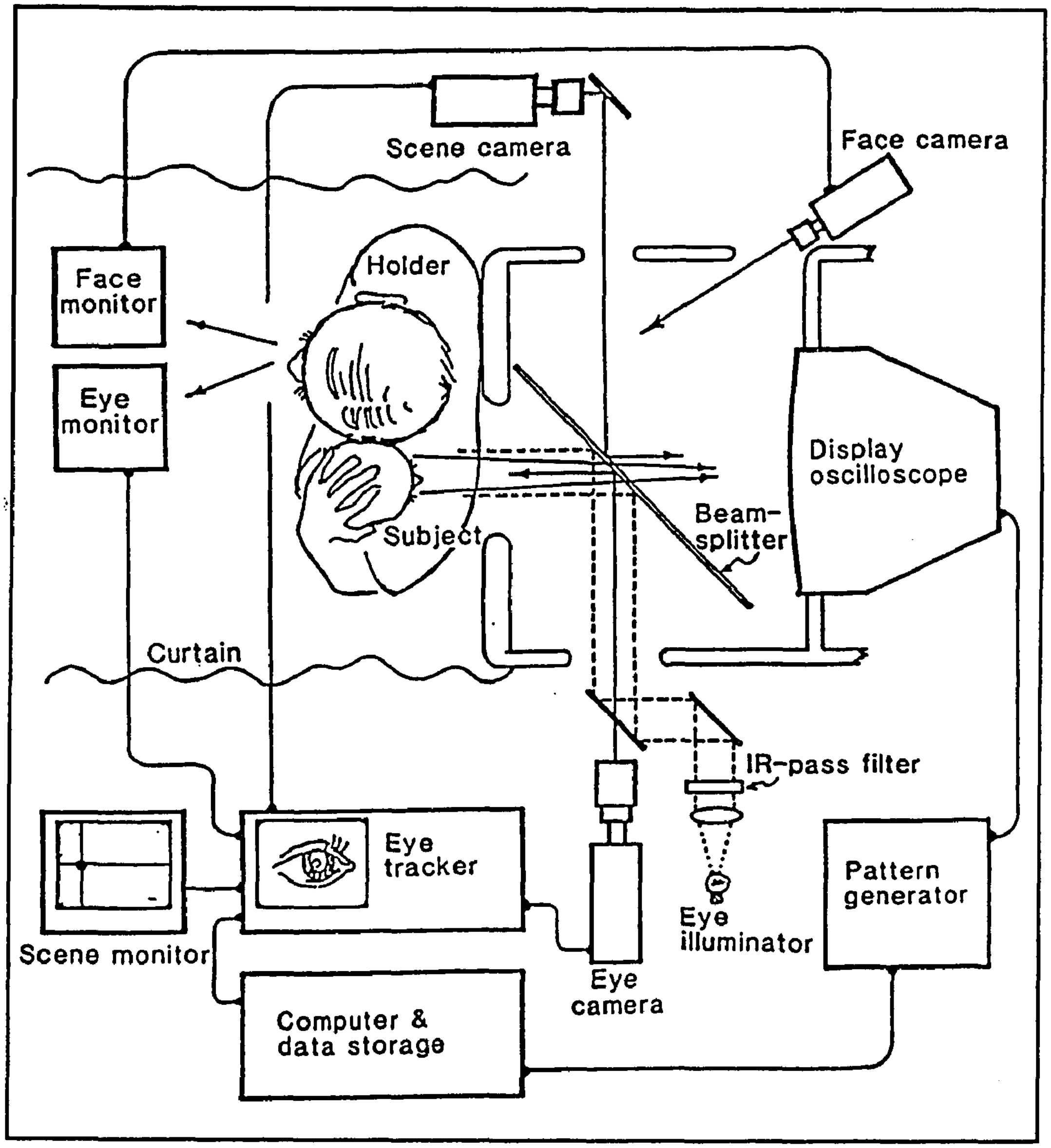
Scene camera
Face camera
Holder
Face monitor
Eye monitor
Display oscilloscope
Beam-splitter
Subject
Curtain
IR-pass filter
Eye tracker
Eye illuminator
Pattern generator
Scene monitor
Eye camera
Computer & data storage

Figure 3

criterion, and controlled stimulus presentation. It also interfaced with the computer that collected the eye movement data. A "face" camera imaged the infant's face on another television monitor, which was also located in the adjacent room and enabled the determination of looks towards and looks away from the stimulus which was used to monitor an infant's progress towards the habituation criterion.

2.4 Procedures

Three experimenters conducted the study once the infant was judged to be awake and alert. During testing, the infant was held upright against one of the experimenter's shoulders with the infant's head gently stabilized and positioned, so that a picture of the right eye appeared centered and focused in the "eye" monitor. After the infant was comfortably placed with the eye in the field of view, the second experimenter adjusted a set of discriminator controls, one for the pupil and another for the corneal reflection. These controls are used to obtain a proper image of the eye, which was crucial for detection by the circuit boards located in the eye movement monitoring system. The third experimenter, situated in an adjacent room, viewed monitors displaying the infant's face, eye, and the stimulus (superimposed with the x and y crosshairs which indicated point of regard), controlled stimulus presentation, and preserved the infant's looks towards and looks away from the stimulus by pressing keys on the computer keyboard for on-line analysis of the progression towards habituation. The experimenters frequently communicated with each other over walkie-talkies regarding the infant's state, the placement of the infant, and the discriminator settings of the eye. Once the infant's eye was correctly discriminated, the experiment began.

The experiment consisted of four phases: Pretest, habituation, test, and posttest. During the pretest and posttest the same pattern was shown for 10 seconds. This stimulus served as a control to insure we were observing habituation and not for instance effector fatigue or adaptation (Bornstein & Benasich, 1986). The infant-controlled procedure was used and consisted of discrete trials that were based on infant looking behavior (Horowitz, Paden, Bhana, & Self, 1972).

Before each stimulus presentation, the infant's attention was directed centrally by a flashing circle displayed on the stimulus monitor. Once the infant was centrally oriented, the habituation stimulus was presented by the third experimenter and remained displayed until the infant was judged to have looked away for 1.5 s. The computer ended a trial by re-presenting the attention-getting stimulus. This constituted a "trial." The baseline score was subsequently calculated as the mean duration of the infant's first two trials. All subsequent trials were compared to this baseline and a percentage of baseline was calculated for each trial. Presentation of the habituation stimulus continued until the infant reached a habituation criterion of two consecutive trials which were equal to or less than 50% of the baseline score. Therefore, all infants received a minimum of four presentations of the habituation stimulus. Immediately following habituation, the infant was tested with 10-second presentations of the habituation stimulus and two novel stimuli in a randomized repeated design. Some infants did not complete all four phases of the study because they became too fussy, sleepy, inattentive, or cried excessively[5]. In

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[5] Seven subjects completed the habituation phase but due to fussiness did not receive the test stimuli. Twenty-five subjects completed both the habituation phase and some of the test stimuli. Of these 15 completed all 6 trials, 1 completed 5 trials, 1 completed 4 trials, 4 completed 3 trials, 3 completed 2 trials and one completed one trial. However, In order for

(continued...)

order to for an infant's data to be included in the study, the infant had to have minimally completed the habituation phase of the experiment.

2.5 Primary Methods of Analysis

2.5.1 Analysis of the global attention and test data. The infant-controlled habituation procedure requires establishing several quantitative parameters: Fixation onset, fixation offset, and a habituation criterion. Using these parameters the global measures of attention were calculated. These included: ***duration of baseline***--the mean looking time during the first two trials; ***accumulated looking time through criterion***--the total amount of time infants looked at the stimulus through the time in which they reached criterion; ***trials to criterion***--the number of discrete trials infants required in order to reach the habituation criterion; ***duration of peak trial***--the duration of looking during the trial in which infants looked the longest; ***ordinal position of the peak trial***--the ordinal position of the trial of the longest look; ***percent decrement***-the percentage looking declined from baseline (or 100% looking) in reaching the criterion; ***slope***--the linear regression of infants' habituation function; ***novelty preference*** --following habituation, one or more novel stimuli are presented and the novelty preference is the amount of looking at the novel stimulus relative to looking at the familiar (habituation) stimulus. It is typically presented as a percent score; and finally ***average fixation***--the accumulated looking time through criterion divided by the number of trials to criterion. Individual differences between babies were investigated by categorizing

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(...continued)
a subject's test data to be included in the subsequent analyses they had to have made at least one fixation to a novel stimulus and one fixation to the habituation (vertically symmetrical) stimulus.

them as "short" and "long" lookers (Colombo, Horowitz, & Mitchell, 1991). A median split of infants' average fixation duration was used to dichotomize infants.

2.5.2 Analysis of the scanning data. The raw data collected during each session was subsequently parsed into episodes of fixations and movements. An interactive computer program, written in the C programming language, displayed the horizontal and vertical eye position versus time on a computer monitor. An observer viewed the data in 5-second segments, dragged a mouse to select a pertinent portion of the record, and then tagged the portion as being either a fixation, saccade, drift, or noise. An example of a parsed eye position record from our laboratory is shown in Figure 4. ***Fixations*** are defined as the relatively stationary flat segments; ***saccades*** are the relatively rapid changes in the eye's position; and ***drifts*** are the low-velocity, non-accelerating eye movements. A segment was categorized as ***noise*** if a blink occurred or if a proper image of the eye could not be maintained. All data was scored by one person to maintain consistent standards. However, informal checks on inter-rater reliability in this study (two raters were seated next to one another at two computers and visually compared a subject's data record that each had parsed) and in previous studies conducted in our laboratory, have demonstrated very high agreement in identifying and classifying eye movement episodes.

2.6 Calibration Procedures

The calibration of eye position data involves procedures which convert relative changes in measures of eye position to eye position with respect to the stimulus. This involves firstly, relating the x and y coordinates of the particular stimulus in the same coordinate system used to measure the eye position data and

Figure 4

An example of the parsing of an eye movement record. An observer isolates and defines the record into its constituent eye movement categories. The upper portion of the trace represents the horizontal component of the eye movement position in time and the lower portion represents the vertical component. The vertical lines indicate the parsed boundaries between successive eye movements.
(From: Harris, Hainline, Abramov, Lemerise, & Camenzuli, 1988.)

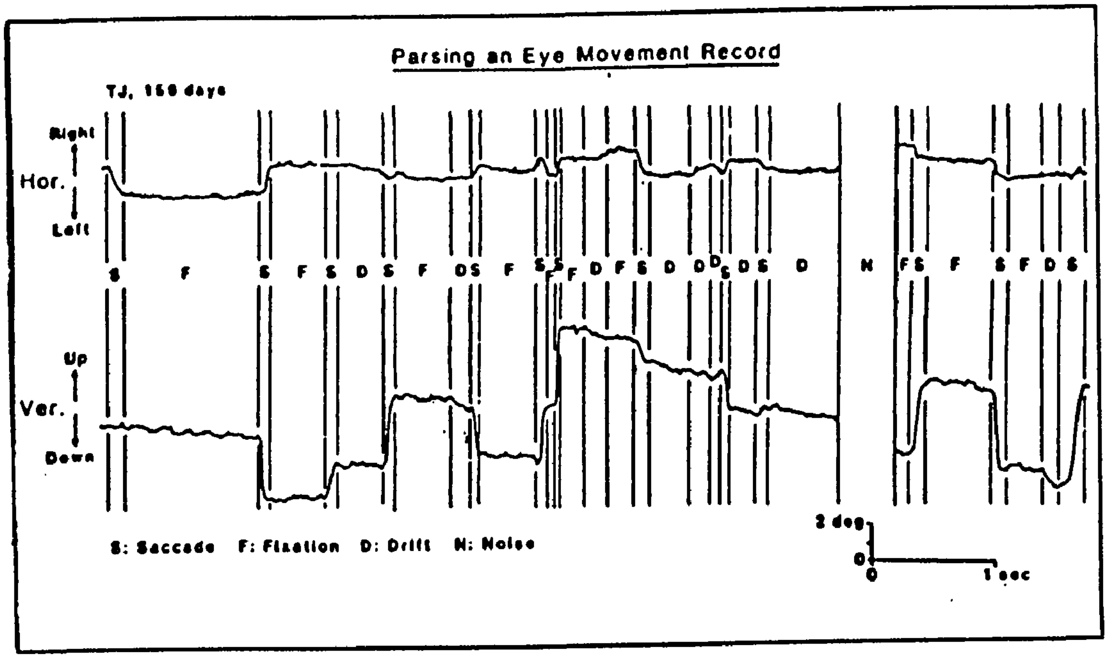
Parsing an Eye Movement Record
TJ, 150 days
Right
Hor.
Left
S F S F S D S F DS F S S F F D F S D D D S D S D N FS F S F D S
Up
Ver.
Down
S: Saccade F: Fixation D: Drift N: Noise
2 deg
0
0
1 sec

Figure 4

secondly, correcting error sources inherent to both the corneal reflection system used to measure eye position, and to individual differences in the subjects being measured. An infant's scanning pattern consists of a series of fixation points located in x and y space and plotted on some arbitrary scale; to determine just what the infant was looking at, representations of the stimulus figures must be overlaid on the scanning pattern after scaling the eye position data to stimulus size.

Hainline and Lemerise (1985) discussed two classes of errors that require calibration: ***dynamic error***, which refers to the velocity of eye movements and is instrument-dependent and ***spatial error***, which refers to the accuracy of estimating where in space the eyes are directed and is dependent on both instrumentation and on individual differences in the optics and physiology between subjects. Dynamic error involves the characteristics of the recording instrument that limits the eye position sampling rate. Extant studies which investigated infant eye movements used systems only capable of recording at low-sampling rates that is, between 1 and 4 Hz (e.g., Leahy 1976; Salapatek, 1967,1969,1975; Salapatek, Haith, Maurer, & Kessen, 1972; Salapatek & Kessen, 1966). The implication of recording at this low sampling rate is that measured eye position cannot be considered a continuous variable and therefore fixation locations cannot be accurately specified. More recent studies have used higher sampling rates on the order of 60 Hz (as in this study), thereby making it possible to isolate fixations and saccadic episodes with greater accuracy (Aslin, 1981; Hainline, 1981; Hainline & Lemerise, 1985; Shea & Aslin, 1990).

Spatial error involves correcting the error in estimating the eye's point of regard in space. Briefly, the basic principle of a corneal reflection system requires locating the first Purkinje image, or corneal reflection of a fixed light source(s), which does not move with change in eye position, relative to a fixed landmark of the eye (usually the center of the pupil) that changes with eye movement. By measuring this relative movement, it is possible to recover the actual position of the eye. It has been determined that the relationship between measured and true eye position is a good first order approximation and can be expressed by the equation $\mathbf{T} = a\mathbf{M} + b$; where **T** represents true eye position and **M**, represents the measured eye position (Hainline, 1981; Hainline & Lemerise, 1985; Harris, Hainline, & Abramov, 1981). One variable ***a***, is a multiplicative gain factor and refers to the amount the eye is reported to have moved as measured by the system, when the eye actually moved a given amount. A gain of 2 means that measured change in eye position is half of the true change, whereas a gain of .5 means that the measured movement is twice the actual one. In our system, this variable is determined by two factors: (I) the distance between the center of curvature of the corneal pole and the distance from the corneal pole to the plane of the entrance pupil; (ii) the setting of the gain potentiometer on the instrument. The other variable ***b***, is an offset factor that is influenced by the angle between the pupillary and the visual axes as well as instrument settings.

Calibration equations for individual subjects are calculated by linearly regressing the observed mean fixation position with the known target location. Following the calculation of the regression functions for the vertical and horizontal components of the eye, the individual calibration equations are then applied to the experimental raw eye position data. This off-line procedure is generally used with noninstructed subjects. For complete calibration data, both the gain and the offset factors need to be calculated for every subject, with separate linear functions for both the vertical and horizontal components of the eye[6]. (For a complete description of a method for calibrating an eye position monitoring system for use with infants see Harris, Hainline, & Abramov, 1981.)

While it would be optimal to obtain calibration data for each subject tested, this is not usually possible when working with infants because of their limited attention spans. Researchers have generally resorted to applying an average calibration that was derived from adult calibration data to the infant experimental data (e.g., Haith, 1980; Leahy, 1976; Salapatek, 1969; 1975). The critical question then is, how appropriate is it to apply this adult average to infant data? It has been determined that there is little developmental change in the average gain factor (e.g.; Abramov, & Harris, 1984; Bronson, 1982;1983; Riddell, Hainline, & Abramov, 1994), therefore, applying an average adult gain factor to infant experimental data is a valid alternative. This however is not true of the offset factor. Corneal reflection systems, such as the one used in this laboratory, uses the pupillary axis to calculate eye position. In normal adult subjects, the line of sight is determined by the fovea, which is located 5° temporally to the location of where the pupillary axis intersects the retina. While there can be individual differences in the location of the fovea relative to the pupillary axis, even in adults, this situation becomes more complicated as it pertains to infants due to foveal immaturities in their retinas'

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[6] It is important to note that calibration can also be accomplished <u>on-line</u> by instructing a subject to fixate on a series of spatially separated points and then adjusting the gain setting of the recording hardware for each individual subject that is, adjusting the amount of crosshair movement to correspond to actual target location. Once this is accomplished the experimental data can then be collected. This technique however, is not useful with infants.

(Abramov, Gordon, Hendrickson, Hainline, Dobson, & LaBossiere, 1982; Riddell, et al., 1994; Slater & Findlay, 1972; 1975; Youdelis & Hendrickson, 1986). Therefore, applying an average adult offset is not advisable (Hainline & Lemerise, 1985).

2.6.1 Adult calibration methods. A calibration procedure was conducted with 10 adult subjects. The calibration stimuli consisted of a 5 x 5 grid of small circles, subtending 14.6° x 11.4° visual angle and the same pretest/posttest stimulus that was used with infants, subtending 1° x 1° visual angle. Subjects sat with their heads stabilized in a chinrest. The pupil and corneal reflection delimiters were adjusted so that they eye was satisfactorily discriminated. Subjects were asked to fixate the center circle (the straight-on position). At this point the horizontal and vertical position controls on the front panel of the eye view monitor were adjusted so that the crosshairs intersected in the middle of the screen on this image. The subject was then requested to fixate on the upper left-hand circle and to progressively move one point over on cue. When the first line was completed, subjects were told to fixate on the next line down. This procedure continued until all the fixation points were viewed and eye position was recorded at each point. The subjects were also shown the pretest/posttest stimulus and asked to fixate on that point. This confirmed that the eye position was centered. Again the experimenter adjusted the x and y position knobs so that the crosshairs intersected the point. "Known" eye position was determined using an "artificial eye," which is a ball-bearing mounted onto a black flat-painted surface. With the use of the scene monitor, which displayed the 5 x 5 grid, the experimenter adjusted the x and y position knobs on the eye movement recording system so that the crosshairs intersected with each of the 25 points and then noted the x and y positions.

The adult calibration and the "artificial eye" eye movement records were subject to the same scoring procedures as used on the infant scanning data (see section 2.5.2 Analysis of the scanning data). Mean eye position was then calculated for each tagged fixation. Observed mean fixation position was then linearly regressed with the known target position. Regressions were performed separately for the horizontal and vertical components of the eye and stimulus positions. An average gain, which pertains to the slope term and an average offset, which pertains to the intercept term was then determined for each subject.

2.6.2 Infant calibration methods. Given the attentional demands placed on an infant participating in an infant-controlled habituation study, it was not possible to obtain a complete set of calibration data. Therefore, individual calibration equations could not be determined for each subject. As a workable compromise, an offset factor was determined for each infant where available[7], using the pretest/posttest stimulus (which was a single point centrally located on the stimulus panel) and an average adult gain factor was applied to the infant experimental data. The individual infant offset was determined by using the mean x and y positions from the pretest and/or the posttest stimulus. By also determining the x and y coordinates of this stimulus for the adult subjects, we were able in effect, to work backwards to determine the offset for the infants. The mean x and y positions for the adults were substituted into the linear regression equations determined from

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[7] For seven infants an average infant offset factor was used either because data from the pre/posttest stimuli presentations were either missing or insufficient.

their data. Infant offset (intercept) was then calculated by multiplying the measured infant eye position by the adult gain (slope) and then subtracting this number from the adult offset (intercept). Figures 5a through 5b present the eye position data overlaid onto the habituation stimulus before either correction factor was applied (Figure 5a), with the offset correction factor applied (Figure 5b), and with both the offset and the gain correction factors applied to the data (figure 5c).

2.7 Secondary Methods of Analysis

2.7.1 Analysis for specifying the eye's point of regard in space relative to the stimulus. This analysis was performed on the parsed data records and involved the estimation of the eye's position in relation to the absolute spatial coordinate system of the stimulus. This was accomplished with a computer program which calculated an infant's true x and y position for each fixation by multiplying the measured eye position by the average adult gain and subtracting the infants offset from that score. In order to overlay the infant's x and y fixation position on the stimulus patterns, it was necessary to align the stimuli in the same coordinate system as infants' fixation positions. The procedure was similar to the one previously used with adult calibration data. Again, "known" eye position was determined using the artificial eye and the 5 x 5 grid of circles. The coordinates of these 25 points within the graphics program (Dr.Halo III™) were also known. By regressing the points determined within the graphics program by the known target location, we were subsequently able to map a point from the coordinate system of the Dr. Halo III™ program into the coordinate system of the eye tracker. Again, regressions were performed separately for the horizontal and vertical components.

Figure 5a

Uncalibrated eye position data overlaid onto the habituation stimulus.

Figure 5b

Eye position data overlaid onto the habituation stimulus with the offset correction factor applied.

Figure 5c

Eye position data overlaid onto the habituation stimulus with both the offset and gain correction factors applied.

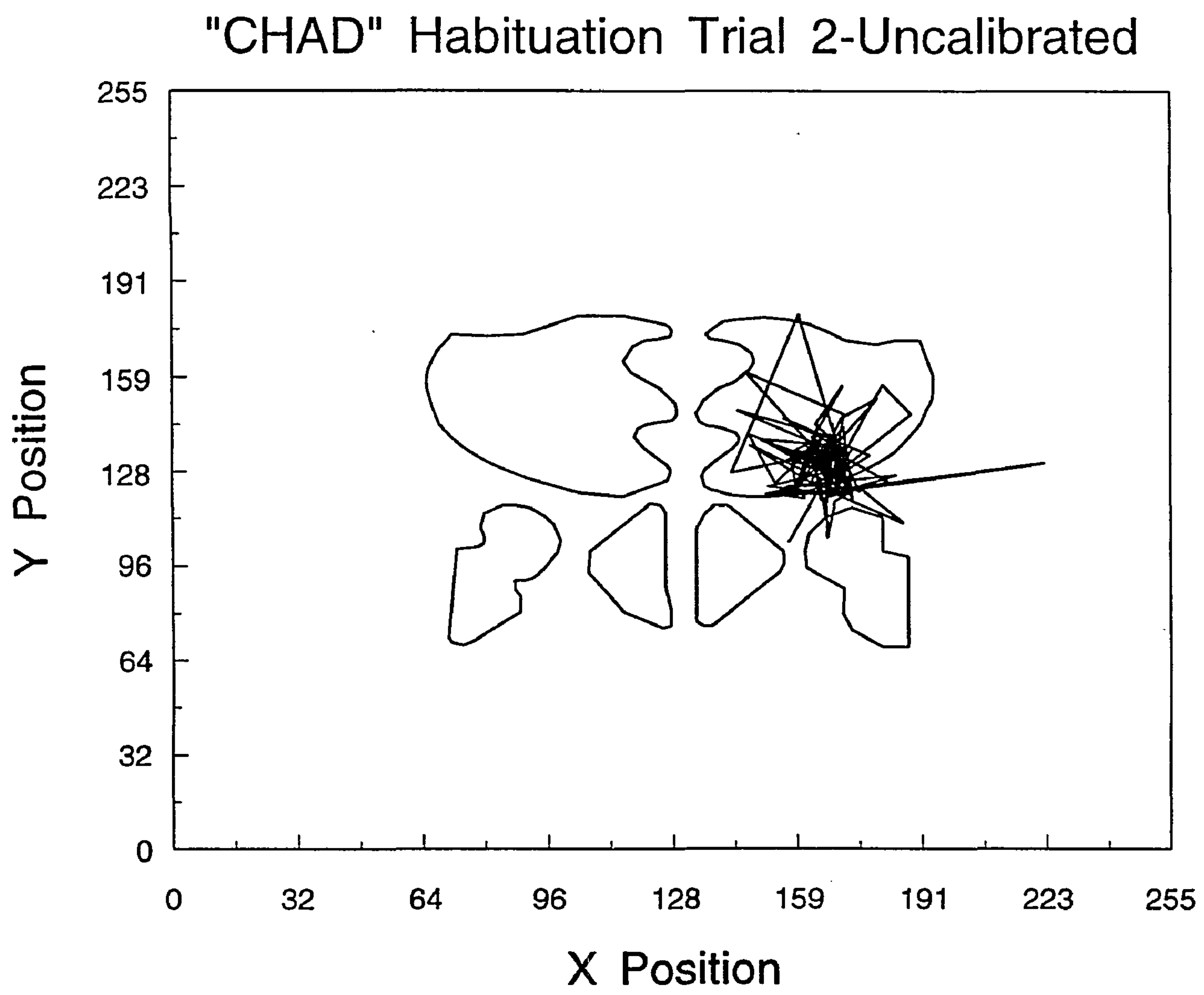

"CHAD" Habituation Trial 2-Uncalibrated
Y Position
255
223
191
159
128
96
64
32
0
0
32
64
96
128
159
191
223
255
X Position

Figure 5a

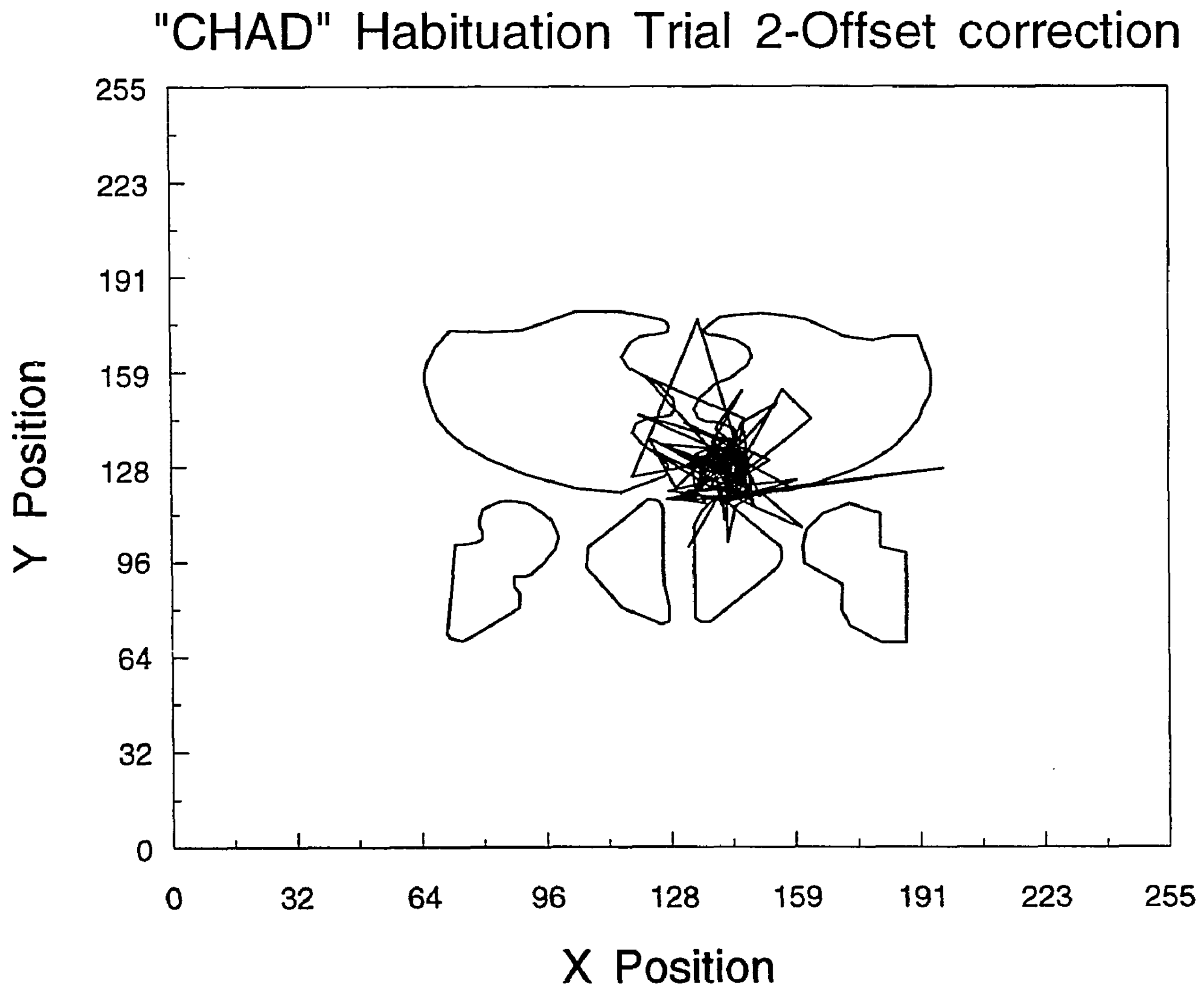

"CHAD" Habituation Trial 2-Offset correction
Y Position
255
223
191
159
128
96
64
32
0
0
32
64
96
128
159
191
223
255
X Position

Figure 5b

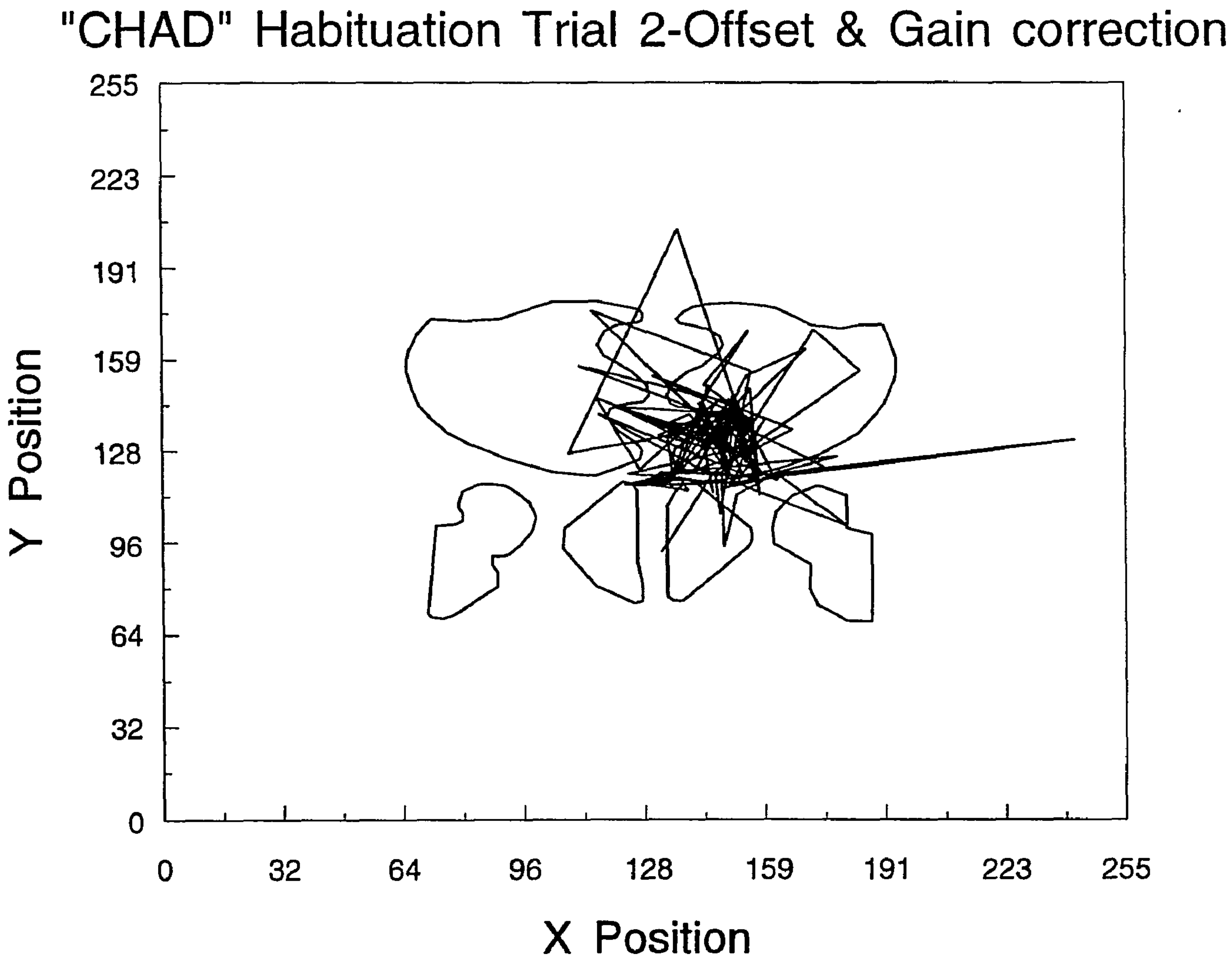

"CHAD" Habituation Trial 2-Offset & Gain correction
Y Position
255
223
191
159
128
96
64
32
0
0
32
64
96
128
159
191
223
255
X Position

Figure 5c

Once the equations were determined, points were then sampled along the outer edge of each of the six shapes that made up each of the three stimuli used in the study (vertically symmetrical stimulus, horizontally symmetrical stimulus, and asymmetrical stimulus), and the x and y coordinates were noted. These coordinates were then substituted into the previously determined regression equations which converted the point created in Dr. Halo III™ into the eye tracker coordinate system. The x and y coordinates for each of these stimuli were then read into a technical plotting program (PSI-PLOT™) along with a subject's scanning data. For each trial, an infants calibrated scanning data was overlaid onto the stimulus pattern (as presented in Figure 5c). This allowed a qualitative assessment of an infant's scanning patterns and the changes that occurred over the course of habituation. Quantitative analyses were also performed.

Stimuli were divided into eight zones; four on-stimulus and four off-stimulus zones. The four on-stimulus zones divided the stimulus into four quadrants and were selected to isolate the salient elements of the stimulus, while maintaining zones of relatively equal area. In addition, the four off-stimulus zones were subsequently collapsed into one "general" off-stimulus zone for subsequent analyses. Figures 6a-c illustrate where these zones fell on the stimuli. It is customary in scanning studies to divide the stimulus into many more zones of equal area for both the on-stimulus and off-stimulus regions than was done in this study. However, because the prime objective here was to examine information processing strategies, we felt it was more intuitive and would facilitate analyses if the stimulus features were isolated as we have done here. A computer program was generated which categorized the mean eye position of each fixation into one of the predefined zones. Frequency and duration of fixations were calculated for each zone for each habituation trial and for each presentation of the test stimuli. Therefore, where, how often, and how long an infant looked at a given zone were the primary data.

Figure 6a

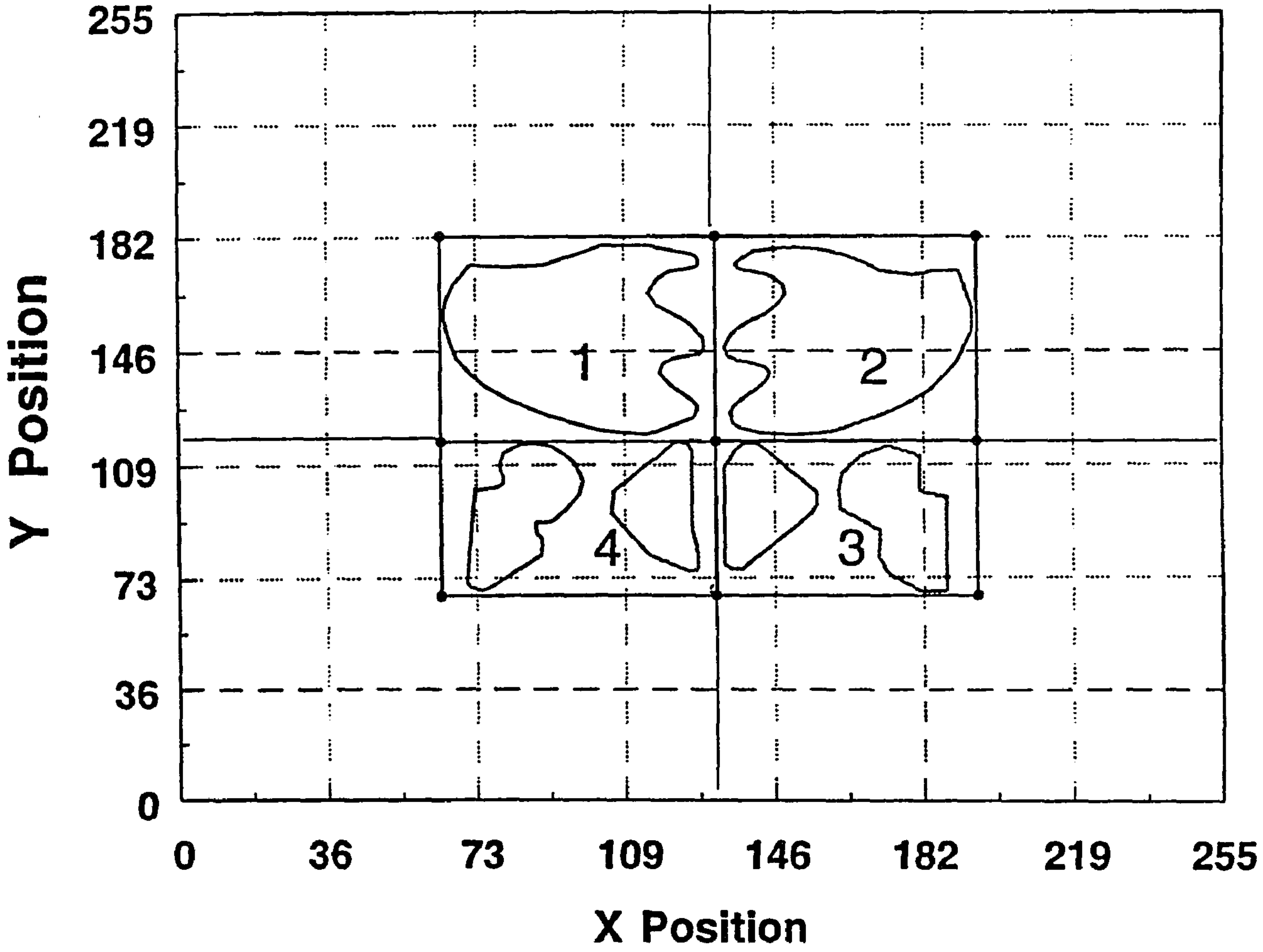
Computer representation of the habituation stimulus (vertical symmetry), illustrating the locations of the on-stimulus and off-stimulus reference zones.

Figure 6b

Computer representation of the horizontal test stimulus (horizontal symmetry), illustrating the locations of the on-stimulus and off-stimulus reference zones.

Figure 6c

Computer representation of the asymmetrical test stimulus illustrating the locations of the on-stimulus and off-stimulus reference zones.



255
219
182
146
109
73
36
0
Y Position
0
36
73
109
146
182
219
255
X Position
1
2
3
4

Figure 6a

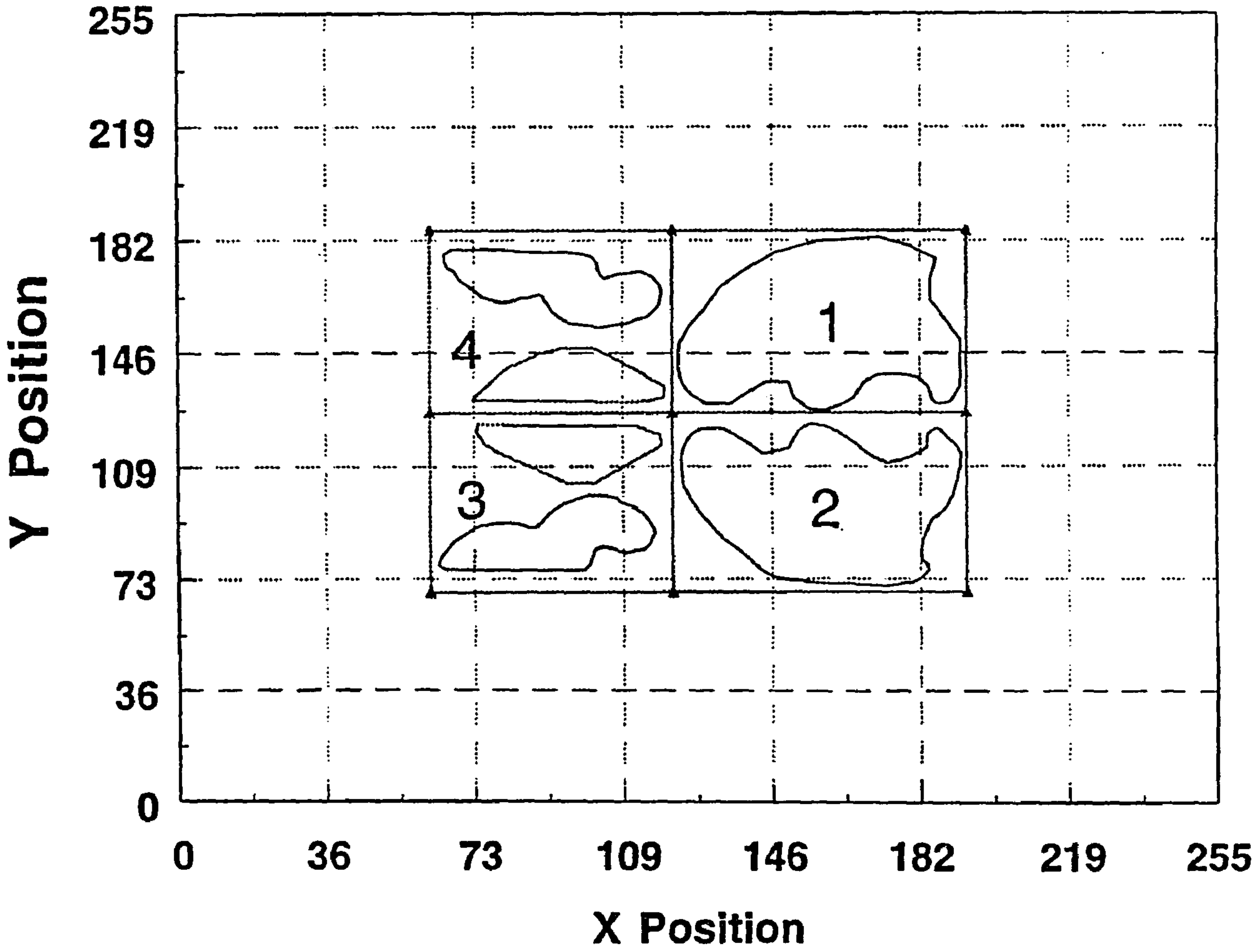

255
219
182
146
109
73
36
0
0
36
73
109
146
182
219
255
Y Position
X Position
1
2
3
4

Figure 6b

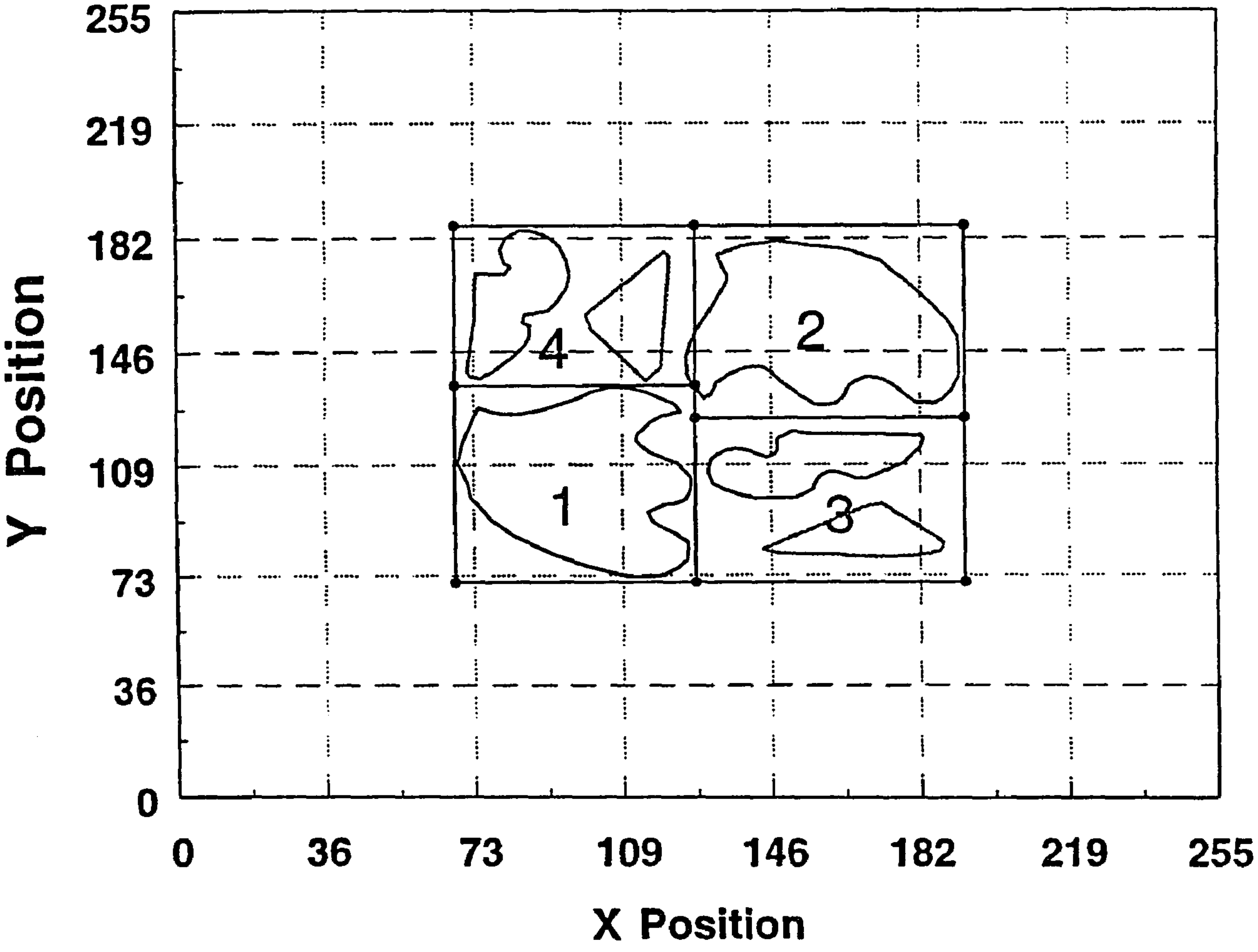

255
219
182
146
109
73
36
0
Y Position
0
36
73
109
146
182
219
255
X Position
4
2
1
3

Figure 6c

[3]

RESULTS

This study focused on the changes in the duration and the number of fixations over the course of habituation and during the presentation of novel stimuli. Therefore how long, how often, and where an infant looked on the stimuli were the primary data. While the infant-controlled procedure is reportedly better at tapping into individual differences in infant information processing abilities and is the most commonly used paradigm, some of the features of its data make simple analysis impossible. The duration of each trial varies both within the course of an infant's session and between infants. In addition, the total number of trials to criterion varies between infants. Typically, researchers have circumvented this problem either by creating summary variables by averaging across habituation trials, or by dividing each infant's data into segments of equal duration once criterion has been reached.[1] The traditional summary variables previously examined in other studies were calculated. In addition, in order to look at the changes in scanning during the habituation process, four habituation trials were selected for study; the first two trials (the baseline trials, when presumably the most information processing is occurring) and the last two trials (the criterion trials, when presumably information processing is complete)[2]. Data from the habituation and the test phases will be presented separately.

3.1 Habituation

3.1.1 Habituation Profile

Each variable was calculated two ways, from the traditional global data[3] and from the scanning data. For example, the amount of time infants' accumulated in looking at the stimulus from the beginning of habituation through criterion was calculated by summing time looking at the stimulus during each trial using the global data (known as accumulated looking time in extant studies) and by summing the duration of fixations at the stimulus during each trial using the scanning data (accumulated fixation time). Table 1 presents a profile of the habituation process on the frequently cited traditional variables as calculated by both the global and scanning data. On average, infants habituated to the stimulus

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[1] For example, Bronson (1991) created a variable of average dwell time which was calculated by determining the mean dwell time for each habituation trial and then averaging over all of the trials. Coles and Sigman (1985) divided each infant's habituation protocol into 5 segments of equal duration.

[2] In fact, in this study 44% of the infants habituated in four trials. However, this does mean that 56% of the subjects had some trials not included in these analyses.

[3] Since we present information on habituation using two similar measures, to prevent confusion, the global measures of attention will be referred to as "looks" and the scanning measures will be referred to as "fixations."

Table 1

Habituation Profile

Variable	M	SD	Range
Duration of baseline			
global	50.4 s[a]	31.9 s	11.4 - 151.9 s
scanning	25.8	20.0	1.9 - 90.8
Trials to criterion	5.8	2.1	4.0 - 11.0
Average fixation duration			
global	32.5 s	18.1 s	7.7 - 86.7 s
scanning	17.9	11.7	1.3 - 50.9
Accumulated looking time			
global	178.3 s	102.3 s	44.8 - 461.6 s
scanning	89.0	59.3	7.9 - 229.6
Duration of peak fixation			
global	81.0 s	31.9 s	14.9 - 251.2 s
scanning	47.4	35.0	3.4 - 154.8
Trial of peak fixation			
global	1.8	1.2	1.0 - 6.0
scanning	2.0	1.3	1.0 - 6.0
Percent decrement			
global	79.6	8.9	59.6 - 99.5
scanning	71.1	43.1	-99.4 - 98.6

Note. While both global and scanning variables are reported, the temporal course of habituation was determined as in the traditional habituation paradigm by the global data. The scanning data were calculated post-hoc.

[a] s = seconds.

in 178.3 s ± 102.2 s and required 5.8 ± 2.1 exposures to the stimulus. Based on the scanning data, infants habituated in 89.0 s ± 11.7 s, less than half the time indicated by the global data. In general, the duration variables derived from the scanning data were statistically less than the same variables derived from the global data.

Table 2 further demonstrates this finding by presenting the duration of fixations on the four analyzed trials derived from both the global and scanning data. For example, the duration of looking during Trial 1 was 62.3 s as derived from the global data and 33.1 s as derived from the analyses of the scanning data, t (30) = 6.84, p < 001. There were exceptions to this observation for example, the determination of percent decrement (also referred to as habituation amount) which is the percentage that looking declined from baseline in reaching the criterion. This variable is derived by subtracting the average duration of the last two habituation trials (the two criterion trials) from the average duration of the first two habituation trials (the baseline score), dividing the resultant by the baseline score, and then multiplying by 100 to convert the number to a percentage score. The percent decrement score derived from the global data was 79.6% whereas the same score derived from the scanning data was 74.6%, t (30) = 1.69, n.s. This was not surprising since percent decrement is a proportion score and not based on absolute amounts.

Table 2

Mean Duration Scores of the Global and Scanning Habituation Measures

Variable	Global Measure	Scanning Measure	t
Duration of looking/fixations, Trial 1	62.3	33.1	8.76**
Duration of looking/fixations, Trial 2	38.5	18.4	5.99**
Duration of looking/fixations, Penultimate trial	9.8	4.6	6.33**
Duration of looking/fixations, Last trial	8.6	3.5	5.08**

*$p < .01$. **$p < .001$

3.1.2 Global Measures versus Scanning Measures: Are they Tapping into the Same Behavior?

Before discussing what additional information can be revealed by analyzing scanning data, it was first important to discern whether scanning measures and global attention measures tap into the same behavior. This section presents the correlations between the scanning variables and the measures of global attention operationally defining habituation. There were significant correlations between the global measures of habituation and the related scanning measures (See Table 3). For instance, the correlation between average fixation time (scanning measure) and average looking time (global measure) was 0.87, $\underline{p} <.001$. Therefore, we concluded that the scanning measures tap into the same behaviors as the global measures. Further, from the pattern of results presented in section 3.1.1 we concluded that the habituation measures, as determined by the scanning data are more precise. They are more precise because the data are filtered in a number of ways which is not possible with the global measures. As previously stated in the methods section, when viewing a visual stimulus there are a number of possible "choices" the eye can make. By analyzing scanning data we are able to distinguish between these different categories of eye movements; non-fixational eye movements are not included in the determination of the duration or number of fixations. Additionally, at times during a session infants become inattentive, with their pupils dilating sufficiently to prohibit the proper discrimination of the eye, the corneal reflex, and therefore the determination of the eye's position. These markings in the data are usually designated as noise in the scanning record and

Table 3

Correlations Between the Global and Scanning Habituation Measures

Variable	r
Accumulated looking time through criterion	.87****
Average fixation	.91****
Duration of looking/fixations, Trial 1	.81****
Duration of looking/fixations, Trial 2	.98****
Duration of looking/fixations Penultimate trial	.77****
Duration of looking/fixations Last trial	.82****
Number of looks/fixations, Trial 1	.40**
Number of looks/fixations, Trial 2	.82****
Number of looks/fixations, Penultimate trial	.47***
Number of looks/fixations, Last trial	.15
Duration of peak look/fixation	.88****
Percent decrement	.21
Slope of the habituation function	.82****

*$p < .05$. **$p < .025$. ***$p < .01$. ****$p < .001$.

are also excluded from the analyses. Thirdly, by knowing the coordinates of the stimulus and the coordinates of the mean eye position of each fixation, we can accurately determine where an infant looked on a stimulus. The implication of this specificity is that we are also able to partition the total fixation time during a trial into the duration of time infants were scanning the stimulus features as opposed to viewing the exterior zones (background) of the stimulus. This level of precision was impossible to attain with the analysis of the global measures of habituation, where only the looks at and looks away from the stimulus screen can be observed. Therefore, it is reasonable to conclude that the global measures inaccurately inflate the duration measures because of the inability to make these distinctions in the data.

Since the use of scanning data in the examination of information processing is relatively novel and the correlations between the scanning data and the global data provided evidence that the scanning measures are indeed tapping into the same behavior as the global measures, further presentation will focus on the additional insights that we can only obtain from the scanning measures. Unless otherwise noted, the analyses of the scanning data is based only on <u>on-stimulus</u> looking, thus excluding looking at the exterior zones.

Six primary types of information were extracted from each subjects' scanning record per trial: (1) duration and number of fixations; (2) thoroughness of scanning that is, the number of zones infants' scanned; (3) extensiveness of scanning that is, the number of times infants changed fixation position; (4) duration and number of off-stimulus fixations; (5) duration and the number of fixations to specific regions on the stimulus; and finally, (6) the evenness of scanning that is, the standard deviation of the duration and number of fixations to the four on-stimulus zones.

Preliminary analyses revealed no sex differences. Also, analyses on a subset of variables (duration of baseline, trials to criterion, average fixation duration, and percent decrement) showed no developmental trend over the limited age range tested in this study. Therefore, all subsequent analyses were collapsed across both sex and age.

3.1.3 Changes in Scanning During the Course of Habituation: Average Infant Performance

Focused contrasts were conducted for this phase of the data analysis.[4] Three contrasts were computed; the first contrast asked whether the average of the first two trials (the baseline trials) was greater than the average of the last two trials (the criterion trials) on the measures of interest; the second contrast asked whether Trial 1 was greater than Trial 2; and finally, the third contrast asked whether the Penultimate trial was greater than the Last trial.

3.1.3.1 Duration and number of fixations. Results indicated that the duration and the number of fixations during the baseline trials were significantly greater than the duration and number of fixations during the criterion trials, $F(1, 93) = 57.42$, $p < .001$ and $F(1, 93) = 12.13$, $p < .01$, respectively (see Figures 7a and 7b). Both figures also clearly demonstrate that the duration and number of

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[4] Contrasts are significance tests of focused questions with which specific predictions can be evaluated by comparing these predictions to the obtained data. This is opposed to omnibus tests which are tests of significance which address unfocused questions. A priori contrasts allow for both greater statistical power and greater clarity in the interpretation of results (see Rosenthal & Rosnow, 1985, for more details on contrast analysis).

Figure 7a

The mean duration of fixations on the stimulus during each of the four analyzed habituation trials.

Figure 7b

The mean number of fixations made on the stimulus during each of the four analyzed habituation trials.

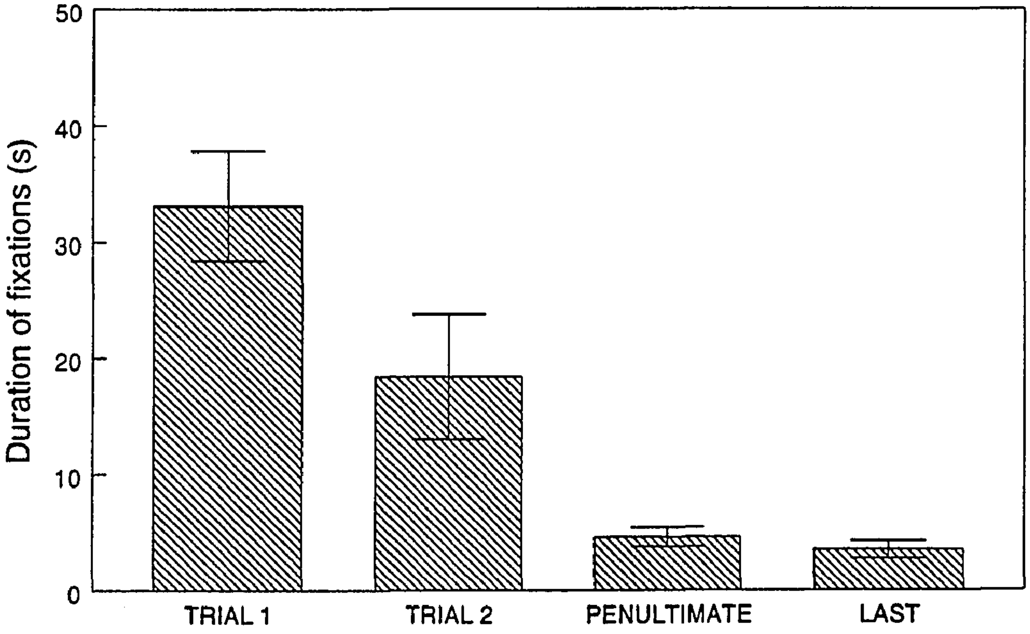

50
40
30
20
10
0
Duration of fixations (s)
TRIAL 1
TRIAL 2
PENULTIMATE
LAST

Figure 7a

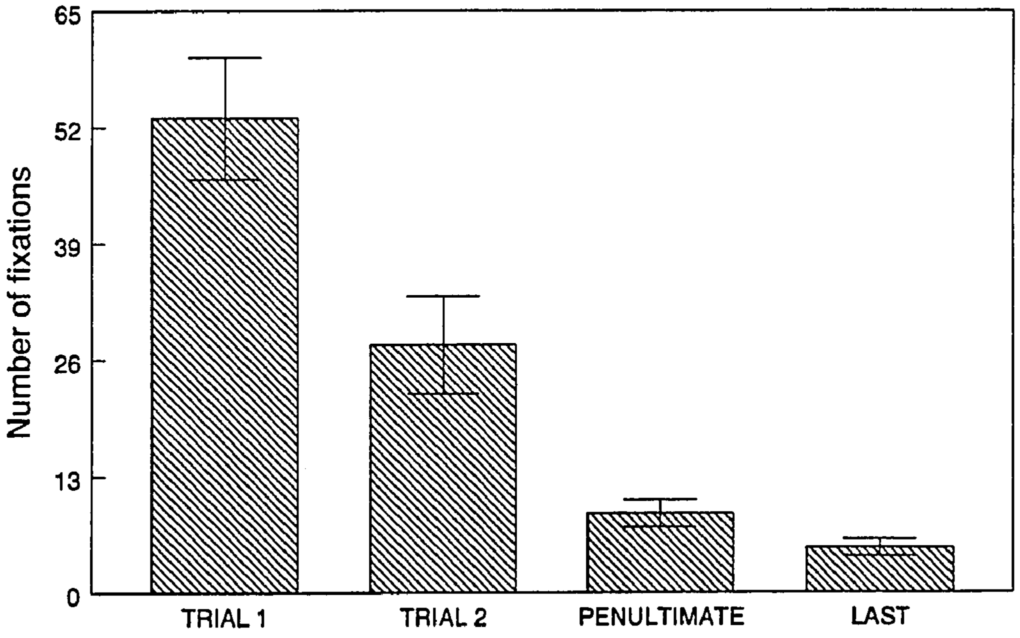

65
52
39
26
13
0
Number of fixations
TRIAL 1
TRIAL 2
PENULTIMATE
LAST

Figure 7b

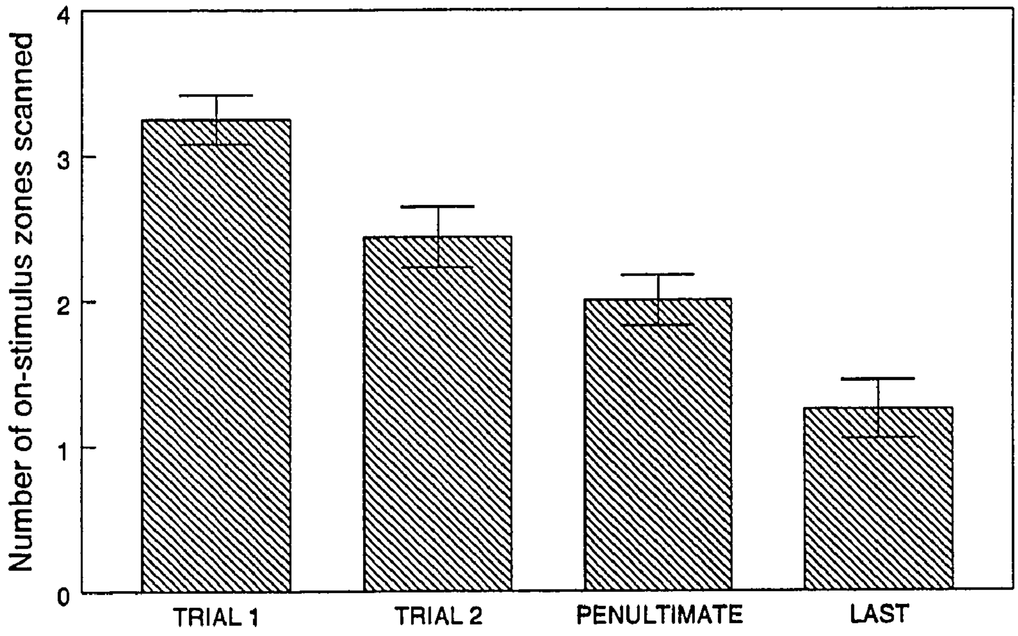
fixations on Trial 1 were significantly greater than Trial 2, $\underline{F}(1, 93) = 13.55$, $\underline{p} < .001$ and $\underline{F}(1, 93) = 16.49$, $\underline{p} < .001$. However, there were no differences between either duration or the number of fixations between the Penultimate and the Last habituation trial, $\underline{F}$'s $(1, 93) < 1$. These results were not unexpected, especially on the duration variable, given the fact that the definition of habituation is the gradual decline in looking. However, the analysis of scanning data is a more "molecular-type" of analysis and it is encouraging to find previous and well-established findings of the global measures replicated with this more precise metric.

3.1.3.2 Thoroughness of scanning. A measure of the thoroughness of scanning is the number of on-stimulus zones infants' scanned during a trial. Figure 8 presents data for each of the four analyzed trials. It is obvious from this figure that infants' scanned significantly more zones during the baseline trials then during the criterion trials, $\underline{F}(1, 93) = 45.70$, $\underline{p} < .001$. Infants also scanned significantly more zones on Trial 1 than on Trial 2, $\underline{F}(1, 93) = 8.65$, $\underline{p} < .01$, and on the Penultimate trial than on the Last trial, $\underline{F}(1, 93) = 45.70$, $\underline{p} < .001$.

3.1.3.3 Extensiveness of scanning. A measure of scanning extensiveness is the number of times infants changed their fixation position within a trial. There are several possible patterns which infants could have exhibited; either they changed the zone of their fixation frequently (or infrequently) during a trial and continued this pattern in the course towards habituation, or they could have employed both scanning strategies in the course towards habituation by first scanning extensively (or less extensively) during the early trials and less extensively (more extensively) during the later trials. For this analysis both the on-

Figure 8

The mean number of on-stimulus zones scanned during each of the four analyzed habituation trials (thoroughness of scanning).



Number of on-stimulus zones scanned
0
1
2
3
4
TRIAL 1
TRIAL 2
PENULTIMATE
LAST

Figure 8

stimulus and off-stimulus zones were included because during a trial infants periodically, although briefly (that is, under 1.5 s), fixated on an off-stimulus zone and then returned to an on-stimulus zone. It therefore seemed intuitive to retain the temporal patterning of scanning by including these brief off-stimulus fixations for this analysis. Figure 9 shows that in fact, infants more frequently changed fixation position on the stimulus during the baseline trials than during the criterion trials, $\underline{F}$ (1, 93) = 68.63, $\underline{p} < .001$. In addition, infants changed fixation position more frequently during Trial 1 than during Trial 2, $\underline{F}$ (1, 93) = 31.84, $\underline{p} < .001$, but showed no significant difference in scanning between the Penultimate and the Last habituation trials, $\underline{F}$ (1, 93) < 1.

3.1.3.4 Off-Stimulus scanning. Another variable of interest was the number of off-stimulus fixations. In habituation studies which measured the global dimensions of information processing, it was not possible to compute this variable. It was therefore, possible for researchers to incorrectly score an infant as looking at the stimulus when in fact they were looking at the background around the stimulus. Similar to the division of the on-stimulus regions into four zones, the off-stimulus regions were also divided into four zones (upper-left, upper-right, lower-left, and lower-right). While we were able to specify accurately which of the off-stimulus zones was scanned on a particular fixation, this level of detail was unessential for this analysis. These four off-stimulus zones were therefore collapsed to form one off-stimulus zone. Figure 10a presents the duration of off-stimulus fixations during each of the four analyzed habituation trials. Infants scanned the off-stimulus zones longer during the baseline trials than during the

Figure 9

The mean number of times infants changed fixation position on the stimulus during each of the four analyzed habituation trials (extensiveness of scanning).

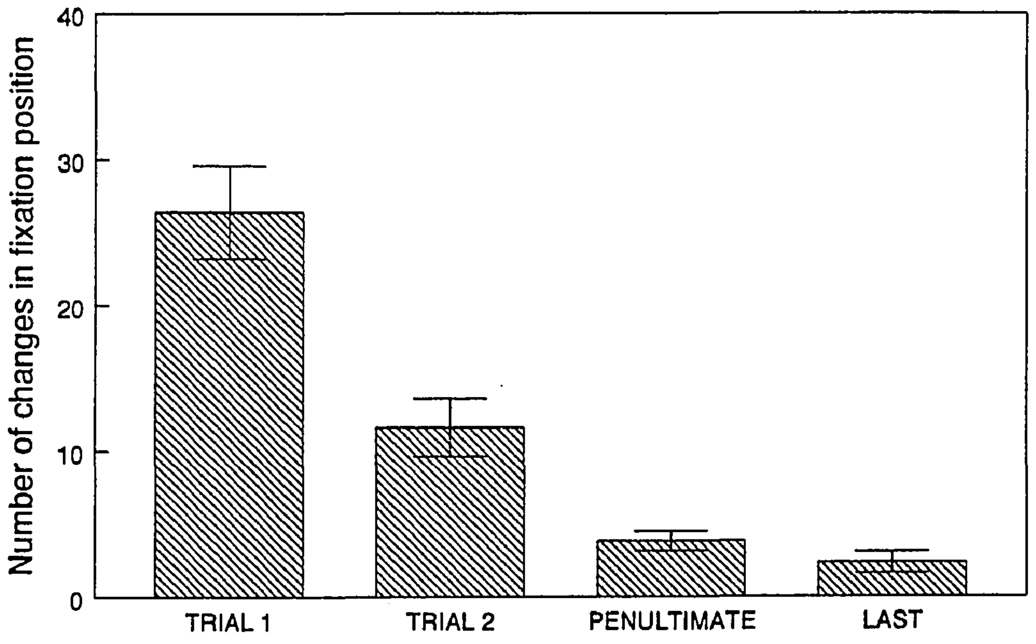

Number of changes in fixation position
0
10
20
30
40
TRIAL 1
TRIAL 2
PENULTIMATE
LAST

Figure 9

Figure 10a

The mean duration of off-stimulus fixations during each of the four analyzed habituation trials.

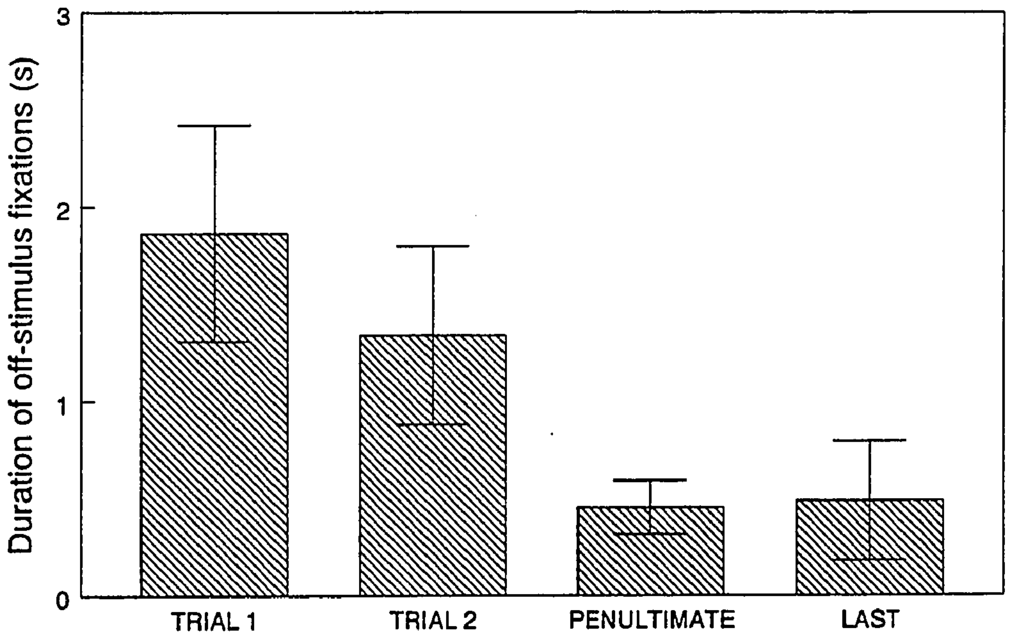

Duration of off-stimulus fixations (s)
3
2
1
0
TRIAL 1
TRIAL 2
PENULTIMATE
LAST

Figure 10a

criterion trials, $\underline{F}(1, 93) = 9.81$, $\underline{p} < .01$. However, there were no significant differences between the duration of off-stimulus fixations either between Trial 1 and Trial 2, $\underline{F}(1, 93) = 1.05$, or between the Penultimate trial and Last trial, $\underline{F}(1, 93) < 1$.

Infants also made more fixations to the off-stimulus zones during the baseline trials than during the criterion trials, $\underline{F}(1, 93) = 17.43$, $\underline{p} < .001$ (see Figure 10b). They also made more fixations to the off-stimulus zones during Trial 1 than during Trial 2, $\underline{F}(1, 93) = 68.63$, $\underline{p} < .001$ and showed no differences in the number of fixations made to the off-stimulus zones between the Penultimate and the Last trial, $\underline{F}(1, 93) < 1$. These two findings at first seemed somewhat incongruent with what we understand about the habituation process. It was reasonable to expect that as habituation progressed, infants would spend greater amounts of time and/or make progressively more, rather than less fixations on the off-stimulus zones. Supposedly, this would be in an attempt to search for new and novel stimulation. However, an alternative explanation, and one which has been verified by these results, is that infants scan very actively during the initial trials of habituation, scanning both on-stimulus and off-stimulus zones in an attempt to process the stimulus and then scan less actively during the final trials of habituation. Certainly, the data show that infants more actively and extensively scan the on-stimulus zones during the initial trials of habituation compared to the later trials and in general, they spend little time and make few fixations overall, on the off-stimulus zones.

3.1.3.5 Duration and number of fixations to specific regions on the stimulus. The strength of the paradigm of analyzing eye movements during the habituation

Figure 10b

The mean number of off-stimulus fixations made during each of the four analyzed habituation trials.

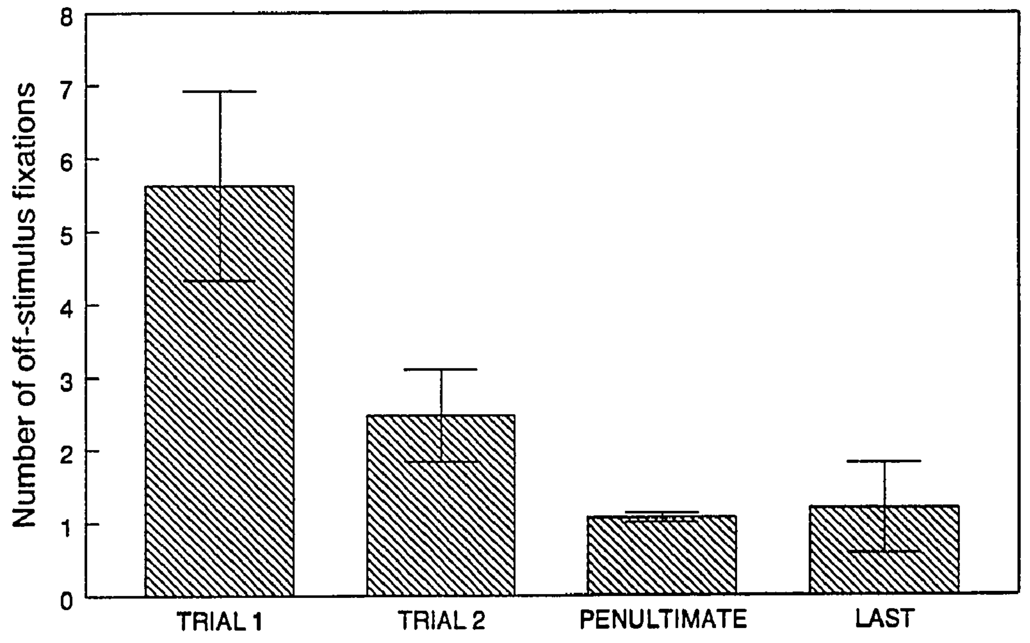

Number of off-stimulus fixations
0
1
2
3
4
5
6
7
8
TRIAL 1
TRIAL 2
PENULTIMATE
LAST

Figure 10b

process lies in the ability to specify where and for how long infants' scanned specific regions on the stimulus. By calculating the duration and number of fixations to the different regions of the stimulus, we could examine a number of important questions. For example, do infants scan the same part(s) of a stimulus on each trial of habituation, or do infants shift their fixations progressively over the stimulus on successive trials such that there is evidence of systematic selection of different stimulus features across trials. This question speaks directly to the serial processing hypothesis. We calculated where and for how long infants scanned each of the four on-stimulus zones, on each of the four analyzed habituation trials and then summed the duration and number of fixations to specific regions on the stimulus; upper and lower regions (quadrants 1 + 2 versus quadrants 3 + 4) and left and right regions (quadrants 1 + 4 versus quadrants 2 + 3) [see Figure 5a for the specification of the on-stimulus zones]. The data on the duration and the number of fixations were analyzed with a 4 x 2 x 2 (trials x up and down scanning x left and right scanning) ANOVA with all three variables serving as repeated measures.

While neither the three-way nor any of the two-way interactions were significant, there were however significant main effects for up and down duration of fixations, $\underline{F}$ (1, 31) = 4.43, $\underline{p} < .043$ and for trial $\underline{F}$ (1.6, 49.9)[5] = 10.13, $\underline{p} < .001$. During each of the four analyzed habituation trials, infants scanned the upper

---

[5] An assumption of the repeated measures ANOVA is that the covariance matrix has a constant variance on the diagonal and constant covariances off the diagonal. If this sphericity assumption is violated, there are several adjustments that can be made to both the numerator and the denominator degrees of freedom. The correction made to these data was the Huynh-Feldt epsilon. The numerator and the denominator $\underline{df}$'s were multiplied by epsilon, and the significance of the $\underline{F}$ ratio was evaluated with the new degrees of freedom (see Keppel, 1982, p. 472).

regions (zones 1 and 2) of the stimulus longer than the lower regions (zones 3 and 4) (see Figure 11a) and infants scanned the stimulus longest during Trial 1 than during any of the other trials (see section 3.1.3.1 and Figure 7a). Therefore, quite surprisingly, infants repeatedly inspected very specific parts of the stimulus rather than progressively shifting their fixation duration to different regions of the stimulus.

Table 4 presents the results of the ANOVA for the number of fixations made to each region. Similar to the duration data, the three-way interaction of trial × number of up and down fixations × number of right and left fixations was not significant. However, the two-way interaction of trial × frequency of up and down fixations was significant, $\underline{F}$ (1.6, 49.9) = 7.37, $\underline{p} < .01$.

Analyses of the simple effects[6] indicated that infants made significantly more fixations to the upper regions of the stimulus than to the lower regions during Trial 1, quasi $\underline{F}$[7] (1, 78.1) = 35.03, $\underline{p} < .001$, and Trial 2, quasi $\underline{F}$ (1, 78.1) = 4.32, $\underline{p} < .05$. However, there were no differences in the number of fixations made to any of the

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[6] The presence of an interaction simply indicates that the main effects do not sufficiently explain the data. One way to analyze significant interactions is by dividing the factorial design into subhypotheses, each focusing on part of the design. In this case the frequency of up and down fixations were analyzed separately for each level of the trial factor. This technique of analyzing a significant interaction is called **an analysis of simple effects** (Keppel, 1982). An examination of the simple effects is performed to statistically determine the nature of the pattern of results.

[7] In order to test for the simple effects of the frequency of up and down fixations × trial, we needed a mean square error term common to both the frequency of up-down fixations and the interaction of the frequency of up and down fixations by trial. However, there was no error term common to both of these factors. The quasi $\underline{F}$ ratio provides this common mean square error term from the pooled sums of the squares and by making an adjustment to the nominal degrees of freedom to compensate for the error mean square terms not being the same size.

Figure 11a

The mean duration of fixations made to the upper and lower regions of the stimulus. The asterisk indicates that infants scanned the upper regions of the stimulus display more than the lower regions.

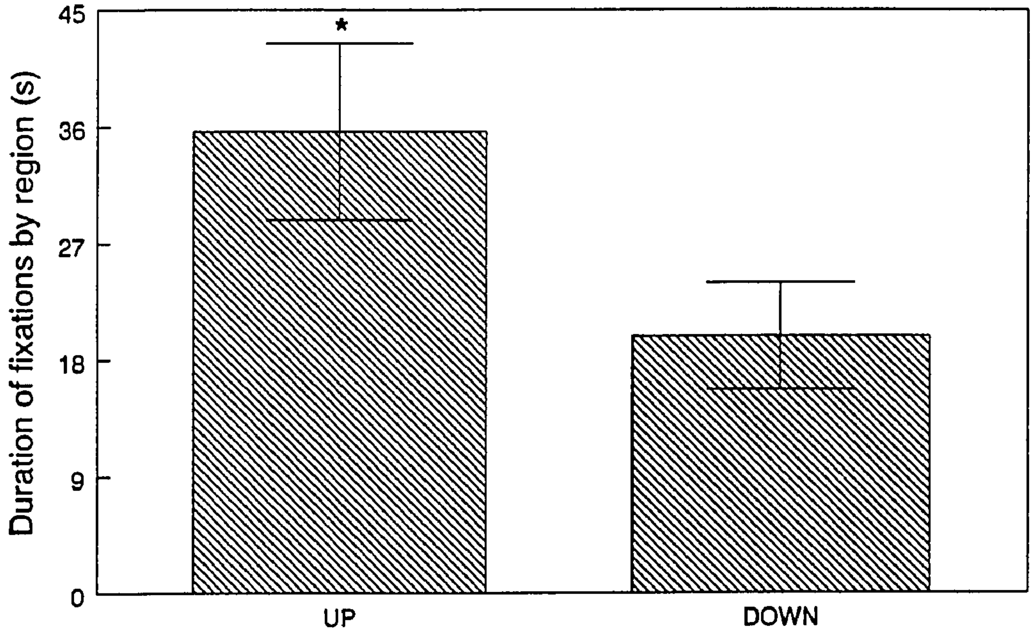

Figure 11a

Table 4

Summary Table: Frequency of Fixations by Zones on the Stimulus by Trial

Source	SS	df	Huynh-Feldt df[a]	MS	F
Left & right	362.81	1		362.81	1.15
Error term	(9739.50)	(31)		(314.18)	
Up &down	2182.13	1		2182.13	15.48***
Error term	(4371.19)	(31)		(141.01)	
Trial	11855.27	3	1.6	1951.76	25.65***
Error term	(14329.42)	(93)	(51.6)	(154.08)	
Left & right x up & down	85.31	1		85.31	.74
Error term	(3559.75)	(31)		(114.83)	
Trial x left & right	498.16	3	2.2	166.05	1.11
Error term	(13850.78)	(93)	(66.6)	(148.93)	
Trial x up & down	2236.29	3	1.9	745.43	7.37**
Error term	(9412.65)	(93)	(60.0)	(101.21)	
up & down for Trial 1	3894.03	1		3894.03	35.03***
up & down for Trial 2	480.50	1		480.50	4.32
up &down for Penultimate trial	32.00	1		32.00	.29
up &down for Last trial	11.88	1		11.88	.11
Error term[b]		(121)	(78.1)	(111.16)	
Trial x left & right x up & down	210.35	3	1.6	70.12	.83
Error term	(7827.84)	(93)	(50.1)	(84.17)	

[a] An assumption of the repeated measures ANOVA is that the covariance matrix has a constant variance on the diagonal and constant covariances off the diagonal. If this sphericity assumption is violated, there are several adjustments that can be made to both the numerator and denominator degrees of freedom. The correction made to these data was the Huynh-Feldt epsilon. The numerator and the denominator df's were multiplied by epsilon, and the significant of the F ratio was evaluated with the reduced degrees of freedom (see Keppel, 1982, p. 472).

[b] Error term as determined by the quasi F ratio. The quasi F provides a common mean square error term from the pooled sums of the squares and by makes an adjustment to the nominal degrees of freedom to compensate for the error mean square terms not being the same size.

$^{*}p < .05$. $^{**}p < .01$. $p < .001$.

stimulus regions during either the Penultimate or the Last habituation trials (see Figure 11b).

3.1.3.6 Evenness of Scanning. An evenness of scanning score was derived by calculating the standard deviation of the duration of fixations to each of the four stimulus zones. A similar score was computed for the number of fixations made to each of the four analyzed habituation trials. A high score on a given trial indicates that the infant concentrated on a limited number of zones. Following the same reasoning, a low standard deviation score indicates that the infant scanned each of the four zones on the stimulus evenly.

Focused contrasts showed that during the baseline trials, infants had a tendency to spend more time on a few stimulus elements compared to the criterion trials, F (1, 93) = 29.80, $p < .001$ (see Figure 12a). While the differences between Trial 1 and Trial 2 did not reach statistical significance, a trend for infants to spend more time on a limited number of stimulus elements during Trial 1 compared to Trial 2 was indicated, F (1, 93) = 3.17, $p < .10$. The data also showed that there was no difference in the variability of fixation duration between the Penultimate and the Last trial, F (1, 93) < 1.

The data on the number of fixations infants made to the regions on the stimulus showed a similar trend to the duration data. Infants had a tendency to make more fixations on a limited number of stimulus elements during the baseline trials than during the criterion trials of habituation, F (1, 93) = 48.13, $p < .001$ (see Figure 12b). This was especially true during Trial 1 compared to Trial 2, F (1, 93) = 8.17, $p \leq .01$, and there was no difference in the variability of the number of

Figure 11b

The mean number of fixations to the upper and lower regions of the stimulus during each of the four analyzed trials. The asterisk indicates that infants made more fixations to the upper regions of the stimulus than to the lower regions during Trials 1 and 2.

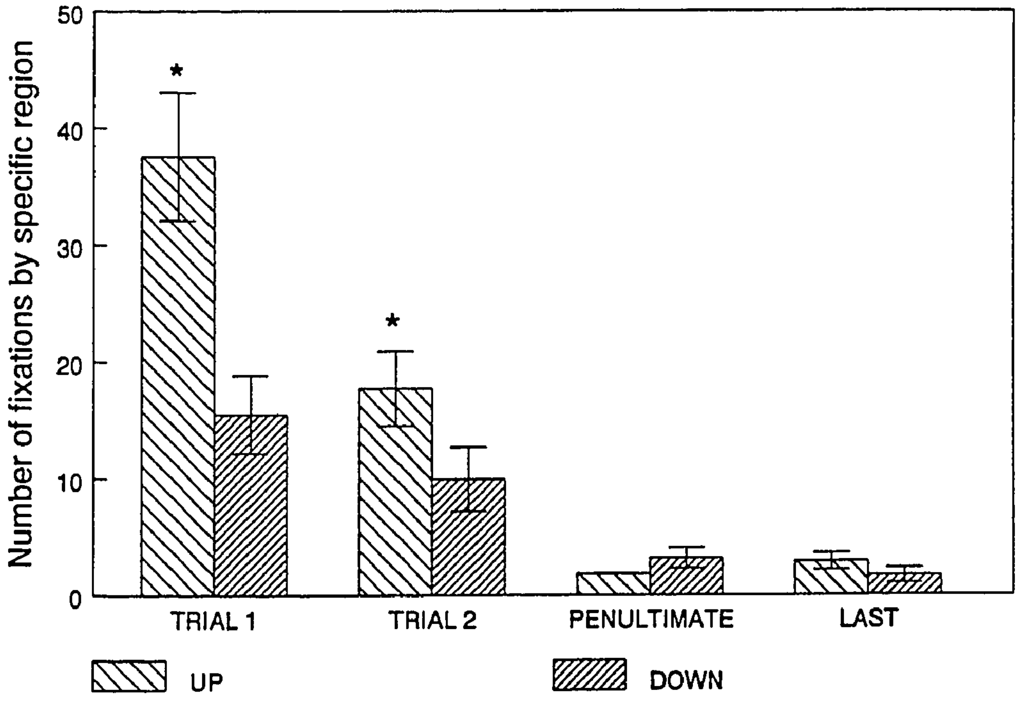
Number of fixations by specific region
50
40
30
20
10
0
*
*
TRIAL 1
TRIAL 2
PENULTIMATE
LAST
UP
DOWN

Figure 11b

Figure 12a

The mean standard deviation score of the duration of fixations made to the four on-stimulus zones during each of the four analyzed habituation trials (evenness of scanning).

Figure 12b

The mean standard deviation score of the number of fixations made to the four stimulus zones during each of the four analyzed habituation trials (evenness of scanning).

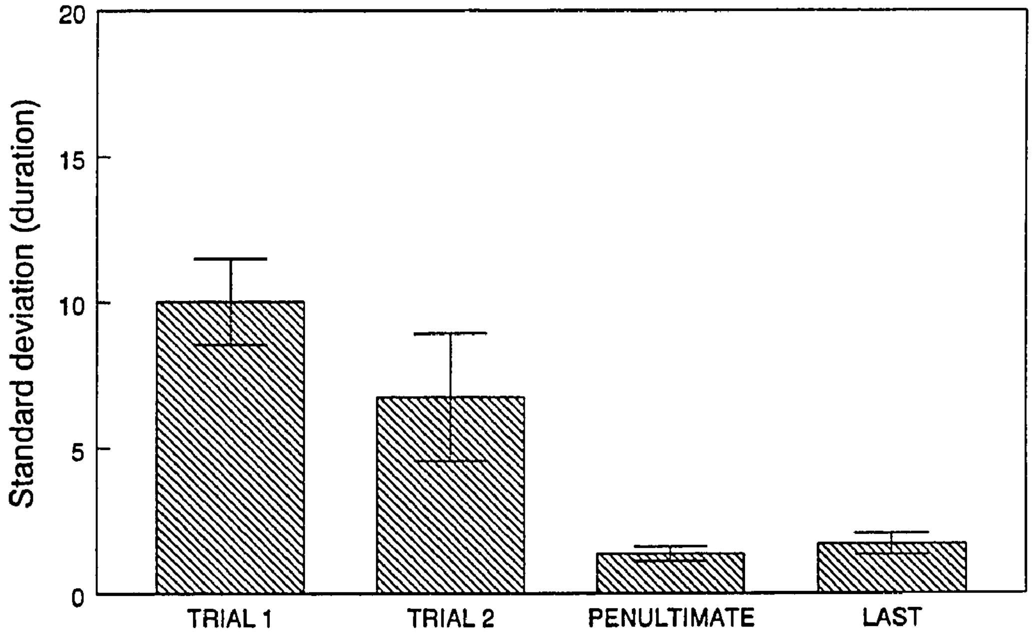
Standard deviation (duration)
0
5
10
15
20
TRIAL 1
TRIAL 2
PENULTIMATE
LAST

Figure 12a

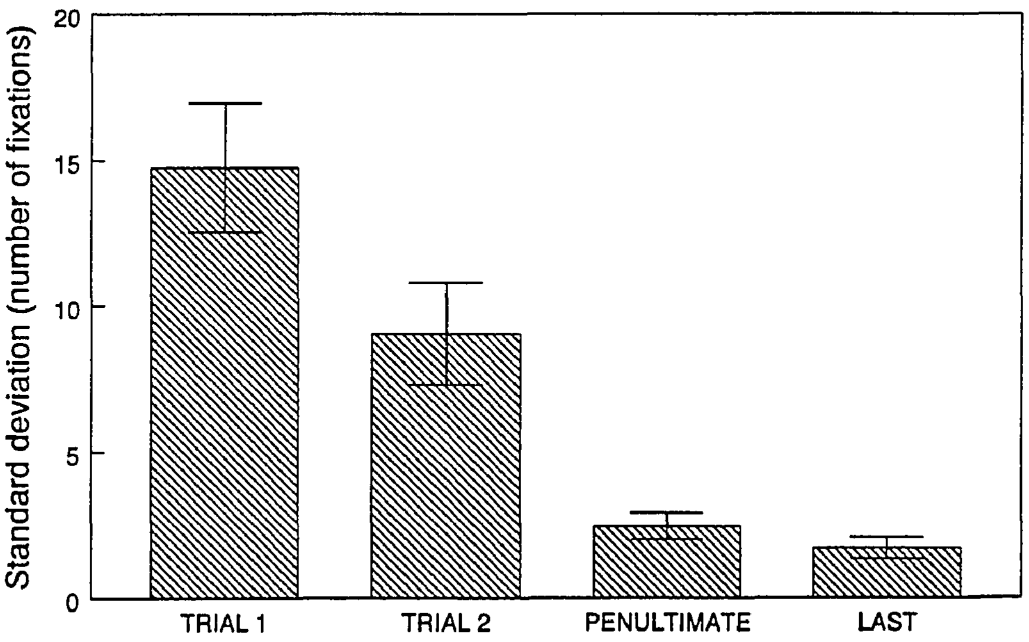
Standard deviation (number of fixations)
20
15
10
5
0
TRIAL 1
TRIAL 2
PENULTIMATE
LAST

Figure 12b

fixations made to each of the four stimulus zones during the Penultimate and Last habituation trials, F (1, 93) < 1.

In summary, analyzing the scanning records during the habituation process is a more refined metric than simply analyzing the global measures of infant attention. We were able to delineate the changes in visual scanning which occurred during the process of habituation. Using this more "molecular-type" of analysis, we found that infants on average, scanned the stimulus longer and made more fixations to the stimulus during the baseline trials than during the criterion trials. In addition, on several of the measures there were statistical differences between the two baseline trials such that, there was more scanning occurring during Trial 1 than during Trial 2. Infants were also observed to scan the stimulus more thoroughly and extensively during the baseline trials. Interestingly, infants also scanned the off-stimulus zones (the background areas of the stimulus) more during the baseline trials than during the criterion trials. We also found exploration to be highly repetitive. This was demonstrated by analyzing the duration and the number of fixations infants made to specific stimulus regions and by also calculating the standard deviation of the duration and numbers of fixations to each of the four stimulus zones. On each of the four analyzed trials, infants scanned the upper regions of the stimulus longer than the lower regions. Infants also made significantly more fixations to the upper regions of the stimulus than the lower regions however, this was only significant for Trial 1. Additionally, there were no differences in the number of fixations either in terms of the time spent or in the number of fixations made during the other analyzed habituation trials. Therefore, *infants did not seem to shift their attention to the different parts of the stimulus display during the course of habituation and we could not confirm the serial processing hypothesis. This finding however, supports the research findings of Coles and Sigman (1987).*

3.1.4 Changes in Scanning During the Course of Habituation: Individual Differences in Infant Performance One way that researchers have described the individual differences between infants is to categorize them as either "short" or "long" lookers based on the average amount of time they looked at/fixated on the stimulus before habituating. In the present study, the average fixation time was calculated by dividing each infants' accumulated duration of fixations by the number of exposures or trials infants required prior to reaching the criterion (Colombo et al., 1991). The median score was calculated (16 s) and infants whose scores fell below the median were categorized as "short" lookers and infants whose scores fell above the median were categorized as "long" lookers. Short lookers had an average fixation duration score of 9.20 s (SD = 1.42 s) and long lookers had an average fixation duration score of 26.64 s (SD = 2.20 s). Since the average amount of time infants examined the stimulus was calculated with both the global data (average looking time) and the scanning data (average fixation duration), it was of interest to see whether the majority of infants would be categorized similarly by each method. A goodness-of-fit chi-square test calculated on the categorical data revealed that infants were indeed categorized similarly on both measures ($\chi^2 = 12.50$, $p < .0004$, $\phi = .63$)[8].

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[8] Thirteen infants who were categorized as short lookers with the global data were also categorized as short lookers with the scanning data; 13 infants were categorized as long lookers using both methods; 3 infants who were categorized as short lookers with the global

(continued...)

A multivariate analysis of variance (Hotelling's $\underline{T}^2$) of eight of the traditional habituation measures, as calculated using the scanning data, indicated that there were significant differences between short and long lookers, $\underline{F}$ (8, 23) = 4.49, $\underline{p} < .002$. Table 5 presents the univariate statistics. Accordingly, long looking infants had larger percent decrement scores; steeper slopes of the linear regression of infants habituation function; accumulated more scanning time in reaching the habituation criterion; had longer average fixation scores; had larger duration of peak fixation scores; and had larger baseline scores. These variables however, present individual differences in the <u>products</u> of performance averaged over all habituation trials. They do not detail the individual differences in the <u>processes</u> of habituation performance. The analysis of differences in scanning styles of short and long lookers on each trial during the progression towards habituation delineates this process. Individual differences in scanning styles exhibited between short and long lookers were analyzed with 2 x 4 (type of looker x each variable's score per trial) mixed-design analysis of variance with the variable's score per trial serving as the repeated measure.[9]

3.1.4.1 <u>Duration and number of fixations.</u> The two-way interaction between duration of fixation and type of looker was significant, $\underline{F}$ (1.6, 47.5) = 4.52, $\underline{p} < .005$. Analyses of the simple effects of duration of fixations for each trial indicated that

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(...continued)
data but categorized as long lookers with the scanning data; and 3 infants who were categorized as long lookers with the global data were categorized as short lookers with the scanning data.

[9] The main effects will not be presented in this section as they were already discussed in section 3.1.3 <u>Changes in Scanning During the Course of Habituation: Average Infant Performance</u>.

Table 5

Univariate Statistics of the Traditional Habituation Measures for Short and Long Lookers as Determined by the Scanning Data

	Short Lookers (n=16)		Long Lookers (n=16)		
	M	SD	M	SD	t
Habituation amount	58.6	18.2	83.5	13.0	1.68
Slope	-4.10	5.2	-12.0	6.8	3.72****
Baseline	12.7	10.9	38.8	18.5	4.88****
Trials to criterion	6.2	2.3	5.3	1.9	1.18
Accumulated fixation duration	56.2	41.4	139.9	59.8	4.60****
Average fixation duration	9.2	5.8	26.6	9.4	6.33****
Duration of the Peak Fixation	23.2	17.2	71.7	31.3	5.43****
Trial of the Peak Fixation	2.1	1.4	1.9	1.3	<1

*p < .05. ** p < .025. ***p < .01. ****p <.001.

long lookers scanned the stimulus for longer periods of time compared to short lookers during Trial 1, quasi F (1, 62.3) = 26.50, p < .001, and Trial 2, quasi F (1, 62.3) = 8.67, p < .01 (see Figure 13a). There were no differences between the two types of lookers on either the Penultimate trial or the Last trial, quasi Fs < 1.

Results were similar for the data on the number of fixations. The two-way interaction between the number of fixations × type of looker was significant, quasi F (1.7, 49.1) = 4.69, p < .004. Analyses of the simple effects for the number of fixations on each trial indicated that long lookers made more fixations on the stimulus than short lookers but, only during Trial 1, quasi F (1, 64.7) = 27.14, p < .01 (see Figure 13b). While the difference in the number of fixations between short and long lookers during Trial 2 was not significant, the data indicated a trend for long lookers to make more fixations to the stimulus during this trial than short lookers, quasi F (1, 64.7) = 2.93, p < .10. Also consistent with the duration data, there were no differences in the number of fixations between short and long lookers during the Penultimate and the Last trials, Fs < 1.

3.1.4.2 Thoroughness of scanning. The two-way interaction of the number of on-stimulus zones scanned per trial × type of looker was not significant, F (3, 90) < 1. Therefore, in these data there were no differences between short and long lookers in terms of the number of on-stimulus zones they each scanned.

3.1.4.3 Extensiveness of scanning. The two-way interaction between the number of changes infants made in fixation position during each trial × type of looker was significant, F (1.8, 52.8) = 6.69, p < .001. The analysis of the simple effects indicated that long lookers made significantly more changes in fixation

Figure 13a

Individual differences in the mean duration of fixations on the stimulus during each of the four analyzed habituation trials. The asterisk indicates that there were significant differences between short and long lookers during Trials 1 and 2.

Figure 13b

Individual differences in the mean number of fixations on the stimulus during each of the four analyzed habituation trials. The asterisk indicates that there were significant differences between short and long lookers during Trial 1.

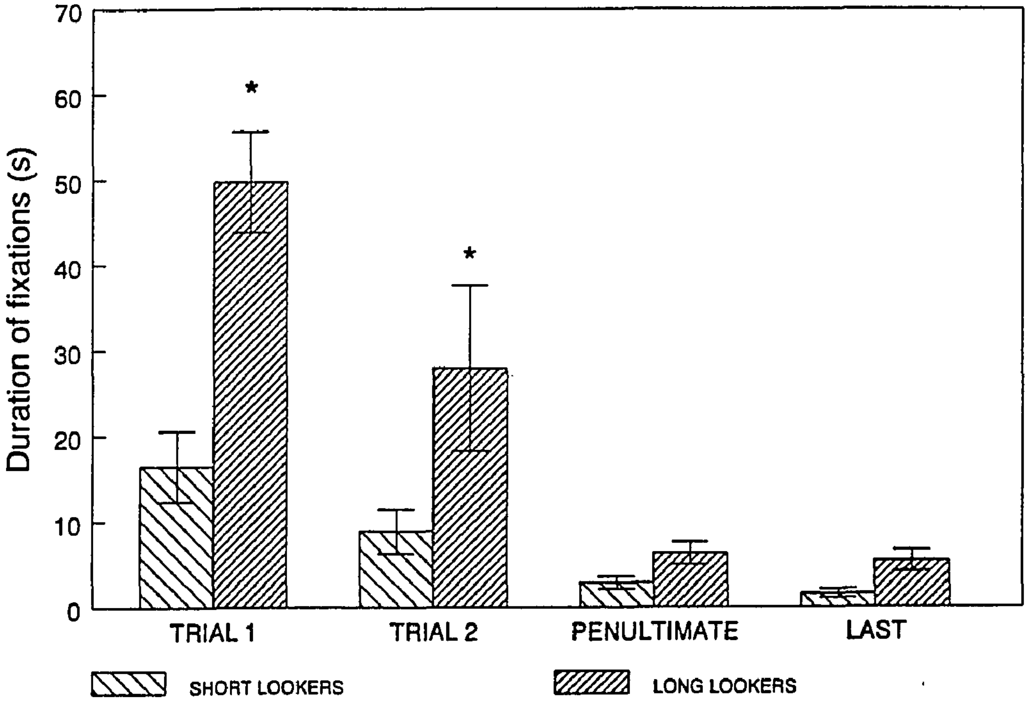
70
60
50
40
30
20
10
0
Duration of fixations (s)
*
*
TRIAL 1
TRIAL 2
PENULTIMATE
LAST
SHORT LOOKERS
LONG LOOKERS

Figure 13a

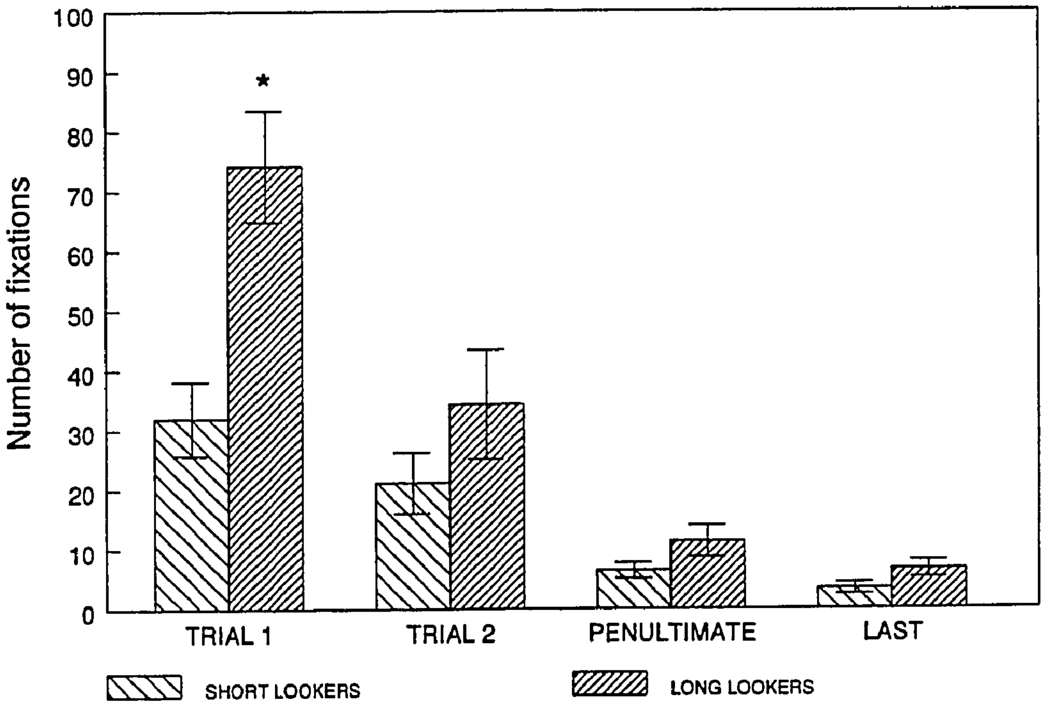
100
90
80
70
60
50
40
30
20
10
0
Number of fixations
*
TRIAL 1
TRIAL 2
PENULTIMATE
LAST
SHORT LOOKERS
LONG LOOKERS

Figure 13b

position during Trial 1 than short lookers that is, long lookers shifted their fixations over the stimulus more frequently than short lookers during this trial, quasi $\underline{F}$ (1,69.8) = 36.37, $\underline{p} < .001$ (see Figure 14). While there was a trend for long lookers to make more changes in fixation position during Trial 2, this did not achieve statistical significance, quasi $\underline{F}$(1, 69.8) = 1.66, $\underline{p} < .25$. The question arises as whether frequently changing the zone of a fixation is a more or a less efficient scanning strategy. Given that there were only five zones to scan (4 on-stimulus and 1 collapsed off-stimulus zone), frequently changing fixation position could reasonably be considered an inefficient scanning style since long lookers are frequently returning to previously scanned zones and probably not gaining additional information about the stimulus properties. This is the most probable explanation, given the results that there are no differences between short and long lookers in terms of the number of on-stimulus zones scanned (see section 3.1.4.3).

3.1.4.4 Off-Stimulus Scanning. Neither the two-way interaction between the duration of off-stimulus fixations on each trial x type of looker, nor the number of off-stimulus fixations during each trial x type of looker were significant, $\underline{F}$ (2.3, 68.9) < 1 and $\underline{F}$ (1.2, 56.4) < 1. Therefore, in this data there were no differences between short and long lookers in terms of the duration or number of off-stimulus fixations exhibited during the four analyzed trials.

3.1.4.5 Duration and number of fixations to specific regions on the stimulus. A 2 x 2 x 2 x 4 (duration of up and down fixations x duration of left and right fixations x type of looker x trial) ANOVA was performed with repeated measures on all four factors. The four-way interaction did not achieve statistical significance,

Figure 14

Individual differences in the mean number of times infants changed fixation position during each of the four analyzed trials. The asterisk indicates that long lookers changed the zone of a fixation more frequently on Trial 1 than did short lookers.

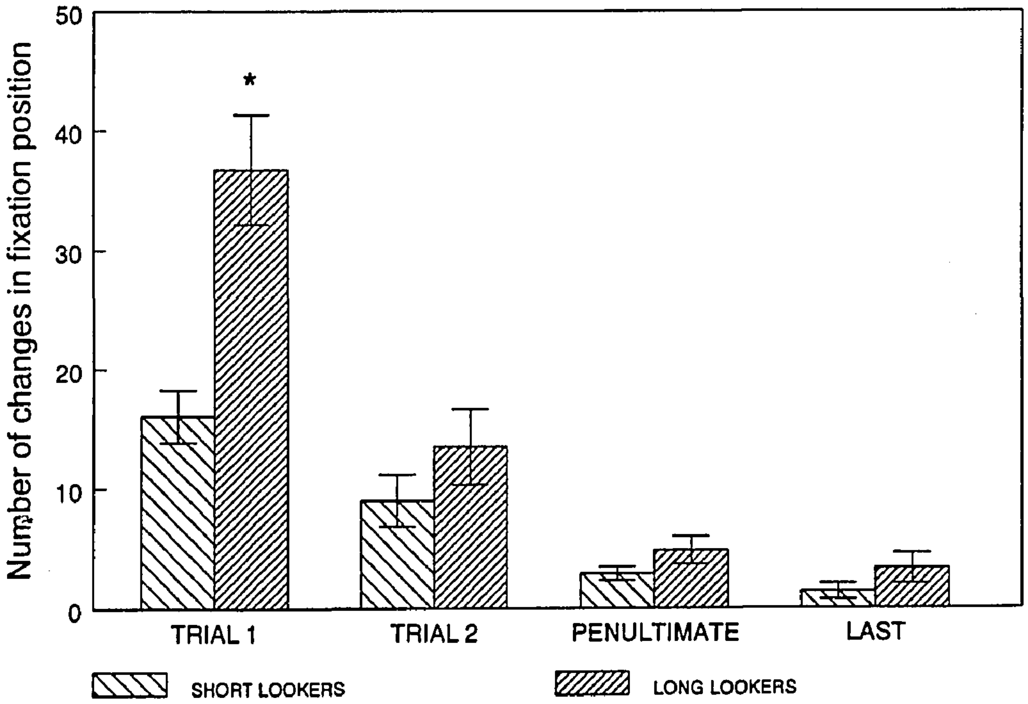
Number of changes in fixation position
0
10
20
30
40
50
*
TRIAL 1
TRIAL 2
PENULTIMATE
LAST
SHORT LOOKERS
LONG LOOKERS

Figure 14

nor were the three-way or the two-way interactions significant. Therefore, in this data there were no differences between short and long lookers in terms of the duration of their fixations to the different regions of the stimulus.

The number of fixations infants made to specific regions on the stimulus presented a different pattern of results. Table 6 presents a summary of the data. The four-way interaction of type of looker x the number of left and right fixations x the number of up and down fixations x trial was significant, $\underline{F}$ (1.9, 57.9) = 11.08, $\underline{p} < .001$. An analysis of the simple effects demonstrated that this interaction only achieved statistical significance on Trial 1, quasi $\underline{F}$ (1, 73.5) = 35.25, $\underline{p} < .001$. Analyses of the simple-simple effects revealed that during Trial 1, the two-way interaction for short lookers for the number of up and down fixations x the number of left and right fixations was not significant quasi $\underline{F}$ (1, 83.3) = 1.48, n.s. but it was significant for long lookers, quasi $\underline{F}$ (1, 83.3) = 31.38, $\underline{p} < .001$. Therefore, there were no differences in the number of fixations short looking infants made to each of the regions on the stimulus during any of the four analyzed habituation trials.

Analyses of the simple-simple-simple effects for long lookers revealed that these infants made more fixations to the upper-left quadrant of the stimulus (zone 1), quasi $\underline{F}$ (1, 164.7) = 50.93, $\underline{p} < .001$, compared to the lower-left quadrant (zone 4). There were also no differences in the number of fixations long looking infants made to the upper-right (zone 2) and lower-right (zone 3) quadrants of the stimulus, quasi $\underline{F}$ (1, 164.7) < 1 (see Figure 15).

3.1.4.6 Evenness of Scanning. Although the two-way interaction between the standard deviation score of the duration of fixations during each trial x type of

Table 6

Summary Table: Frequency of Fixations by Zones on the Stimulus by Trial by Style of Scanning

Source	SS	df	Huynh-Feldt df[a]	MS	F
Looker x left and right x up and down for Trial 1		1		2574.04	35.25***
Looker x left and right x up and down for Trial 2		1		45.13	.62
Looker x left and right x up and down for Penultimate trial		1		5.28	.07
Looker x left and right x up and down for Last trial		1		5.28	.01
Error term		(114.2)	(83.3)	(73.08)	
Trial 1:					
Left and right x up and down for Short lookers		1		108.78	1.48
Error term		(221.7)	(164.7)	(93.34)	
Left and right x up and down for Long Lookers		1		2292.02	31.38***
Up and down for left half of stimulus		1		4753.13	50.93***
Up and down for right half of stimulus		1		1.53	.05
Error term		(221.7)	(164.7)	(93.34)	
Looker x trials x left and right x up and down	2111.38	3	1.9	703.79	11.08***
Error term	(5716.46)	(90)	(57.9)	(63.52)	

[a] An assumption of the repeated measures ANOVA is that the covariance matrix has a constant variance on the diagonal and constant covariances off the diagonal. If this sphericity assumption is violated, there are several adjustments that can be made to both the numerator and denominator degrees of freedom. The correction made to these data was the Huynh-Feldt epsilon. The numerator and the denominator *df*s were multiplied by epsilon, and the significant of the F ratio was evaluated with the reduced degrees of freedom (see Keppel, 1982, p. 472).
[b] Error term as determined by the quasi F ratio. The quasi F provides a common mean square error term from the pooled sums of the squares and by making an adjustment to the nominal degrees of freedom to compensate for the error mean square terms not being the same size.

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

Figure 15

The mean number of fixations for long lookers by area on the stimulus. The asterisk indicates that long lookers made more fixations to the upper-left quadrant of the stimulus display.

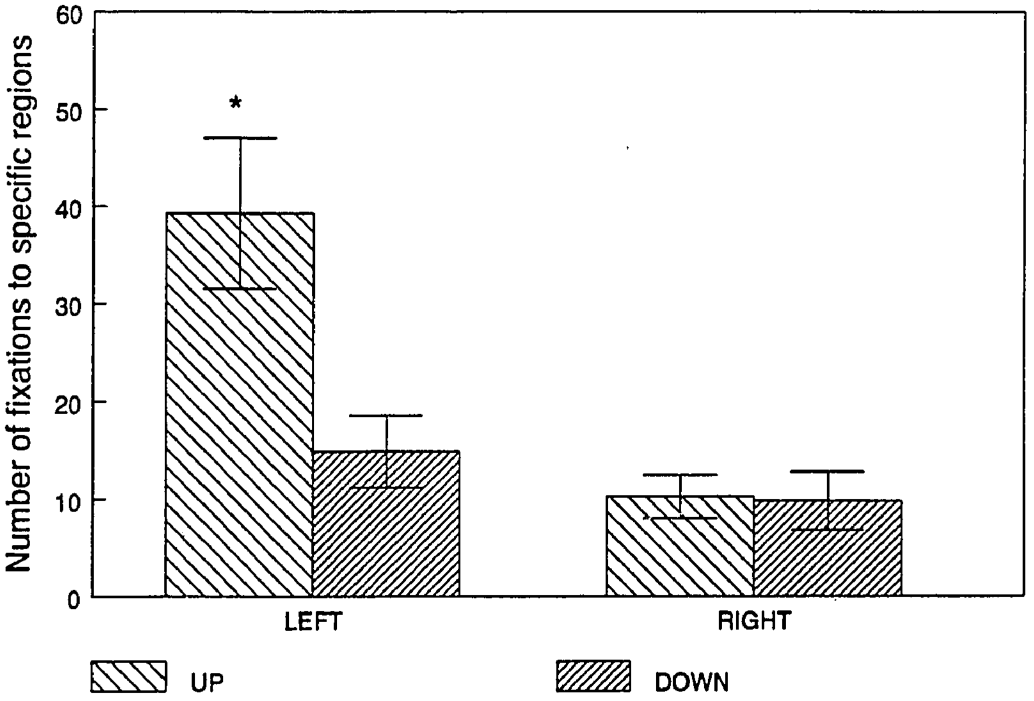
Number of fixations to specific regions
0
10
20
30
40
50
60
*
LEFT
RIGHT
UP
DOWN

Figure 15

looker was not statistically significant, the data indicated a trend, *F* (1.6, 47.4) = 2.93, *p* < .10. Analyses of the simple effects of the standard deviation score of the duration of fixations during each trial × type of looker indicated that long lookers had a tendency to spend more time on a limited number of stimulus elements during both Trial 1, quasi *F* (1, 119.6) = 10.27, *p* < .01 and Trial 2, quasi *F* (1, 119.6) = 7.50, *p* < .01 compared to short lookers (see Figure 16a). Therefore, during the baseline trials long looking infants repeatedly scanned a limited number of stimulus elements. Moreover, there was no difference between short and long lookers in terms of the variability in fixation duration during both the Penultimate and Last trials of habituation, quasi *F*s (1, 119.6) < 1.

The trend was similar for the standard deviation score of the number of fixations exhibited by infants. While the two-way interaction of the standard deviation of the number of fixations during each trial × type of looker did not reach statistical significance, a trend was observed in the data, *F* (1.7, 50.0) = 2.83, *p* <.10. However, an analysis of the simple effects indicated that long lookers had a tendency to make more fixations to a few stimulus elements only during Trial 1, quasi *F* (1, 66.6) = 9.55, *p* < .01, compared to short lookers (see Figure 16b). In addition, there were no differences in the variability of the number of fixations on the stimulus elements during either the Penultimate or Last trials.

3.1.4.7 *Differences Between Long and Short Lookers: Summary Variables.* Similar to other research groups investigating individual differences in information processing, we created six summary variables to profile infant habituation performance. These included the average number of fixations, average duration

Figure 16a

Individual differences in the mean standard deviation of the duration of fixations made on the stimulus during each of the four analyzed habituation trials. The asterisk indicates that long lookers concentrated on a limited number of stimulus elements during Trials 1 and 2.

Figure 16b

Individual differences in the mean standard deviation of the number of fixations on the stimulus during each of the four analyzed habituation trials. The asterisk indicates that long lookers made more fixations on a limited number of stimulus elements during Trial 1.

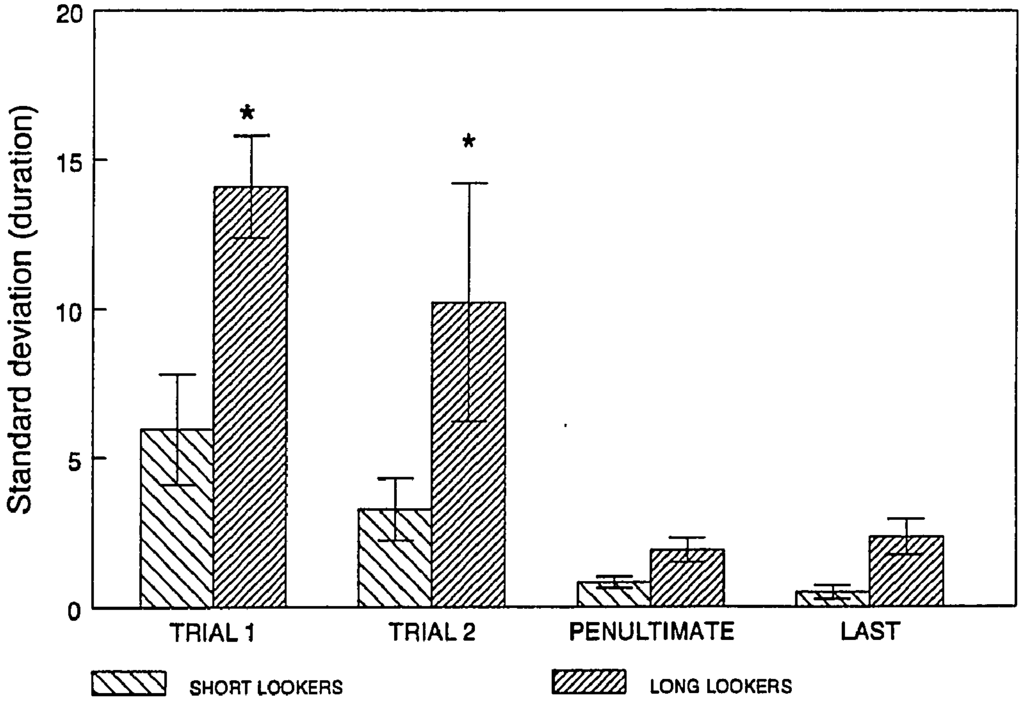
20
15
10
5
0
Standard deviation (duration)
*
*
TRIAL 1
TRIAL 2
PENULTIMATE
LAST
SHORT LOOKERS
LONG LOOKERS

Figure 16a

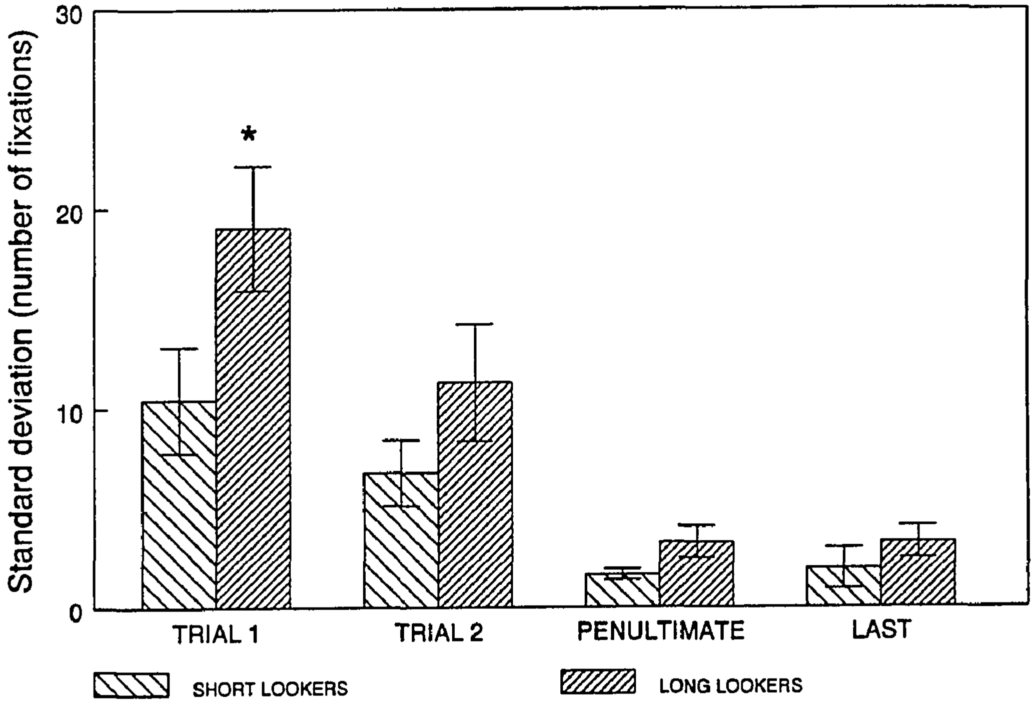
30
20
10
0
Standard deviation (number of fixations)
*
TRIAL 1
TRIAL 2
PENULTIMATE
LAST
SHORT LOOKERS
LONG LOOKERS

Figure 16b

of fixations, average number of on-stimulus zones scanned, average number of changes in fixation position, evenness of fixation duration and the evenness of the number of fixations. For this analysis all habituation trials were included in the analyses. The summary variables were determined by calculating each variable during each habituation trial, then averaging over all the trials. A multivariate analysis of variance (Hotelling's T^2) with these six variables indicated that there were significant differences between short and long lookers, F (6,25) = 9.14, $p < .001$. Table 7 presents the univariate statistics. Long lookers had higher average fixation duration of fixation scores, t (30)= 6.36, $p < .001$; made more fixations on the stimulus, t (30) = 5.79, $p < .001$; more frequently changed their fixation position during a trial, t (30) = 5.38 $p < .001$; scanned more of the on-stimulus zones over the course of habituation, t (30) = 2.30, $p < .029$; and were more repetitious in their scanning, reexamining previously scanned zones, t (30) = 3.14, $p < .004$ than short lookers.

In summary, there are individual differences in the style with which infants scanned the habituation stimulus. Infants were categorized as "short" lookers if their average fixation duration score (based on the scanning measure) fell below the median of the distribution of scores and "long" lookers if their average fixation score fell above the median score. In fact, the median of the distribution of average fixation duration scores was in close agreement to the median score as calculated by Columbo, et al., (1991)[10]*. When differences emerged between short and long lookers, they emerged on either Trial 1 or on both baseline trials. In addition, there*

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[10] The median score of the distribution of average fixation scores in the Colombo, et al. (1991) study was 14 seconds.

Table 7

Univariate Statistics of the Summary Habituation Measures for Short and Long Lookers

	Short Lookers (n=16)		Long Lookers (n=16)		
	M	SD	M	SD	t
Duration of fixations	3.0	1.9	7.8	2.3	6.36***
Number of fixations	16.8	8.2	34.7	9.2	5.79***
Number of zones scanned	2.2	.6	2.6	.4	2.30*
Number of changes in fixation position	8.2	4.4	16.1	4.0	5.38***
Standard deviation of the duration of fixations	7.8	6.2	11.1	5.2	1.65
Standard deviation of the number of fixations	4.3	4.4	9.1	4.2	3.14**

*p < .05. **p < .01. ***p < .001.

were no differences in these data between the two types of lookers on either criterion trials. Not surprisingly, long lookers scanned the stimulus for longer periods of time, made more fixations to the stimulus, and shifted their fixations over the stimulus more frequently than short lookers. Interestingly, there were no differences between short and long lookers in terms of how thorough they scanned the stimulus on any of the four analyzed habituation trials.

Furthermore, we found differences between scanning style and the number of fixations infants made to specific regions on the stimulus such that, while there were no differences in the number of fixations short lookers made to specific regions on the stimulus, long lookers concentrated their fixations on a very specific area on the stimulus; the upper-left quadrant (zone 1) of the stimulus display. In analyzing the standard deviation of the duration and the number of fixation scores, we found corroborating evidence; long lookers had a tendency to spend more time and make more fixations on a limited number of stimulus elements than short lookers.

We can conclude that while long lookers more actively scanned the stimulus during the initial phases of habituation, that is, they changed their locus of fixations repeatedly during these trials, they were more repetitious in their scanning than short lookers. The question then becomes, what is the functional importance of scanning repetitiveness? Do long looking infants gain additional information about the stimulus, enabling them to form a more complete mental representation than short lookers? Or is this repetitiveness unnecessary and time-consuming, and short lookers are forming as complete an image as long lookers, but are doing so more efficiently that is, in a shorter period of time? The evidence thus far presented *seems to support the speed or efficiency processing interpretation of information processing as proposed by Colombo et al. (1991).*

3.1.5 Individual Differences in Scanning Before, During, and After the Peak Trial

The peak trial is the trial during the habituation sequence in which infants are looking/fixating on the stimulus the longest (it is also referred to in the literature as the trial of the longest look). Moreover, it is assumed that they are therefore processing more information on this trial than on any other trial during the habituation sequence. Although the peak trial generally occurs early on in the habituation process, it sometimes occurs later. Figure 17 presents the distribution of the ordinal position of the peak trial (as determined from the scanning data) obtained in this study. A majority (72%) of the infants looked at the stimulus longest during the first two trials of habituation (for 47% of the infants their peak trial occurred during Trial 1 and 25% during Trial 2). Interestingly, a Pearson product-moment correlation between the number of trials an infant needed to reach the habituation criterion and the ordinal position of the peak trial was 0.70 ($\underline{p} < .001$). Therefore, infants requiring few trials to reach the habituation criterion had their peak trial earlier on in the habituation sequence than infants requiring more trials to reach criterion.

Similar to the derivation of other habituation variables, the ordinal position of the peak trial was determined from both the global data and the scanning data. Infants were categorized similarly by both measures as indicated by a goodness-of-fit chi-square test, $\chi^2 = 49.41$, $\underline{p} < .001$, $C = .78$. In addition, for 7 (44%) short

Figure 17

The percentage of subjects having their peak trial on each habituation trial.

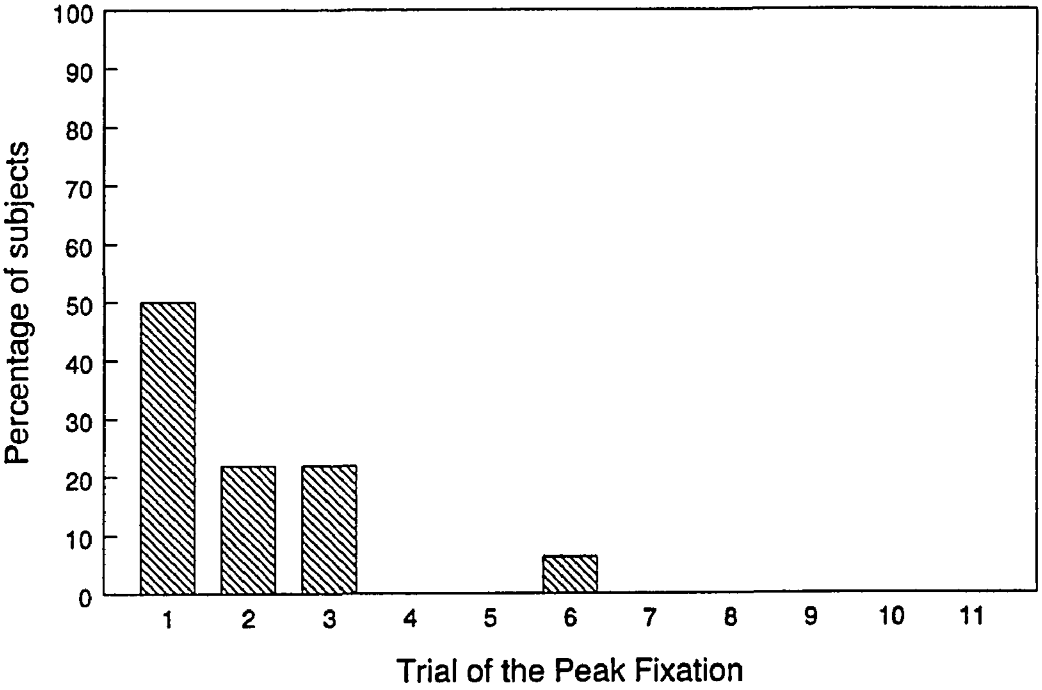

100
90
80
70
60
50
40
30
20
10
0
Percentage of subjects
1
2
3
4
5
6
7
8
9
10
11
Trial of the Peak Fixation

Figure 17

looking infants the peak trial occurred on Trial 1 and for 9 (56%) short looking infants the peak trial occurred on a later trial. For 9 (56%) long looking infants the peak trial occurred on Trial 1 and for 7 (44%) long looking infants the peak trial occurred later during the habituation sequence. A goodness-of-fit chi-square test indicated that there was no difference in the ordinal position of the peak trial between short and long lookers, $\chi^2 = .50$, $\underline{p} > .10$.

Traditional habituation studies have been limited to observations of the duration and the ordinal position of the peak trial. This section presents an analysis of the quality of scanning that occurred during this trial compared to the quality of scanning that occurred on the trial preceding and succeeding the peak trial. Given the nature of the infant-controlled procedure, all subjects had stimulus presentations following the peak trial. However, 15 of the subjects (47%) did not have a trial preceding the peak trial because their peak trial occurred on the first habituation trial. Two analyses were therefore conducted on these data; one which looked at the differences between scores on the peak trial compared to the trial succeeding the peak trial ($\underline{n}$=32). A second analysis looked at the differences between scores on the trial preceding the peak trial compared to the trial succeeding the peak trial ($\underline{n}$=16). We hypothesized that there would be differences between short and long lookers during the peak trial and that there would be no differences between short and long lookers on the succeeding trial. Further, we hypothesized that there would be no differences between short and long lookers on either the trial preceding or succeeding the peak trial. An additional variable was derived which categorized the relative position of the peak trial in the habituation sequence. For one group of infants, the peak trial occurred on Trial 1 and for a second group, the peak trial occurred later on in the habituation sequence. A 2 x 2 x 2 (type of looker x trial x relative position of the peak trial) mixed-design ANOVA, with trial serving as a repeated measure was conducted on each of the scanning variables to examine the differences between the quality of scanning which occurred on the peak trial in comparison to the succeeding trial. Additionally a 2 x 2 x 2 (type of looker x trial x relative position of peak fixation) mixed-design ANOVA, again with trial serving as a repeated measure was conducted to examine the differences between the quality of scanning which occurred on the trial preceding the peak trial in comparison to the succeeding trial.

3.5.1.1 *Duration and number of fixations.* While the three-way interaction was not significant, the two-way interaction between type of looker x the duration of fixations during each trial was significant, *F* (1, 28) = 18.94, *p* < .001. Analyses of the simple effects indicated that there were differences between short and long lookers in the duration of their peak trial, quasi *F* (1, 55.9) = 48.41, *p* < .001, and there were no differences between short and long lookers on the trial succeeding the peak trial, quasi *F* (1, 55.9) < 1. Long lookers accumulated more time scanning the habituation stimulus during the peak trial than during the succeeding trial (see Figure 18a). As expected, there were no differences between short and long lookers on either the trial preceding or succeeding the peak trial, *F* 's (1, 28) < 1.

The same pattern of results was evident for the data on the number of fixations. While the three-way interaction was not significant, the two-way interaction between type of looker x the number of fixations within a trial was

Figure 18a

Individual differences in fixation duration during the peak trial and the trial succeeding the peak trial. The asterisk indicates that long lookers scanned the stimulus significantly longer than short lookers during the peak trial.

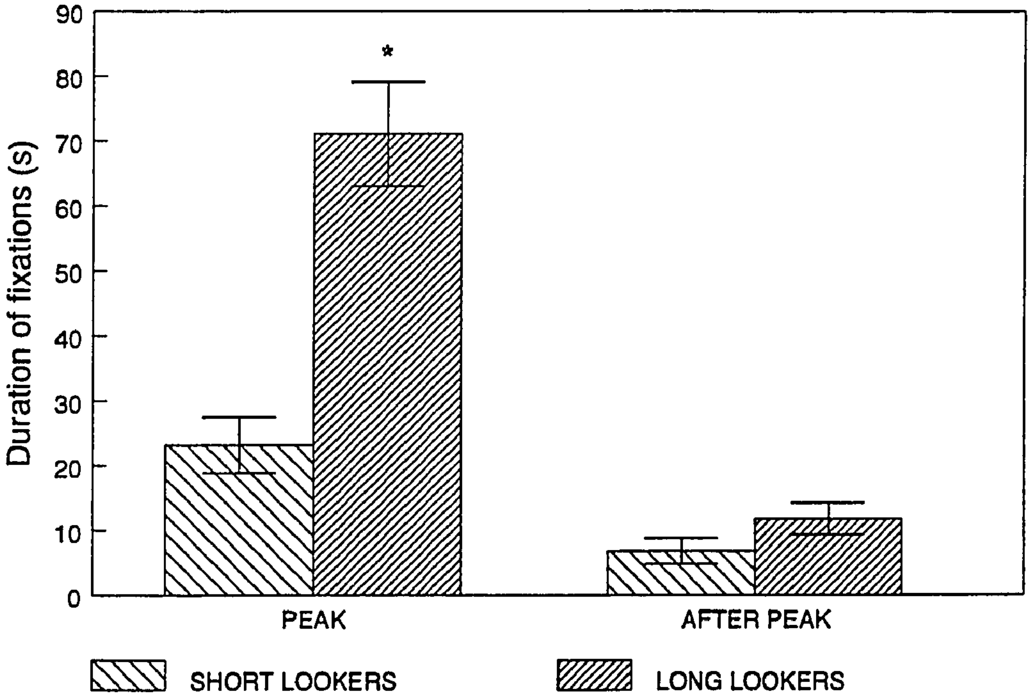

90
80
70
60
50
40
30
20
10
0
Duration of fixations (s)
*
PEAK
AFTER PEAK
SHORT LOOKERS
LONG LOOKERS

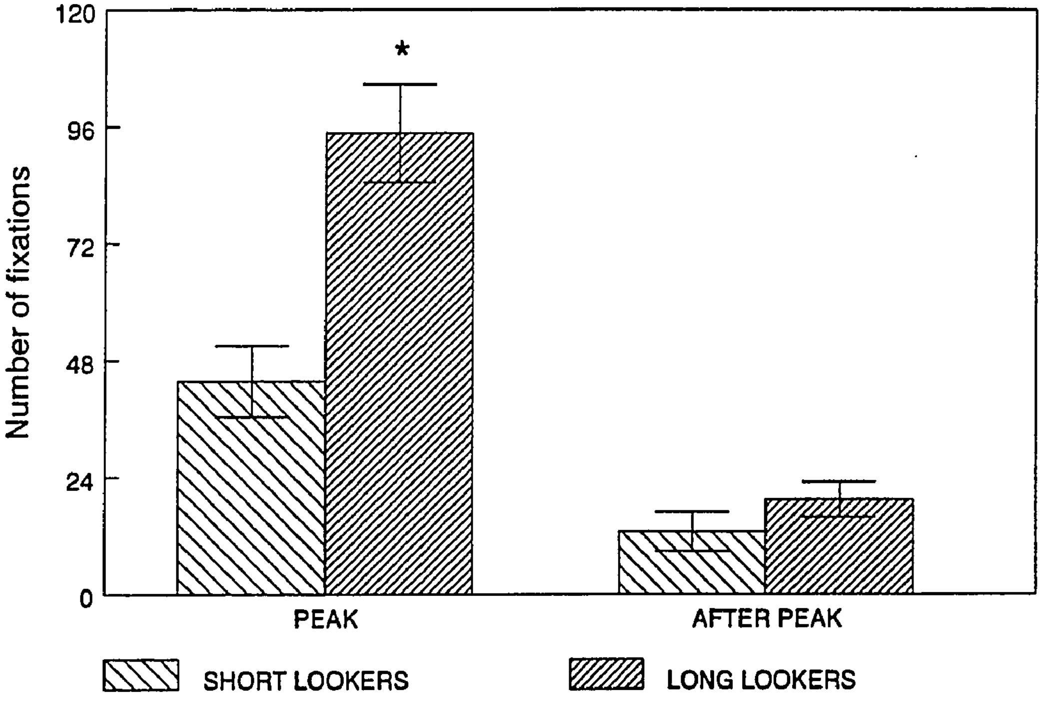
Figure 18a

significant, F (1, 28) = 10.76, $p \leq .003$. Analyses of the simple effects indicated that there were differences between short and long lookers during the peak trial, quasi $F(1, 55.7) = 26.80$, $p < .001$, but no differences between them during the succeeding trial, quasi $F(1, 55.9) < 1$. Therefore, long lookers made significantly more fixations to the stimulus during the peak trial than during the succeeding trial (see Figure 18b). Again as predicted, there were no differences between short and long lookers on the trial preceding or succeeding the peak trial.

3.1.5.2 Thoroughness of Scanning. Neither the three-way, nor any of the two-way interactions were significant. Therefore, there were no differences between short and long lookers in terms of the number of zones each scanned on the trial of, or succeeding the peak trial. There was however, a significant main effect for trial such that, infants in general scanned significantly more zones during the peak trial compared to the trial succeeding peak , $F(1, 28) = 35.35$, $p < .001$ (see Figure 19). Interestingly, it can be seen in this figure that infants were more variable in the number of zones they scanned during the trial succeeding the peak trial than on the peak trial. Figure 20a presents the raw data on the number of zones scanned by infants on the peak trial and shows that the majority of infants scanned all four on-stimulus zones (69%) during this trial; they extensively scanned all the stimulus zones. Figure 20b demonstrates that on the trial succeeding the peak trial infants scanned between 1 and 4 of the zones. Additionally, it is also apparent that many fewer infants scanned all four zones (16%) on this trial, therefore the majority of infants scanned the stimulus less extensively during the trial succeeding the peak fixation than during the peak trial.

Figure 18b

Individual differences in the number of fixations during the peak trial and the trial succeeding the peak. The asterisk indicates that long lookers made significantly more fixations to the stimulus than short lookers during the peak trial.



120
96
72
48
24
0
Number of fixations
*
PEAK
AFTER PEAK
SHORT LOOKERS
LONG LOOKERS

Figure 18b

Figure 19

Thoroughness of scanning during the peak trial and the succeeding trial. Infants in general scanned more of the on-stimulus zones during the peak trial than during the succeeding trial.

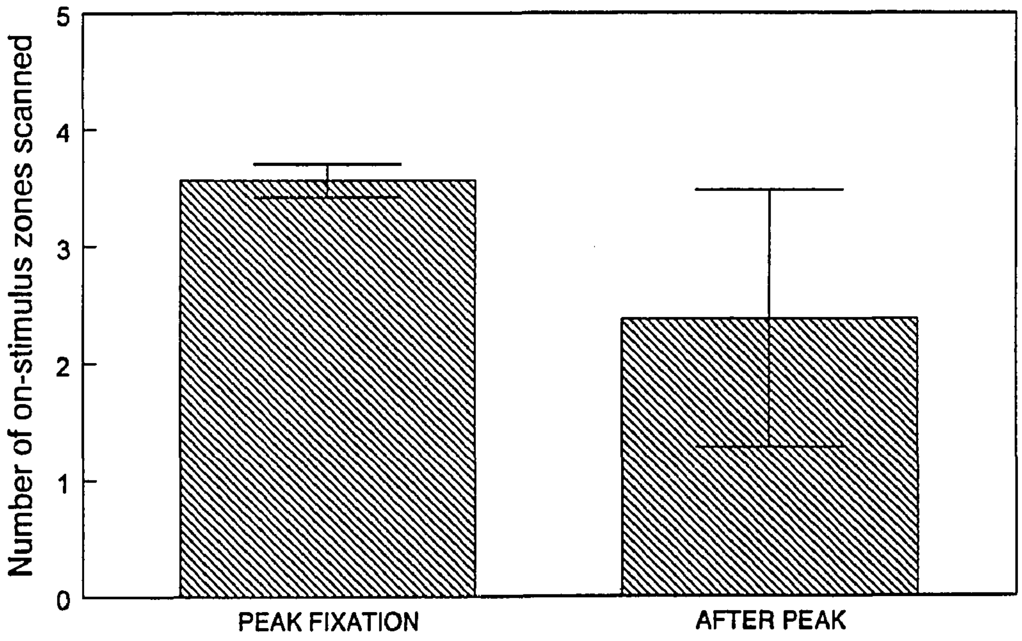

Number of on-stimulus zones scanned
0
1
2
3
4
5
PEAK FIXATION
AFTER PEAK

Figure 19

Figure 20a

The frequency distribution of the number of on-stimulus zones infants scanned during the peak trial.

Figure 20b

The frequency distribution of the number of on-stimulus zones infants scanned during the trial succeeding the peak trial.

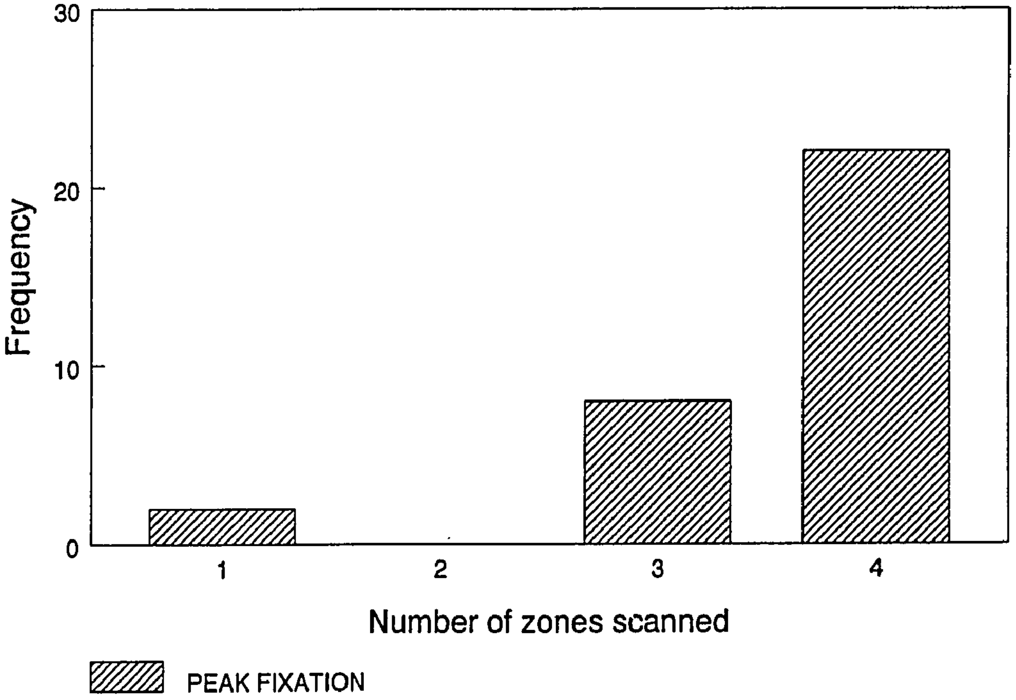

30
20
10
0
Frequency
1
2
3
4
Number of zones scanned
PEAK FIXATION

Figure 20a

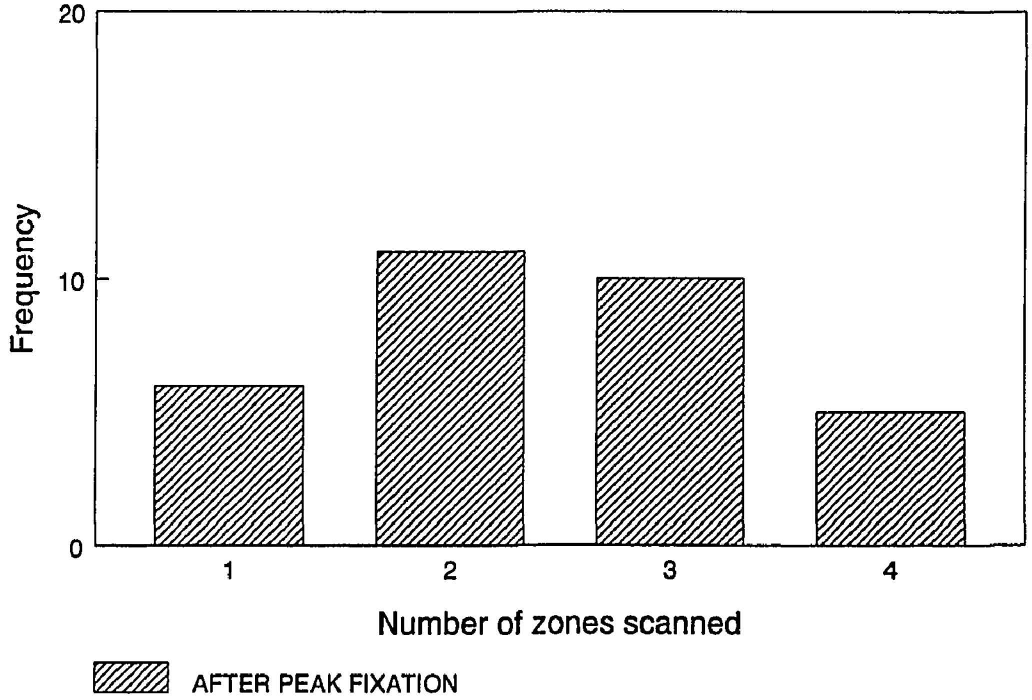

20
10
0
Frequency
1
2
3
4
Number of zones scanned
AFTER PEAK FIXATION

Figure 20b

Furthermore, the result that infants scanned more of the on-stimulus zones during the peak trial is not a function of the longer duration of this trial compared to that of the succeeding trial. The rate of infant looking was determined for each trial; mean duration of fixations was calculated for infants who scanned only one zone, for infants who scanned two zones, and so forth. While infants spent a longer amount of time scanning the stimulus on the peak trial compared to the succeeding trial, rate of scanning was consistent within a trial. For example, during the peak trial, infants scanned one zone for approximately 12 seconds, they scanned two zones for approximately 11 seconds and scanned all four zones for approximately 13 seconds. During the succeeding trial whether infants scanned one, two, or three zones, they did so for approximately 5 seconds. In addition, there were no differences between short and long lookers on the trial preceding or succeeding the peak trial.

3.1.5.3 Extensiveness of Scanning. While the three-way interaction was not significant, the two-way interaction of type of looker x the number of changes in fixation position during a trial was significant, F (1, 28) = 5.90; $p < .022$. Analyses of the simple effects demonstrated that long lookers made significantly more changes in fixation position during the peak trial , quasi F (1, 54.9) = 16.01, $p < .001$ than short lookers (see Figure 21). However, there were no differences between the two types of lookers on the trial succeeding the peak trial, quasi F (1, 54.9) < 1. Consistent with previous findings, there were no differences between short and long lookers during the trial preceding or succeeding the peak trial, F(1, 90) <1.

Figure 21

Individual differences in the number of changes infants made in fixation position during the peak trial and the succeeding trial. The asterisk indicates that long lookers made signficantly more changes than short lookers in fixation position during the peak trial.

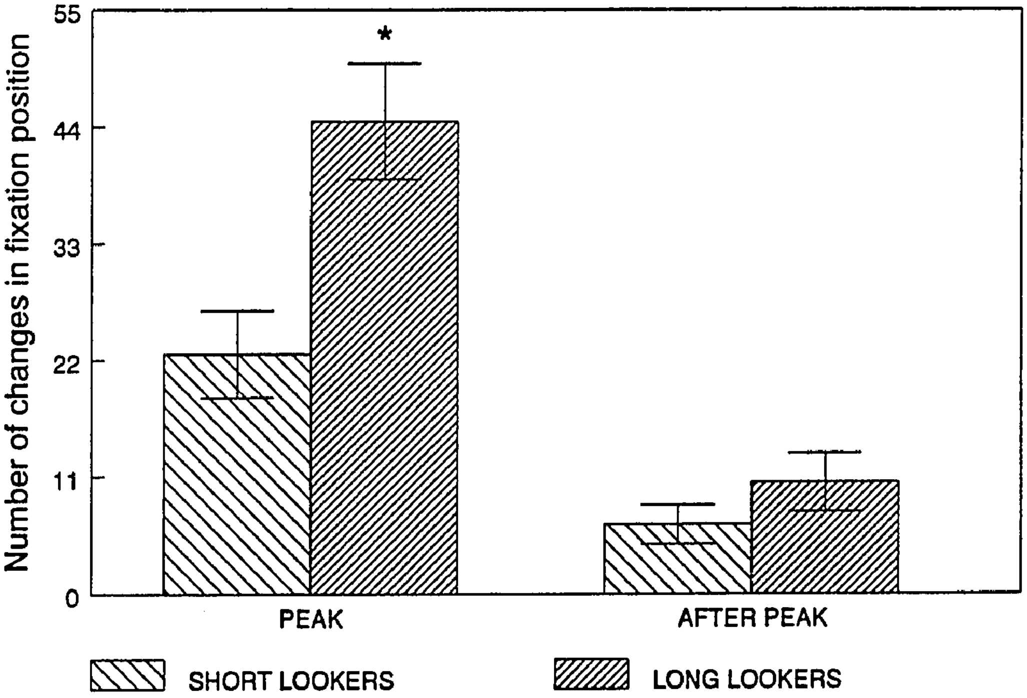

Number of changes in fixation position
55
44
33
22
11
0
*
PEAK
AFTER PEAK
SHORT LOOKERS
LONG LOOKERS

Figure 21

3.1.5.4 Duration and number of fixations to specific regions on the stimulus. Table 8 presents ANOVA results on the duration of fixations to specific regions on the stimulus. The five-way interaction of type of looker × relative position of the peak trial × trial × the duration of fixations to the left and right regions of the stimulus × duration of fixations to the upper and lower regions of the stimulus was significant, F (1, 28) = 4.90, p < .035. The analysis of the simple effects of trial (peak versus after peak) indicated that there was a significant four-way interaction between type of looker × relative position of the peak trial × duration of fixations to the upper and lower regions of the stimulus × duration of fixations to the left and right regions of the stimulus during the peak trial, quasi F (1, 54.5) = 8.87, p < .01, but not during the trial succeeding peak trial, quasi F (1, 54.5) < 1. Therefore, on the trial succeeding the peak trial, there were no differences between short and long looking infants in terms of the duration of fixations to each of the various regions of the stimulus. There were also no differences between infants whose peak trial occurred early in the habituation sequence compared to infants whose peak trial occurred later.

Analysis of the simple-simple effect during the peak trial for long lookers indicated a significant three-way interaction of the relative position of the peak trial × duration of fixations to the left and right regions of the stimulus × duration of fixations to the upper and lower regions of the stimulus, quasi F (1, 54.5) = 8.78, p < .01. Analyzing the simple-simple-simple effects revealed a significant two-way interaction for the duration of fixations to the left and right regions of the stimulus × duration of fixations to the upper and lower regions of the stimulus for long

Table 8

Summary Table: Duration of Fixations by Regions on the Stimulus by Trial

SOURCE	SS	df	MS	F
Looker x trials x position x left & right x up & down	593.22	1	593.22	4.90*
Error term	(3391.80)	(28)	(3391.80)	
Looker x position x left & right x up &down for peak		1	1287.14	8.87**
Error term		(54.5)	(145.65)	
Position x left & right x up & down for short lookers		1	224.41	1.54
Error term		(54.5)	(145.65)	
Left & right x up & down		1	366.71	2.51
Error term		(54.5)	(145.65)	
Position x left & right		1	174.85	.84
Left-right		1	437.83	2.12
Error term		(53.5)	(206.20)	
Position x up & down		1	127.67	.60
Up & down		1	1265.66	5.95**
Error term		(55.9)	(212.69)	
Position		1	74.76	.78
Error term		(55.9)	(95.05)	
Position x left & right x up & down for long lookers		1	1278.55	8.78***
Error term		(54.5)	(145.65)	
Left & right x up & down for peak position= later		1	291.15	2.00
Error term		(54.5)	(145.65)	
Left & right		1	365.41	1.77
Error term		(53.5)	(206.20)	
Up & down		1	566.92	2.66
Error term		(55.9)	(212.69)	
Left & right x up & down for peak position=Trial 1		1	1204.90	8.27***
Error term		(54.5)	(145.65)	
Up & down left side		1	1966.69	10.98***
Up-down right side		1	22.49	.13
Error term		(107.1)	(179.17)	
Looker x position x left & right x up & down for After peak		1	119.48	.82
Error term		(54.5)	145.65	

Note. This variable indicated whether the peak fixation occurred on Trial 1 or on a trial later on in the habituation sequence. For half of the infants the trial of the peak fixation occurred on Trial 1 and for the other half, it occurred later on in the habituation sequence.

*p < .05. **p < .025 . ***p < .01. ****p ≤ .001.

lookers whose peak trial occurred on Trial 1, quasi F (1, 54.5) = 8.27, $p < .01$, but was not significant for long lookers whose peak trial occurred on a succeeding trial, quasi F (1, 54.5) = 2.00, $p < .25$. The interaction of duration of fixations to the left and right regions of the stimulus × duration of fixations to the upper and lower regions of the stimulus was not significant for long looking infants whose peak trial occurred on a trial later on in the habituation sequence. The main effects of duration of fixations to the right and left regions of the stimulus and the duration of fixations to the upper and lower regions of the stimulus were also not significant. Further analysis of the peak trial for long looking infants, whose peak trial occurred on Trial 1, revealed that there were differences in the duration of fixations for the different stimulus zones. Long lookers scanned the upper-left quadrant (zone 1) of the stimulus display longer than the lower-left quadrant (zone 4) of the stimulus, quasi F (1, 107.1) = 10.98, $p < .01$(see Figure 22a). In addition, there were no differences in fixation duration for scanning the upper-right (zone 2) and lower-right (zone 3) quadrants of the stimulus display, quasi F (1, 107.14) < 1.

The three-way interaction for short lookers was not significant, quasi F (1, 54.5) = 1.54, $p < .25$. Neither were any of the two-way interactions (see Table 8). There was however, a significant main effect for the duration of fixations to the upper and lower regions of the stimulus for short lookers, quasi F (1, 55.9) = 5.95, $p < .025$ such that, short lookers looked longer on the upper regions of the stimulus display (zones 1 and 2) than the lower regions (zones 3 and 4) (see Figure 22b). Additionally, on the trial preceding peak trial, there were no differences in the duration of fixations towards the various regions of the stimulus either between

Figure 22a

The mean duration of fixations to specific regions on the stimulus for long looking infants whose peak trial occurred on Trial 1. The asterisk indicates that long lookers scanned the upper-left quadrant (zone 1) of the stimulus more than other regions.

Figure 22b

The mean duration of fixations to specific regions on the stimulus for short looking infants during the trial of the peak trial. Short lookers spent more time scanning the upper-regions (zones 3 and 4) than the lower regions (zones 1 and 2) of the stimulus display.

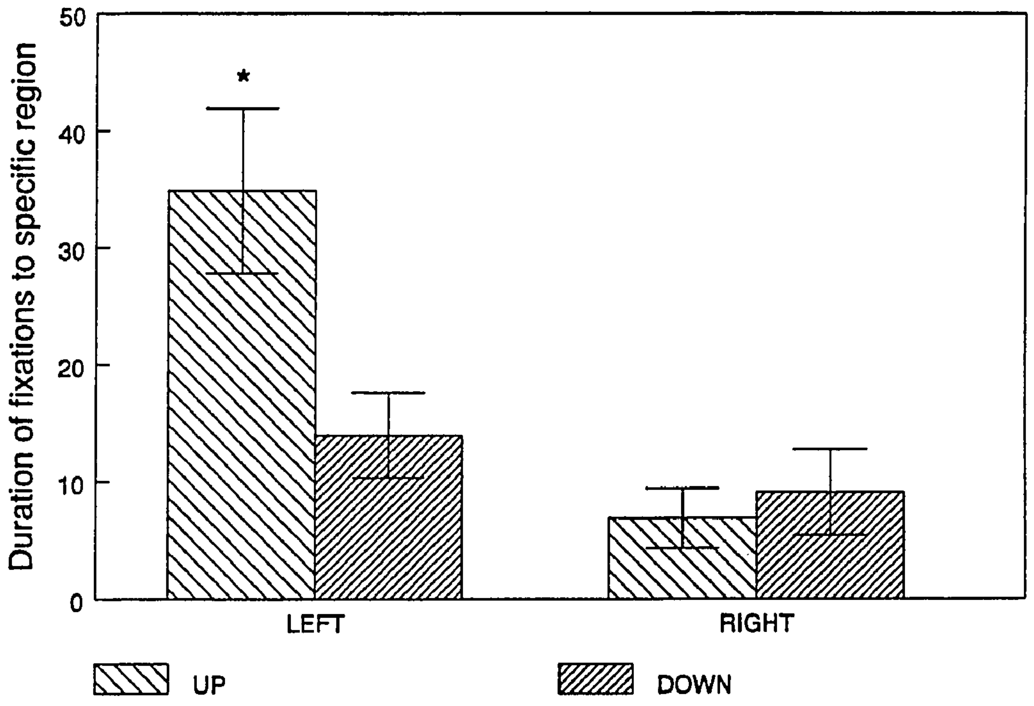

Duration of fixations to specific region
0
10
20
30
40
50
*
LEFT
RIGHT
UP
DOWN

Figure 22a

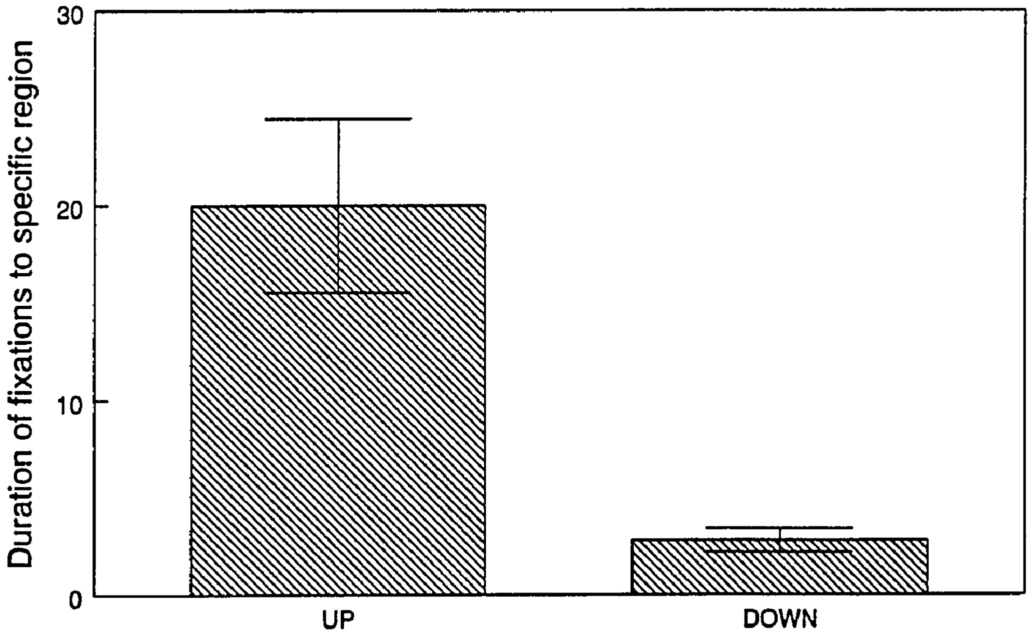


Figure 22b

short and long lookers or between infants whose peak trial occurred on Trial 1 compared with infants whose peak trial occurred on a trial later on in the habituation session.

Table 9 presents the ANOVA results for the number of fixations by region on the stimulus. The five-way interaction of type of looker x trial x relative position of the peak trial x the number of fixations made to left and right regions of the stimulus x the number of fixations made to the upper and lower regions of the stimulus was significant, quasi F (1, 28) = 4.54, $p < .05$. Analysis of the simple effects indicated a significant four-way interaction between the type of looker x relative position of the peak trial x the number of fixations to the upper and lower regions of the stimulus x the number of fixations to the left and right regions of the stimulus during the peak trial, quasi F (1, 53.0) = 8.96, $p < .01$ but not during the trial succeeding the peak trial, quasi F (1, 53.0) < 1. While the three-way interaction did not achieve significance for short lookers, quasi F (1, 53.0) = 2.96, $p < .10$), a trend in the data warranted the study of the simple-simple-simple effects. This analysis indicated a significant two-way interaction between the number of fixations to the left and right regions of the stimulus x the number of fixations to the upper and lower regions of the stimulus for short looking infants whose peak trial occurred on Trial 1, quasi F (1,53.0) = 6.57, $p < .025$. However, this interaction was not significant for infants whose peak trial occurred on a trial later on in the habituation sequence, quasi F (1,53.0) < 1. In addition, none of the main effects were significant for these infants. Therefore, short looking infants whose peak trial occurred on a trial later than Trial 1 showed no differences in

Table 9

Summary Table: Number of Fixations by Regions on the Stimulus by Trial

SOURCE	SS	df	MS	F
Looker x trials x position x left & right x up & down	644.88	1	644.88	4.54*
Error term	(3972.87)	(28)	(3972.87)	
Looker x position x left & right x up & down for peak		1	1663.89	8.96**
Error term		(53.0)	(185.77)	
Position x left & right x up & down for short lookers		1	550.62	2.96
Error term		(53.0)	(185.77)	
Left & right x up & down for peak position =later		1	17.36	.09
Error term		(53.0)	(185.77)	
Left & right x up & down for peak position = Trial 1		1	1222.32	6.57**
Error term		(53.0)	(185.77)	
Left & right		1	103.14	.43
Up & down		1	3552.07	14.69****
Error term		(100.9)	(241.87)	
Long looker: position x left & right x up & down		1	1171.11	9.21***
Error term		(53.0)	(185.77)	
Left & right x up & down for peak position = later		1	78.89	.42
Error term		(53.0)	(185.77)	
Left & right x up & down for peak position = Trial 1		1	1736.11	9.35***
Error term		(53.0)	(185.77)	
Up & down for left side		1	3146.89	13.01****
Up & down for right side		1	8.00	.03
Error term		(100.9)	(241.87)	
Looker x position x left & right x up & down for After peak		1	23.79	.13
Error term		(53.0)	(185.77)	

Note. This variable indicated whether the peak fixation occurred on Trial 1 or on a trial later on in the habituation. For half of the infants the trial of the peak fixation occurred on Trial 1 and for the other half, it occurred later on in the habituation session.

$^{*}p < .05$. $^{**}p < .025$. $^{***}p < .01$. $^{****}p < .001$.

where they scanned the habituation stimulus during the peak trial. Further analysis of the number of fixations by short looking infants to specific regions on the stimulus, whose peak trial occurred on Trial 1 indicated that these infants scanned the upper regions (zones 1 and 2) of the stimulus display more than the lower regions (zone 3 and 4), quasi F (1, 100.9) = 14.69, p < .001, but there were no differences in the number of fixations these infants made to the right and left regions on the stimulus display, quasi F (1, 100.9) <1, (see Figure 23a).

In addition, analyses revealed that there was a significant three-way interaction during the peak trial for long lookers between the relative position of the peak trial x the number of fixations to the left and right regions of the stimulus x the number of fixations to the upper and lower regions of the stimulus, quasi F (1, 53.0) = 9.21, p < .01. Further analyses revealed that while there were no differences in the number of fixations to the different regions of the stimulus in infants whose peak trial occurred on a trial later than Trial 1 during the habituation sequence, quasi F (1, 53.0) < 1, there was a significant two-way interaction between the number of fixations to the upper and lower regions of the stimulus x the number fixations to the left and right regions of the stimulus, quasi F(1, 53.0) = 9.35, p < .01. These infants made more fixations to the upper-left quadrant (zone 1) of the stimulus display compared to the lower-left quadrant (zone 4), quasi F(1, 100.9), p < .001, and there were no differences in the number of fixations made to the upper and lower quadrants of the right side of the stimulus display (zones 2 and 3, respectively), quasi F(1, 100.9) < 1 (see Figure 23b).

Figure 23a

The mean number of fixations to specific regions on the stimulus for short looking infants during the peak trial. Short lookers made more fixations to the upper regions (zones 1 and 2) of the stimulus display than to the lower regions (zones 3 and 4) of the stimulus display.

Figure 23b

The mean number of fixations on the regions on the stimulus during the peak trial for long looking infants whose peak trial occurred on Trial 1. The asterisk indicates that these infants made more fixations to the upper-left quadrant (zone 1) of the stimulus display compared to the lower-left quadrant (zone 4) of the stimulus display.

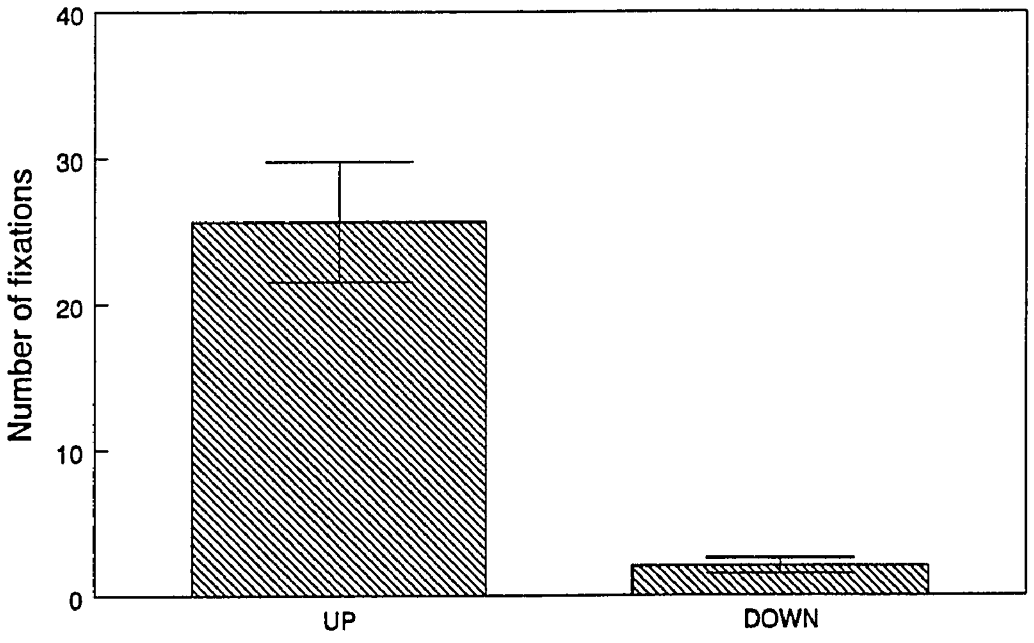


Figure 23a

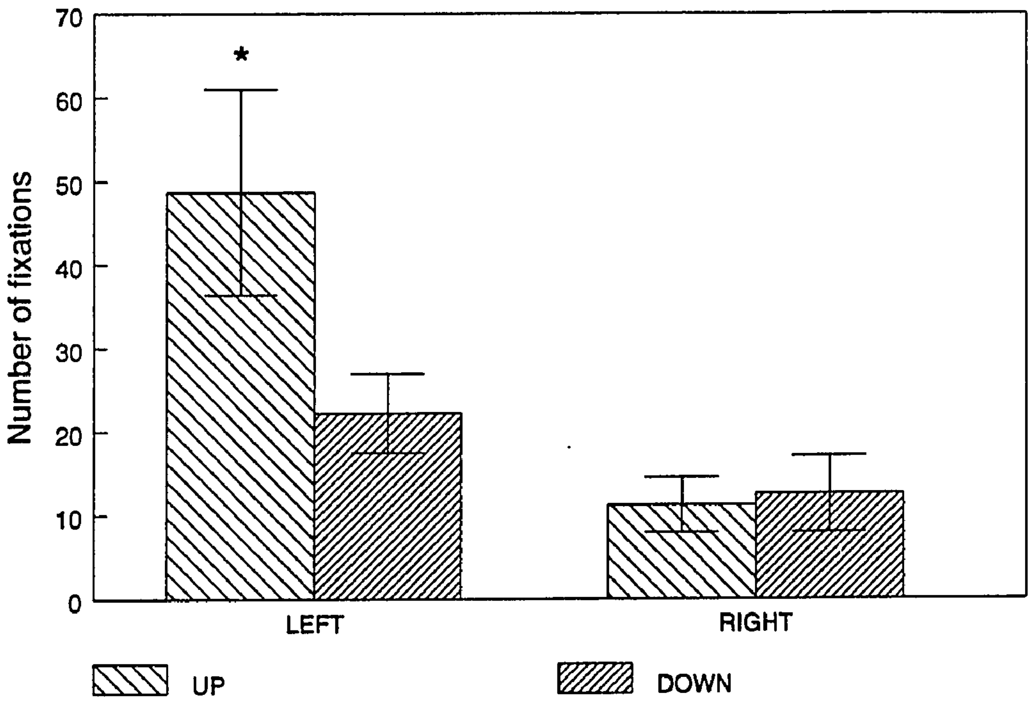


Figure 23b

In analyzing the trial succeeding the peak trial, none of the interactions, nor any of the main effects were significant. Therefore, there were no significant differences in the number of fixations infants made to specific regions on the stimulus either between short and long lookers or between infants whose peak trial occurred on Trial 1 and infants whose peak trial occurred later on in the habituation.

Additionally, there was no difference in the number of fixations to the various regions on the stimulus between short and long lookers or between infants whose peak trial occurred on Trial 1 and infants whose peak trial occurred later on in the habituation sequence on either the trial preceding or succeeding the peak trial.

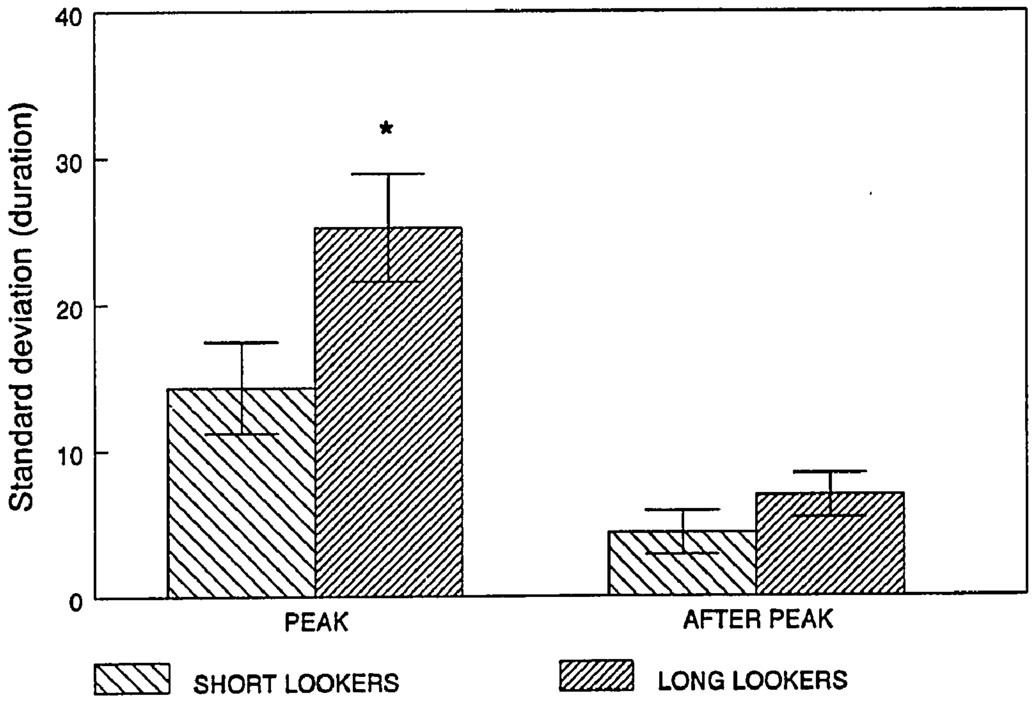
3.1.5.5 Evenness of Scanning. While the three-way interaction was not significant, the two-way interaction between type of looker × the standard deviation score of fixation duration by trial was significant, $F(1, 28) = 7.39$, $p < .011$. Analyses of the simple effects of the standard deviation score of fixation duration × type of looker during the peak trial indicated that long lookers spent a large part of their fixation time scanning a limited number of stimulus zones, quasi $F(1, 56) = 19.48$, $p < .001$ (see Figure 24a). In addition, there were no differences in the standard deviation duration scores between short and long lookers on the trial succeeding the peak trial, quasi $F(1, 56) < 1$).

There were also no differences in the standard deviation duration of fixation score between short and long lookers either on the peak trial or on the trial succeeding the peak trial, quasi $F(1, 56) < 1$.

Similar to the duration data, the three-way interaction of the standard deviation score of the number of fixations was not significant. The two-way

Figure 24a

Individual differences in the standard deviation of fixation durations between long and short looking infants. The asterisk indicates that long lookers spent a significantly longer time scanning a limited number of stimulus regions during the peak trial.



Standard deviation (duration)
0
10
20
30
40
*
PEAK
AFTER PEAK
SHORT LOOKERS
LONG LOOKERS

Figure 24a

interaction while not significant, F (1, 28) = 2.79, $p < .10$, indicated a trend in the data. Analysis of the simple effects confirmed this trend and demonstrated that there were differences between short and long lookers in terms of the standard deviation score of the number of fixations infants made to the on-stimulus zones during peak trial, quasi F (1, 55.5) = 7.88, $p < .01$, but there were no differences in this score on the succeeding trial, quasi F (1, 55.5) < 1. Long lookers therefore, made more fixations to a limited number of stimulus zones during the peak trial than short looking infants (see Figure 24b). Additionally, there were no differences in the standard deviation of the number of fixations between short and long lookers, either on the trial preceding or succeeding the peak trial, quasi F (1, 56) < 1.

For the majority of infants tested, the peak trial occurred early on in the habituation sequence that is, on either Trial 1 or 2. In summary, scanning during the peak trial is both quantitatively and qualitatively different from scanning which occurred on the preceding or succeeding trial. Additionally, there were differences in scanning style between short and long lookers on most of the measures examined. Long lookers accumulated more time and made more fixations on the stimulus during the peak trial than short lookers.

While there were no differences between short and long lookers in terms of the number of stimulus zones each scanned during the peak trial, infants in general, scanned significantly more zones during the peak trial compared to the succeeding trial. Another interesting finding was that infants were more variable in the number of zones they scanned on the trial succeeding the peak trial such that, some infants scanned only one zone, others scanned two zones and still others scanned three

Figure 24b

Individual differences in the standard deviation of the number of fixations between short and long looking infants. The asterisk indicates that long lookers made more fixations to a limited number of stimulus regions during the trial of the peak trial.

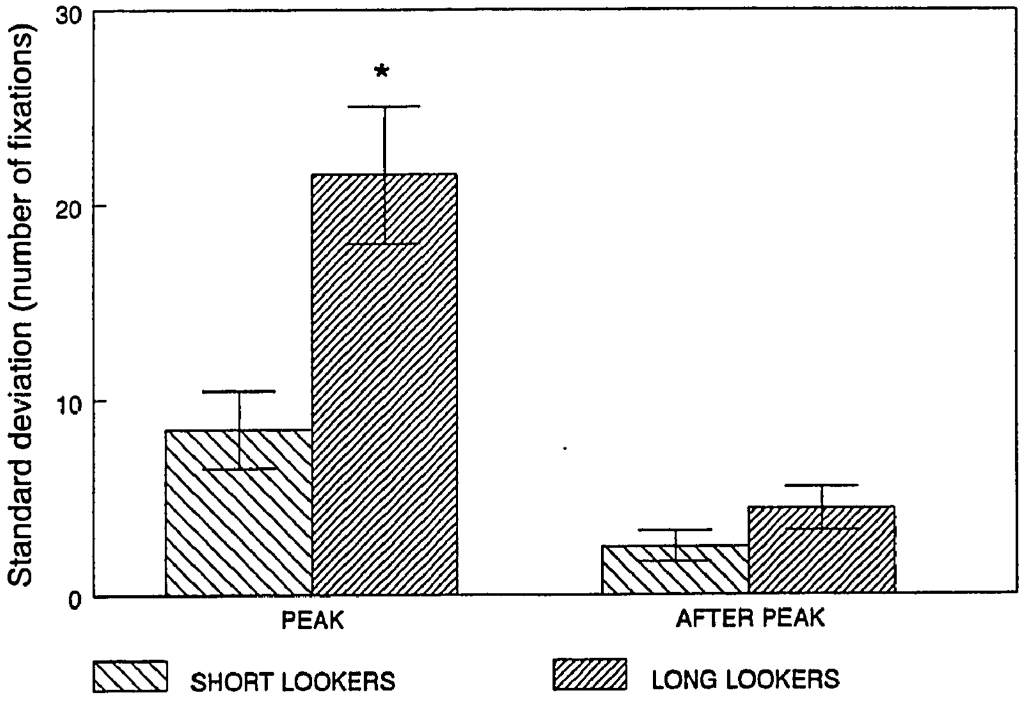

Standard deviation (number of fixations)
30
20
10
0
*
PEAK
AFTER PEAK
▧ SHORT LOOKERS
▨ LONG LOOKERS

Figure 24b

zones. In addition, very few infants scanned all four zones on this trial. This was in contrast to the low variability in the number of zones infants scanned during the peak trial; the majority of infants scanned all four zones during this trial. We found that this pattern of results was not a function of the longer duration of the peak trial compared to succeeding trial; the rate of infant looking was consistent within a trial. In addition, long lookers made significantly more changes in fixation position during the peak trial than short lookers. This finding is consistent with the findings from the overall habituation data; long looking infants made significantly more changes in fixation position during Trial 1 than short looking infants and there was a trend for long looking infants to make more changes in fixation position during Trial 2, although this was not statistically significance. It is especially meaningful in light of the fact that the peak trial occurred for the majority of infants during the first two trials.

We also found differences between short and long looking infants in terms of the duration of fixations made to specific regions on the stimulus during the peak trial. Differences between long looking infants whose peak trial occurred on Trial 1 compared to long looking infants whose peak trial occurred later on in the habituation session were also apparent. While there were no differences in the duration of fixations in the scanning of the specific regions on the stimulus for long looking infants whose peak trial occurred on a later habituation trial, long looking infants whose peak trial occurred on Trial 1 looked longer and made more fixations at the upper-left quadrant (zone 1) of the stimulus display than at the lower-left *quadrant. In addition, there were no differences in fixation duration for scanning the upper-right (zone 2) and lower-right (zone 3) quadrants of the stimulus display.*

There also were no differences in the duration of fixations to specific regions of the stimulus display for short looking infants whose peak trial occurred on Trial 1 compared with short looking infants whose peak trial occurred on a later trial. In general, short looking infants scanned the upper regions (zones 1 and 2) of the stimulus display for longer periods of time than the lower regions (zones 3 and 4) of the stimulus display. There also were no differences in the duration of right (zones 2 and 3) and left (zones 1 and 4) scanning for short looking infants. The findings on the number of fixations made to specific regions on the stimulus was similar.

These findings were corroborated by the standard deviation score of the duration and the number of fixations occurring on the zones of the stimulus. Long lookers spent more time and made more fixations to a limited number of stimulus zones than short lookers during the peak trial.

On all of the examined scanning variables, we consistently found no differences between the scanning of short and long lookers on either the trial preceding or succeeding the peak trial. Taken together, we can conclude that infants are in fact most extensively scanning and therefore processing the stimulus to a greater extent during the peak trial than during either the preceding or succeeding trial.

3.2 Test Phase

3.2.1 Test Phase Profile

Immediately following habituation, infants were tested with two presentations each of the habituation stimulus and the two novel stimuli (a horizontally symmetrical and an asymmetrical pattern). Data for each test phase stimulus were summed across the two presentations of that stimulus and analyses were performed on the combined score. Similar to the derivation of habituation variables, the test phase variables were determined in two ways; based on the global data and based on the scanning data.

Table 10 presents a profile of the test phase data. It is obvious from this table and similar to the results from habituation phase that there were significant differences between the scores derived from the global data and those derived from the scanning data. The scanning duration measures were significantly less than the global duration measures. For example, the total duration of infant looks (the global measure) to the asymmetrical stimulus was 14.9 s and the total duration of infant fixations (the scanning measure) was 7.3 s, $\underline{t}$ (12) = 4.81, $\underline{p} < .001$. Additionally, there were no differences between global and scanning novelty preference scores. This was not surprising given the fact that this measure is a proportion score, calculated by dividing the sum of the duration of fixations/looks at the novel stimulus by the sum of the duration of fixations/looks to both the novel and familiar stimuli.

Paired $\underline{t}$ tests were also performed for each novelty preference score against 50 percent. As a group, infants did not demonstrate a preference for novelty,

Table 10

Test Phase Profile

Variable	M	s	t	Range
Novelty Preference: Asymmetry				
Number of fixations				
global	49.0	10.9	.06	25.0-71.4
scanning	51.3	14.3		28.6-77.3
Duration				
global	54.6	14.1	1.01	22.0-88.4
scanning	53.6	10.1		40.2-74.2
Novelty Preference: Horizontal				
Number of fixations				
global	46.6	12.1	.31	25.0-71.4
scanning	45.4	18.1		27.0-78.3
Duration				
global	54.5	14.5	.50	32.2-86.2
scanning	52.1	18.6		17.7-75.4
Number of fixations: Vertical				
global	4.1	1.5	4.92***	2.0- 7.0
scanning	10.8	6.4		1.0-20.0
Duration of fixations: Vertical				
global	12.6	5.5	4.19**	2.4-19.4
scanning	6.8	5.1		.2-16.9
Number of fixations: Asymmetry				
global	4.1	1.9	3.64**	2.0- 9.0
scanning	11.8	7.4		2.0-31.0
Duration of Fixations: Asymmetry				
global	14.9	5.5	4.81***	1.3 -19.6
scanning	7.3	5.3		1.1 -17.7
Number of fixations: Horizontal				
global	3.4	1.6	4.21***	1.0 -6.0
scanning	11.6	7.5		1.0-28.0
Duration of Fixations: Horizontal				
global	15.4	4.4	8.05***	6.7-19.6
scanning	6.9	4.7		.5-16.5

Note. Both duration and frequency scores are summed across the two presentations of each stimulus.

*p < .05. **p < .01. ***p < .001

either for the horizontally symmetrical or for the asymmetrical stimulus, as determined by either the global or the scanning data. For example, the novelty preference score for the asymmetrical stimulus derived from the scanning data, against 50%, was not significant, t (12) < 1.

3.2.2 Global Measures versus Scanning Measures: Are they tapping into the Same Behavior?

Results from the habituation phase robustly indicated that the global measures and the scanning measures were tapping into the same behavior; there were significant correlations between the global measures of habituation and the comparable scanning measures. This however, was not the outcome of the same analyses performed with the test phase data. There were no significant correlations between the global measures and the scanning measures.

An additional analysis was performed wherein each infant's score was dichotomized as either having demonstrated a preference for novelty or not. Again, this was done for both the global and the scanning data. A goodness-of-fit chi-square test was then performed on the categorical data between the measures. This analysis revealed that infants were categorized differently by the two measures. We however, believe that the scanning data provides a more accurate account of the information processing occurring with exposure to a novel stimulus, because of the level of precision and the additional information provided about the processes of visual attention. This section presents the test phase scanning data for each novel stimulus, in comparison to the familiar stimulus.

3.2.3 Changes in Scanning to Novel Stimuli. A 2 x 2 x 2 (stimulus; novel versus familiar) x type of looker (as determined by infants' habituation performance; short versus long looker) x preference for novelty (that is, whether infants demonstrated a preference for novelty to a particular stimulus or not) mixed-design ANOVA was performed on both the duration and the number of fixations, with stimuli serving as the repeated measure.

3.2.3.1 Number of fixations by stimulus. Data on the number of fixations made to each of the novel stimuli in comparison to the familiar stimulus (habituation stimulus; vertically symmetrical stimulus) demonstrated that infants who showed a novelty preference made significantly more fixations to the novel stimuli in comparison to the familiar. The three-way interactions between stimulus x type of looker x whether infants showed a preference for novelty or not, was not significant for either the asymmetrical stimulus, F (1, 13) < 1, or the horizontally symmetrical stimulus, F (1, 12) < 1, when compared to the vertically symmetrical stimulus. However, the two-way interactions between the stimulus viewed and whether infants showed a preference for novelty were significant for both stimuli (asymmetrical stimulus, $F(1,13) = 9.03$, $p < .01$; horizontally symmetrical stimulus, $F(1, 12) = 19.34$, $p < .001$). Figure 25a presents the results of the analyses of the simple effects of the number of fixations to the asymmetrical stimulus by whether or not infants showed a preference for novelty. Infants who showed a preference for novelty made more fixations to the asymmetrical stimulus than infants who did not show a preference for novelty, quasi $F(1, 13) = 10.73$, $p < .01$. Figure 25b presents the results of the analyses of the simple effects between the horizontally

Figure 25a

Mean number of fixations to the asymmetrical stimulus (novel) and the vertically symmetrical stimulus (familar) for infants who showed a preference for novelty versus those who did not show a preference for novelty. The asterisk indicates that infants who showed a preference for novelty made significantly more fixations to the novel stimulus than infants who did not show a preference for novelty.

Figure 25b

The mean number of fixations to the horizontally symmetrical stimulus (novel) and the vertically symmetrical stimulus (familar) for infants who showed a preference for novelty versus those who did not show a preference for novelty. The asterisk indicates that infants who showed a preference for novelty made significantly more fixations to the novel stimulus than infants who did not show a preference for novelty.

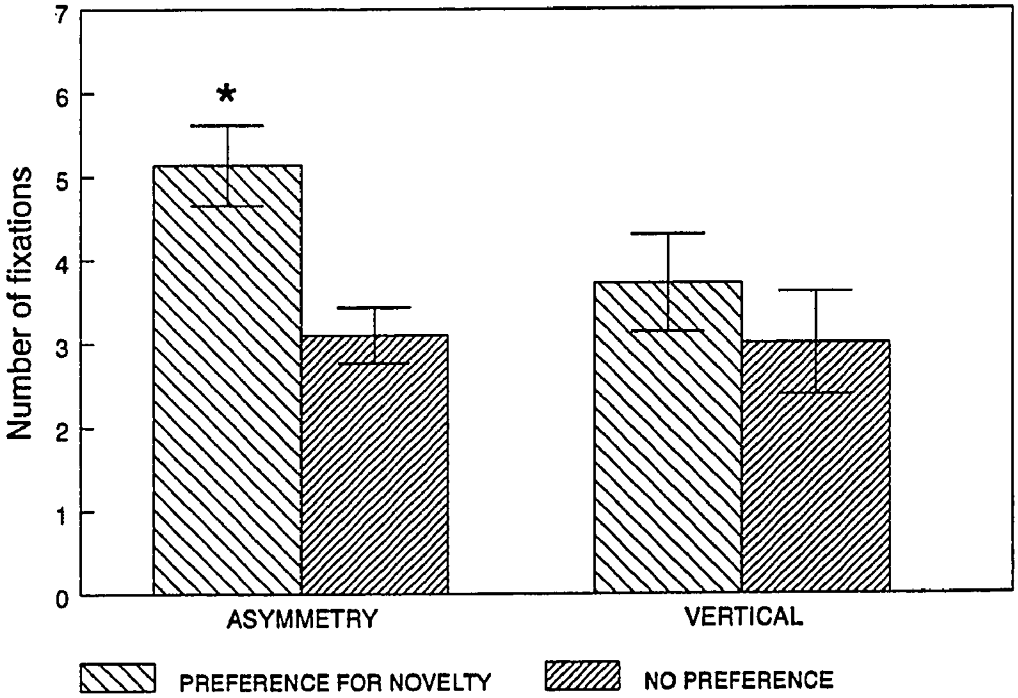
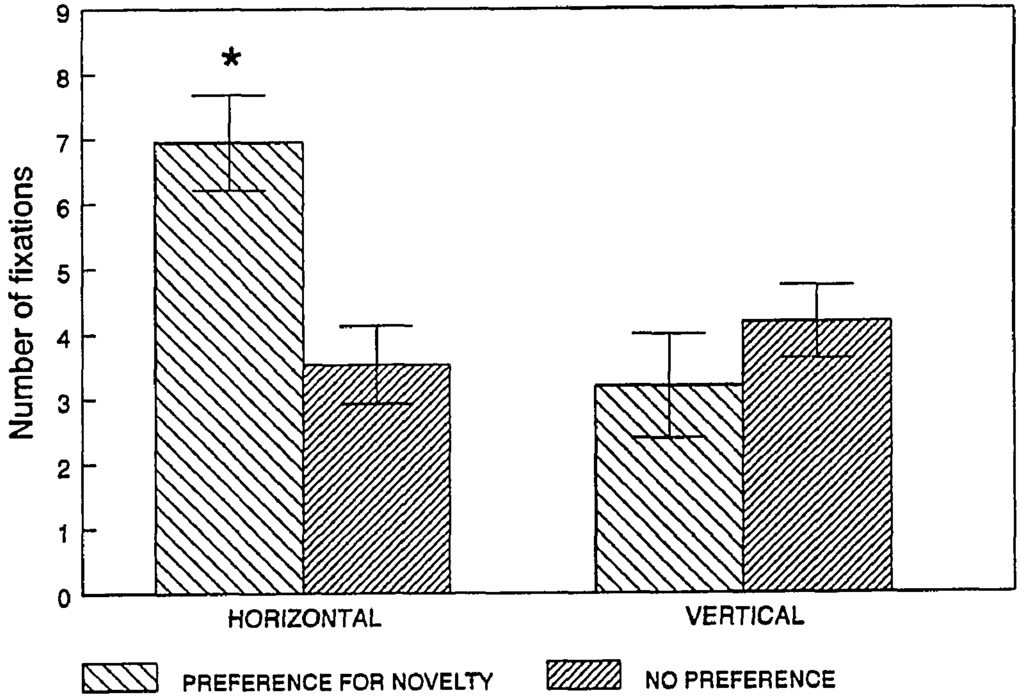

7
6
5
4
3
2
1
0
Number of fixations
*
ASYMMETRY
VERTICAL
PREFERENCE FOR NOVELTY
NO PREFERENCE

Figure 25a



Number of fixations
0
1
2
3
4
5
6
7
8
9
*
HORIZONTAL
VERTICAL
PREFERENCE FOR NOVELTY
NO PREFERENCE

Figure 25b

symmetrical stimulus by whether infants showed a preference for novelty or not. Infants who showed a preference for novelty made significantly more fixations to the horizontally symmetrical stimulus than infants who did not show a preference for novelty, quasi F (1, 12) - 20.30, p < .001, whereas there were no differences in the number of fixations for either stimuli for infants that did not show a preference for novelty, F (1, 13) = 3.59, n.s.

3.2.3.2 Thoroughness of Scanning. Neither three-way interactions between the number of zones infants scanned during the presentation of each of the novel stimuli compared to the familiar stimulus x type of looker x whether or not they showed a preference for novelty were significant, nor were any of the two-way interactions. However, there were significant main effects for the number of zones infants scanned on the novel stimuli compared to the familiar stimulus such that, infants scanned more zones on the asymmetrical stimulus, F (1,13) = 10.82, p < .006 (see Figure 26a) and on the horizontally symmetrical stimulus, F (1,12) = 9.18, p < .01, when compared to the familiar, vertically symmetrical stimulus (see Figure 26b).

3.2.3.3 Scanning Extensiveness by Stimulus. The three-way interaction between the number of changes infants made in fixation position when presented with the horizontally symmetrical stimulus x type of looker x whether or not infants showed a preference for novelty, was significant, F (1,9) = 6.59, p < .03. Analysis of the simple effects demonstrated a significant two-way interaction between the number of changes made in fixation position for infants who showed a preference for novelty during the presentations of the horizontally symmetrical stimulus x type

Figure 26a

Mean number of zones infants scanned during the presentation of the asymmetrical stimulus compared to the vertically symmetrical stimulus. The asterisk indicates that infants scanned more of the on-stimulus zones on the novel stimulus than on the familar stimulus.

Figure 26b

Mean number of zones infants scanned during the presentation of the horizontally symmetrical stimulus compared to the vertically symmetrical stimulus. The asterisk indicates that infants scanned more of the on-stimulus zones on the novel stimulus than on the familar stimulus.

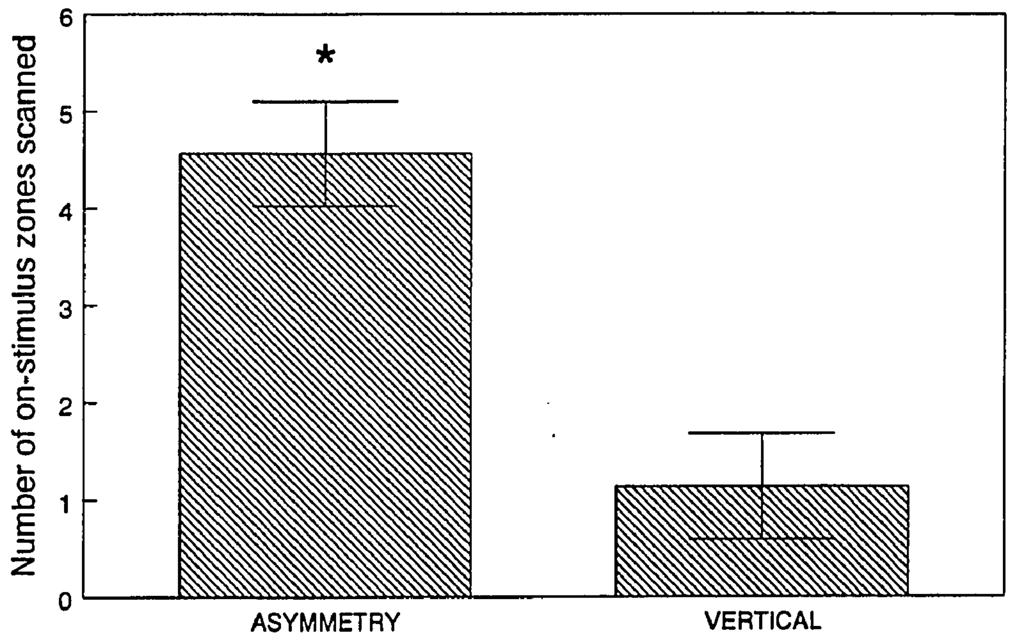
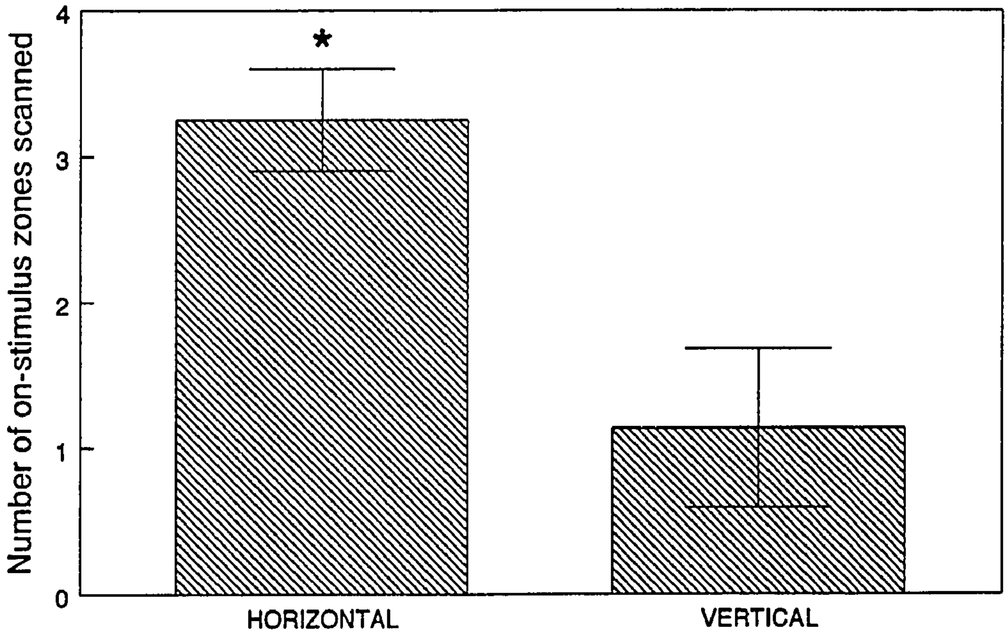

Number of on-stimulus zones scanned
0
1
2
3
4
5
6
*
ASYMMETRY
VERTICAL

Figure 26a



Number of on-stimulus zones scanned
4
3
2
1
0
*
HORIZONTAL
VERTICAL

Figure 26b

of looker, quasi F (1, 9) = 10.03, p < .025. As expected, the interaction was not significant for infants who did not show a preference for novelty, quasi F (1, 9) < 1.

Analyses of the simple-simple effects of the horizontally versus the vertically symmetrical stimulus x type of looker indicated that short lookers made more changes in fixation position when they viewed the horizontally symmetrical stimulus than when they viewed the vertically symmetrical stimulus, quasi F (1, 9) = 5.52, p < .05 (see Figure 27). There was however, no differences in the number of changes in fixation position for long looking infants when scanning the horizontal stimulus in comparison to the vertical stimulus.

The three-way interaction between the number of changes infants made in fixation position when presented with the asymmetrical stimulus x type of looker x whether infants showed a preference for novelty was not significant. The two-way interaction between the number of changes in fixation position by whether infants showed a preference for novelty while not significant however, indicated a trend in the data, F (1, 12) = 3.18, p < .10. Analysis of the simple effects, while also not significant, revealed a trend for infants who showed a preference for novelty to change fixation position more frequently than infants who did not show a preference for novelty, quasi F (1,12) = 3.20, p < .10.

3.2.3.4 Off-Stimulus Scanning by Stimulus. Neither the three-way interaction, nor any of the two-way interactions, nor any of the main effects achieved statistical significance for either the duration or the number of fixations to off-stimulus regions for either the vertically symmetrical, horizontally symmetrical, or asymmetrical stimulus. Therefore, there were no differences in either the

Figure 27

Mean number of zones infants scanned during the presentation of the horizontally symmetrical stimulus compared to the vertically symmetrical stimulus. The asterisk indicates that short lookers who showed a preference for novelty made more changes in fixation position than long lookers during the presentation of the horizontally symmetrical stimulus.

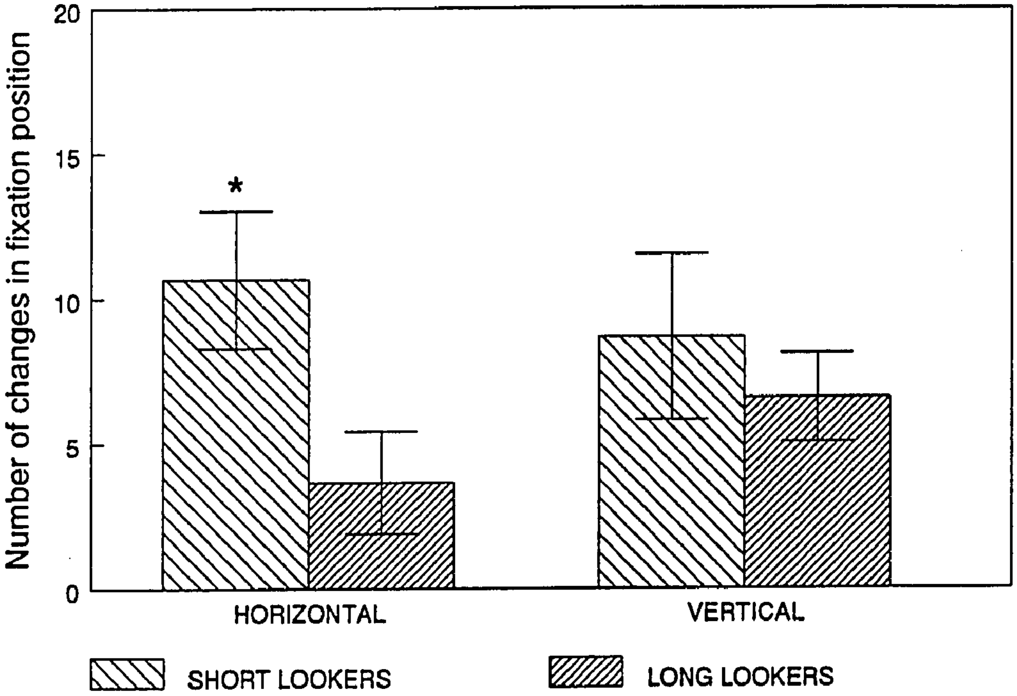

20
15
10
5
0
Number of changes in fixation position
*
HORIZONTAL
VERTICAL
SHORT LOOKERS
LONG LOOKERS

Figure 27

duration or in the number of fixations infants made to the off-stimulus regions and there were no differences between either short or long lookers in terms of whether or not they showed a preference for novelty.

3.2.3.5 Duration and number of fixations to specific regions on the stimulus. Numerous studies have documented infants exhibiting a preference for novelty when, following habituation, they are presented with a novel stimulus; infants will typically look for longer periods of time at the novel stimulus compared to the familiar stimulus. However, these studies were not able to assess where on the stimulus infants scanned/looked which facilitated the discrimination of novelty. The strength to collecting eye movements during the test phase would be in the ability to determine the location of infant fixations on a novel stimulus in comparison to the location of fixations on the familiar stimulus. This might possibly give us insight into what makes a discrimination of novelty possible. Either infants may scan regions on the novel stimulus which had been previously inspected on the familiar stimulus, find a different element in that location, and conclude that the stimulus is different; or they may look at the same stimulus element, which is now in a different location than it had been previously and again conclude that the stimulus has changed.

Four 2 x 2 x 2 x 2 x 2 (stimulus x type of looker x up and down fixations x left and right fixations x whether or not infants showed a preference for novelty) mixed-design ANOVA were performed with stimulus, up and down fixations, and right and left fixations served as repeated measures. One ANOVA was performed on the duration data between the horizontally symmetrical stimulus versus the vertically symmetrical stimulus, another on the duration data between the asymmetrical stimulus versus the vertically symmetrical stimulus, and the same two comparisons were made on the number of fixations made to each of the stimuli. None of the interactions nor any of the main effects were significant for either novel stimulus in terms of either the duration or the number of fixations made to the stimuli. Therefore, there did not seem to be differences in where infants looked on either novel stimulus compared to the familiar stimulus. Further, there were also no differences between short and long looking infants or between infants who showed a preference for novelty and those who did not. Given the fact that only a subsample of infants gave sufficient test phase data we hypothesize that power was significantly reduced and may have obscured these differences. Unfortunately, the implication of this is that we are unable to delineate the process(s) which facilitate infants' ability to successfully discriminate among stimuli or what processes inhibit the discrimination between stimuli.

3.2.3.6 Evenness of Scanning: Zone by Stimulus. Similar to previous analyses, mixed-design ANOVAs were conducted on the standard deviation of the duration and the number of fixations in order to investigate whether infants are more or less repetitive in their scanning of each of the novel stimuli, compared to the familiar stimulus. Similar to previous analyses, there did not seem to be differences in the standard deviation scores of the duration or in the number of fixations to either novel stimuli or to the familiar stimulus.

There was also no evidence of individual differences in the repetitiveness of scanning based on whether infants were classified as short or long looking infants or whether they were categorized a showing a preference for novelty or not. As explained in the preceding analyses, this may be due to the reduction of power which occurred for the test phase of this study.

In summary, as a group, infants did not show a preference for novelty, when presented with either the horizontally symmetrical or the asymmetrical stimuli; novelty preference percentages were not statistically significant from 50 percent. This was true whether we examined the global or the scanning data. When analyses were performed which dichotomized infants as either demonstrating a preference for novelty or not, we found the expected differences on some of the scanning parameters. Infants made more fixations to both novel stimuli (the horizontal symmetry and asymmetry) in comparison to the familiar stimulus (vertical symmetry). We however, found that infants as a group scanned more of the on-stimulus zones on both novel stimuli compared to the familiar stimulus. In terms of scanning extensiveness, we found further differences between infants who showed a preference for novelty compared to those who did not; short lookers made more changes in fixation position when they viewed the horizontally symmetrical stimulus than when they viewed the vertically symmetrical stimulus. While not statistically significant, there was a trend in the data which indicated that infants who showed a preference for the asymmetrical stimulus made more changes in fixation position on this stimulus than infants who did not show this preference.

We were however, unable to determine the processes used by infants in successfully discriminating novel from familiar stimuli. We found no differences in the duration or in the number of fixations to any of the specific regions on either novel stimuli. Moreover, the standard deviation scores of fixation duration and the *number of fixations made to the stimuli, showed no differences in variability of these two measures to any of the stimuli. There also did not seem to be differences between short and long lookers or between those infants who preferred novelty compared with those that did not.*

Interestingly, in general, with the exception of the data on the extensiveness of scanning to the horizontally symmetrical stimulus, there were no differences in test phase performance between short and long lookers. This was a surprise given the previous research which has demonstrated the superiority of the performance of short lookers with novel stimuli. We further hypothesized that because so few infants gave sufficient test phase data, power was therefore reduced considerably and quite possibly with a larger sample of infants these relationships might emerge.

3.3 Individual Differences in Habituation Performance and Novelty Preference and Infants' Accommodative Response During Photorefraction

Several hypotheses have been tested in an attempt to explain the processes which underlie the differences between the performance of short and long lookers. For example, Colombo et al. (1991) specifically examined whether infants differ in the speed with which they process visual information or in the type of information that each process. Short looking infants in their study proved to be faster and more efficient information processors.

We hypothesized that the differences in information processing performance between short and long lookers might be determined by differences in their accommodative responses such that, long lookers require more exposure to the stimulus because they are not correctly accommodating to the target's distance. Naturally, infants correctly accommodating will see the stimulus better, possibly extracting more details which may not be perceptible to an infant not correctly accommodating. As previously stated in the Methods section (see section 2.1) we evaluate the accommodative responses of all infants participating in studies at the Brooklyn College Infant Study Center, using the method of photorefraction, as part of a larger developmental study on the accommodative responses of infants during the first year of life (see Abramov, Hainline, & Duckman, 1990). These data were available from 27 of this study's infants. Accommodative responses were measured using highly attractive targets at five distances from the infants; 200 cm (½ diopters; [D], 100 cm (1D), 50 cm (2D), 33 cm (3D), and 25 cm (4D). The varying distances of the target elicit changes in accommodation. The distance at which infants were tested during the habituation and test phases was 57 cm, which requires approximately 2D of accommodation.

As part of the larger developmental study, the accommodative demand of each target's distance was plotted against the infant's accommodative response at each target distance for the left eye, right eye, and average response of both eyes. Reasoning that if infants correctly accommodated to the 2D target they would also correctly accommodate to the stimuli used in this study (and vis-a-versa), we examined the graph for each infant that participated in the present study and specifically noted their accommodative response to the 2D target. Three types of analysis were then performed. One analysis consisted of categorizing each infant's performance as either correctly or incorrectly accommodating to the target's distance and performing a goodness-of-fit chi-square test between this variable and the categorical data on infants' average fixation duration (the scanning variable as opposed to the global variable) during habituation, that is short versus long lookers. Results indicated that there were no differences between short and long lookers in whether they correctly or incorrectly accommodated to 2D target, $\chi^2 < 1$. Another analysis consisted of using the categorical data for accommodative responses and the continuous data of average fixation duration. Again, there were no differences between infants who accommodated correctly from those that did not: horizontally symmetrical stimulus $\underline{F}(1, 16) < 1$; asymmetrical stimulus $\underline{F}(1,17) < 1$.

Reasoning that categorical data may not be sufficiently sensitive to these differences, a third type of analysis was performed wherein continuous variables were used for both variables. For example, instead of categorizing infants as correctly or incorrectly accommodating, the amount of accommodative error was calculated. For example, if the infant's accommodative response to the 2D target was 4D, a 4D response minus a 2D target equals 2D of error. Again, the continuous variable of average fixation duration was used. A Pearson product-moment correlation revealed no relationship between an infant's average fixation duration and the error of their accommodative response to the 2D target, $\underline{r} = -.05$, n.s.

We also examined whether differences in performance during the test phase could be explained by differences in infants' accommodative response at the 2D target. Similar to the habituation data we performed three types of analyses. One analysis was performed with categorical data for both the test phase and accommodative response. As previously described, for the analysis of the test phase data infants were dichotomized as either showing a preference for novelty or not, to each of the novel stimuli. A goodness-of-fit chi-square test on the categorical data demonstrated that there was no difference between infants that accommodated correctly and infants that did not in terms of whether they showed a preference for novelty to either the horizontal, $\chi^2 = 2.80$, n.s. or the asymmetrical stimulus, $\chi^2 = 1.81$, n.s. The second analysis consisted of using the categorical data for infants accommodative response and the continuous data of novelty preference score for each novel stimulus. Again, there were no differences between infants who accommodated correctly from those that did not in terms of their novelty preference score for either the horizontal, $F(1,16) < 1$ or the asymmetrical stimuli, $F(1, 17) < 1$. Finally, using the continuous measures for both variables, a Pearson product-moment correlation revealed no relationship between an infant's novelty preference score for either the asymmetrical stimulus and the magnitude of their accommodative error to the 2D target, $r = -.10$, n.s., or between an infant's novelty preference score for the horizontally stimulus and the magnitude of their accommodative response to the 2D target, $r = -.09$, n.s.

In summary, in these data, differences in infants' accommodative response does not seem to effect either habituation performance or the discrimination of novelty.

[4]

DISCUSSION

The results of this study demonstrated that the eye-mind relationship is applicable to 2- and 3-month old infants, that is, visual scanning is related to information processing. While previous research demonstrated that infants' oculomotor systems are fairly well developed and that they scan more broadly than was previously believed, this study has provided sufficient evidence to conclude that information is in fact being processed on each fixation. Infant eye movement and habituation researchers have expressed concern that there is a significant gap in our knowledge in terms of either how oculomotor behaviors reflect cognitive processes or in what processes underlie the habituation of attention. By analyzing the distribution of attention, that is, eye position at each successive fixation over the course towards habituation, we were able to describe the function of an oculomotor activity (i.e., fixations) and the processing of visual information. Many of the variables that were derived from the scanning data could not be derived from the global habituation data. Studies which have examined the global dimensions of information processing could only assess rather gross measures of attention; whether infants looked at or away from the stimulus display. Variables such as, duration and number of on-stimulus fixations; duration and number of off-stimulus (or stimulus background) fixations; the thoroughness (i.e., the number of on-stimulus zones were scanned), extensiveness (i.e., the number of changes in fixation position that occurs on a trial), and evenness of scanning (i.e., the standard deviation of the duration and number of fixations); and where and how long infants scanned specific regions on the stimulus, could not be computed from the global parameters of attention. Analyzing eye movements is therefore a more molecular and precise method of analysis and therefore the variables that are derived from such an analysis are useful adjuncts to the traditional global measures of habituation. This study focused on the changes that occurred on these variables over the course of habituation and during the presentation of novel stimuli.

Average infant performance was examined on four specific habituation trials, the two baseline trials (Trial 1 and Trial 2) and the two criterion trials (Penultimate trial and Last trial). The baseline trials were selected because it is assumed that during this phase the most information is processed. Conversely, yet complimentarily, the criterion trials were selected because it is assumed that information processing is completed during this phase. The average infant scanned longer, made more fixations, and more thoroughly and extensively scanned the stimulus during the baseline trials of habituation compared to the criterion trials.

Contrary to our hypothesis, infants also scanned the off-stimulus zones for longer durations of time and made more fixations to these zones during the baseline trials than during the criterion trials. This was somewhat surprising and incongruent with what we understand about the habituation process. We concluded that this is an indication that infants are very active in their scanning behavior during the initial trials of habituation, extensively scanning both the on-stimulus and the off-stimulus regions. However, as they become familiar with the stimulus, scanning both the on- and off-stimulus zones declines. Certainly, the duration and the number of fixations to on-stimulus zones were significantly greater than those to the off-stimulus zones during all four analyzed trials.

A serial processing hypothesis has been proposed to account for the decline in attention which occurs with repeated exposure to a stimulus. It is assumed that infants initially process those stimulus features which are most salient. When they become sufficiently familiarized with this feature they then proceed to scan the next salient feature and continue this process until all the features have been processed. By calculating the duration and number of fixations infants made to the various regions of the stimulus (left and right regions and upper and lower regions), we were able to test the validity of this hypothesis. We calculated where, for how long, and the number of fixations infants made to each of the four on-stimulus zones, during each of the four analyzed habituation trials. Rather than progressively shifting their attention to the different regions of the stimulus, we found infants repetitively scanned a very specific region on the stimulus. Infants spent longer periods of time scanning the upper regions of the stimulus during Trial 1. They also made more fixations to the upper zones of the stimulus during both Trial 1 and 2. Interestingly, from an adult's perspective the two upper zones of the stimulus are the most salient as they resemble a profile orientation of a face. There were no differences in either the duration or in the number of fixations to specific regions on the stimulus between the Penultimate and Last trials. Quite possibly the whole stimulus is not being processes or perhaps the peripheral visual system carries the rest of the information.

Measures of whether infants scanned the stimulus, on average, for short or long periods of time before habituating, has been one means for describing individual differences in habituation performance. Colombo et al. (1991) hypothesized that differences between short and long lookers would be most evident during the initial stages of information processing. We found that infants who were categorized as long lookers or short lookers, based on their average fixation duration score, engaged in both qualitatively and quantitatively different patterns of scanning during the baseline trials of habituation and there were no differences between them on either the Penultimate or the Last habituation trial. Besides scanning the stimulus for longer periods of time, infants who were categorized as long lookers also made more fixations on the stimulus than short lookers. In addition, long lookers also changed fixation position more frequently than short lookers during Trial 1. While not significant, there was an obvious trend in the data to suggest that long lookers changed fixation position more frequently during Trial 2. Given that there were only 5 zones (4 on-stimulus and one collapsed off-stimulus), we concluded that long looking infants were repeatedly scanning previously inspected zones and were most likely not gaining additional information about the stimulus' properties compared to short lookers. Therefore, we hypothesized that this is an inefficient processing style.

Interestingly, there were no differences in the number of zones scanned on any of the four analyzed habituation trials between infants with different information processing styles. Therefore, in this data, the thoroughness of scanning does not seem to be influenced by the style of information processing each infant brings to the task.

We hypothesized that there would be differences between short and long lookers in terms of the duration and the number of fixations each type of scanner made to specific regions on the stimulus. Similar to the analysis performed on the average infant data, we calculated the duration and the number of fixations infants made to the left and right regions of the stimulus and to the upper and lower regions of the stimulus. In these data, there were no differences in the duration of fixations infants made to specific regions on the stimulus which were dependent on their style of processing. Interestingly, the data on the number of fixations made to specific regions presented a different pattern of results than that observed with the duration data. We found differences between short and long lookers in terms of the number of fixations each made to the stimulus, but only during Trial 1. There were no differences in the number of fixations infants made to the various regions of the stimulus during the other three analyzed habituation trials. Additionally, there were no differences in the number of fixations short looking infants made to the pre-defined stimulus regions. However, long looking infants made more fixations to the upper-left quadrant compared to the lower-left quadrant and there were no differences in number of fixations made to the upper- and lower-right quadrants. Therefore, long looking infants were more repetitive in where they scanned the stimulus in terms of the number of fixations they made. Corroborating evidence was provided by the analysis of the standard deviation of both the duration and the number of fixations scores; long lookers had a tendency to spend more time and make more fixations to a limited number of stimulus regions than short lookers. At this time, we do not know the functional importance of the long looking scanning style. Given that short and long lookers scanned a comparable number of zones, it is reasonable to conclude that short lookers formed as complete an image as long lookers, but did so more efficiently, that is, in a shorter period of time. However, why the number of fixations made to the specific regions of the stimulus was more sensitive to these differences cannot be answered at this time.

An infant's peak trial is assumed to be the phase in the habituation process in which they are processing the most information about the stimulus. The only evidence researchers have had to support this assumption has been simply that during this trial, infants look at the stimulus longer compared to the other habituation trials and that looking rapidly declines thereafter. In addition, because of the assumption that where an infant looks on a stimulus is what they are presently processing, this conclusion seems intuitive. This study unequivocally demonstrated that there are both qualitative and quantitative individual differences in scanning during the peak trial whereas, there are no such differences in scanning during either the preceding or succeeding trial. Long looking infants accumulated more time and made more fixations on the stimulus during the peak trial compared to short looking infants. In addition, we found that in general infants scanned more of the stimulus during this trial. Consistent with the findings of infant performance during the baseline trials of habituation, there were no differences between short and long lookers in terms of the thoroughness of scanning. Interestingly, infants were more variable in the number of zones they scanned during the trial succeeding the peak trial than they were during the peak trial. Furthermore, the rate of infant fixations was consistent within a trial so this finding was not the result of the longer duration of the trial of the peak fixation. Long lookers also made more changes in fixation position during the peak trial compared to short lookers. Again, because there were no differences between short and long looking infants in terms of the thoroughness of scanning during this trial, changing fixation position more frequently is probably a less efficient scanning style in that these infants were frequently returning to previously scanned zones.

Additionally, we found differences between the two types of scanning styles in terms of the duration and number of fixations each style of infant made to specific regions on the stimulus during the peak trial. Both short and long lookers whose peak trial occurred on Trial 1 concentrated their fixations on a very specific region on the stimulus; the elements of the stimulus that resembled profiles of a face. However, short lookers concentrated their fixations on a larger area than long lookers. Short lookers scanned the entire upper region of the stimulus compared to long lookers who only scanned one quadrant of the upper region. Quite possibly, this style allowed them to more quickly process the salient stimulus information compared to long lookers, who limited their scanning to a very narrow stimulus area. These data corroborate the earlier presented findings on the individual differences observed between short and long lookers during Trials 1 and 2 of the habituation sequence. For the majority of infants, the peak trial occurred on either one of the baseline trials. Therefore, the differences between short and long looking infants is in fact most evident during the initial trials of habituation.

There were no observed differences between infants whose peak trial occurred on Trial 1 compared to infants whose peak trial occurred later for any of the other variables analyzed. We can speculate the implication of this finding that both short and long lookers whose peak trial occurred on Trial 1 differentially attended to specific regions on the stimulus. Perhaps, analyzing where on the stimulus infants specifically scanned better taps into these differences than any of the other variables. Quite possibly, having the peak trial earlier during a habituation session is a more efficient scanning style, regardless of whether infants were short or long lookers. This finding may also be age specific, in that studies of the developmental maturation of the various parameters of infant habituation indicated that with age the peak trial appears later on during the progression toward habituation (Mayes & Kessen, 1989).

It appears that rather than progressively or incrementally processing the stimulus, infants encode simple stimuli, such as the one presented in this study, in basically one presentation (i.e., the peak trial). Although the relative duration and number of fixations vary between infants, once peak scanning occurred there were no longer differences on any of the various parameters of scanning between trials. This leads us to question what we are in fact measuring when we take infants to the habituation criterion. Perhaps, infants use these additional exposures to the stimulus to further refine the image they have of the stimulus.

Furthermore, similar to Coles and Sigman (1985) we did not find evidence which supported the serial processing hypothesis, that is, infants did not seem to proceed from exploring the more salient features of a stimulus to scanning the progressively less salient features of the stimulus. Infants were in fact very repetitive in their scanning behavior, frequently returning to a limited number of regions on the stimulus. This was especially true for long looking infants.

Previous research demonstrated that while the infant oculomotor and visual systems undergo major maturational changes during the first year of life, these systems function surprisingly well in the young infant. We did not find a developmental trend in these data. There were no differences either in terms of the global measures of habituation or in the scanning measures in infants between 2-and 3-months of age. Quite possibly the age range studied was too limited or that there are no substantial differences in information processing between these two age groups

Immediately following habituation, researchers have presented infants with novel stimuli and compared the amount of time they looked at the novel stimuli in comparison to the amount of time they looked at the re-presentation of the familiar stimulus. Using this procedure, researchers have tested whether and what infants remember about the familiar stimulus and what discriminations they can make between the familiar and novel stimuli. These studies have demonstrated that short looking infants perform better than long looking infants on a variety of related cognitive tasks. They demonstrated that processing style has implications both concurrently and predictively. Other researchers postulated that once infants have attained the habituation criterion differences between them will no longer be evident, that is, short and long looking infants have both similarly encoded the information and will therefore perform comparably during the test phase. In general, contrary to former findings and in support of the latter findings, we did not find differences between short and long lookers (as determined by their habituation data) in terms of either the qualitative or quantitative aspects of their scanning novel stimuli.

There were no differences between short and long lookers in the magnitude of their preference for novelty, that is, short lookers were no more likely to demonstrate a preference for novelty than long lookers (and vis-a-versa). It is possible that they made the discrimination between the familiar stimulus and the novel stimuli but just did not show a preference for the novel stimuli, a problem inherent to studies of the global measures of attention. However, analyzing the scanning measures seems to suggest that the scanning patterns of infants who showed a preference for novelty were different from those infants that did not show a preference. Infants who showed a novelty preference, made significantly more fixations to both novel stimuli compared to the familiar (habituation) stimulus. We also observed that infants scanned more zones on the novel stimuli than they did on the familiar stimulus; that is, they more thoroughly scanned the novel stimuli than they scanned re-presentations of the familiar stimulus. However, there were no differences either between short and long looking infants, or between those infants who showed a preference for novelty in comparison to those who did not show this preference. Why infants who did not show a preference for the novel stimuli actually scanned more of the on-stimulus zones of these patterns is curious. Perhaps different scanning measures tap into different scanning behaviors.

While we found no differences in the extensiveness of scanning the novel stimuli in comparison to the familiar stimulus in infants who did not show a preference for novelty, there was otherwise no clear pattern of results regarding the extensiveness of scanning. For example, we found that short looking infants who demonstrated a preference for the novel stimulus compared to the familiar stimulus made more changes in fixation position when they viewed the horizontally symmetrical stimulus than when they viewed the vertically symmetrical stimulus; however, we did not find a difference in scanning extensiveness for long looking infants. In addition, there were no differences in the extensiveness of scanning the asymmetrical stimulus between short and long lookers. We did however find a trend in the data to indicate that infants who showed a preference for novelty tended to change their fixation position more frequently when viewing the asymmetrical stimulus in comparison to the familiar stimulus. There are two aspects to these findings that need to be discussed. Firstly, given the fact that in general, we did not observe differences in the test phase performance between short and long lookers, perhaps the observed differences in processing the horizontally symmetrical stimulus was a chance finding. Secondly, during the habituation phase, long lookers made more changes in fixation position and we concluded that this was an inefficient scanning style. Given that there were only 5 zones to scan however, during the test phase it is the short lookers who more frequently changed fixation position. If these differences are in fact reliable, perhaps the extensiveness of scanning during each phase serves a different function. Also the duration of exposure to the novel stimulus was short and preset by the experimenter (i.e., 10 second presentations) therefore, the results from each phase may not be directly comparable.

While most studies found that infants demonstrate a preference for novelty following repeated exposure to another stimulus, these studies could not assess where on the stimulus infants looked on any particular fixation. We hypothesized that by examining where infants fixate a novel stimulus compared to where they fixate the re-presentation of the familiar stimulus might give us insight into what makes a discrimination of novelty possible or for that matter the scanning patterns which impede a preference for novelty. However, in these data, we found no differences between either short or long looking infants or between infants who showed a preference for novelty compared to those who did not, in terms of the duration and the number of fixations they made on specific regions on the novel stimuli in comparison to the similar regions on the familiar stimulus. Since only approximately half of the infants gave the minimal required data for the test phase, we hypothesized that power was significantly reduced and may have obscured these differences. Unfortunately, the implication of these results is that we are unable to delineate either the scanning patterns which facilitate the demonstration of a preference for novelty and the scanning patterns which impede the demonstration of a preference for novelty.

Interestingly, while there were significant correlations between the global and scanning habituation phase measures, we did not find the same relationship between the global and scanning test phase measures. The data have consistently shown that the global measures overestimate the duration of looking. We hypothesized that the scanning measures are more accurate and precise. Why the two types of measures portray infant information processing performance similarly during the habituation phase but differently during the test phase cannot be definitively answered at this time except to resort to the explanation a reduction in power because of our small sample size.

Colombo et al. (1991) demonstrated that the differences between short and long lookers is in terms of the speed with which they process visual information. They concluded that short lookers are faster and more efficient information processors and that there were no differences in the type of information (e.g., global versus featural information) each of these types of lookers processed. Therefore, while long lookers need more time to habituate, once they do, they have obtained as complete and faithful a mental representation of the stimulus as short lookers and therefore differences in performance with novel stimuli would not be expected. We attempted to explain why short looking infants are faster and therefore more efficient information processors. We hypothesized that the difference in information processing performance exhibited by infants might be dependent on differences in their accommodative responses such that, infants who correctly accommodate to a stimulus, will see the stimulus better, and are therefore will be better able to extract more of the details of the stimulus they are scanning. Several analyses were performed between the scanning style infants exhibited during habituation and their accommodative responses observed with the technique of photorefraction. In general, we did not find any evidence that differences in infants' accommodative performance is related to either their performance on a habituation task or in their ability to discriminate novel stimuli.

The database obtained with the analysis of eye movements is incredibly rich. There are many other questions that could be addressed with this data set. For example, are there "scanpaths" characteristic of a given infant, that is, is there a fixed pattern of fixation locations when they are viewing a pattern? In addition, previous research showed that there were special properties inherent to symmetrical patterns: they are preferred, processed faster, and remembered better than asymmetrical patterns in both adult and infants (Bornstein et al., 1981; Bornstein & Krinsky, 1985). Further, these studies found that this is especially true of vertically symmetrical patterns. Bornstein et al. (1981) proposed that the data on infant visual attention to vertical symmetry suggests that the recognition of vertical symmetry is either innate, matures very quickly, or learned very soon after birth. Therefore, it would interesting and it would certainly extend our knowledge about the processing of this special and ubiquitous type of pattern, if we specifically analyzed infants' temporal patterns of scanning. We may therefore be able to describe visual scanning patterns which facilitate the processing of vertical symmetry.

While a single study cannot address all the questions we have, or provide definitive answers on these issues, investigating visual scanning during habituation and upon the presentation of novel stimuli has advanced our knowledge of early information processing. There is a great number of studies which can be done to further the knowledge we have gained thus far. Firstly, converging evidence from studies using different types of stimuli are essential. Also, since research with adults has shown a linear relationship between the complexity of the material scanned and the duration of fixations, further studies should manipulate the complexity of the material presented to infants to see if this relationship is similar in infants. It also seems reasonable that there would be differences in information processing abilities which are age-dependent, either because of maturation or experience with visual stimuli. In order to developmentally delineate these changes a longitudinal study which follows infants from birth to the end of the first year, would be invaluable.

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