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Extended Visual Fixation in Young Infants: Look Distributions, Heart Rate Changes, and Attention

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Visual fixation in infants from 3 to 6 months of age was examined for its fit to the theory of "attentional inertia." This theory posits that during the progression of a look there is increasing attention toward the stimulus and an "inertia" to continue looking. An extended audiovisual stimulus was presented for 20 min to infants while fixation was videotaped and heart rate (HR) was recorded. Consistent with the attentional inertia theory, look duration toward the stimulus had a lognormal distribution. Hazard functions describing these distributions showed a decreasing conditional probability of looking away with increases in look duration. Look onset and stimulus changes that occurred within a look were accompanied by HR deceleration. The average HR level continued to decrease over the duration of a look and returned to prestimulus level immediately prior to the fixation offset. Infant fixation has characteristics similar to fixation in children and adults, and attention appears to increase over the course of a look in young infants.

INTRODUCTION

There are dramatic changes in visual attention during the infant and preschool years. Ruff and Rothbart (1996) summarize research on visual attention development in the preschool years. They hypothesize that an "orienting/investigative" type of attention predominates the first year of life. A second attention system, one involving higher-level control, planning, and self-regulation, is hypothesized to emerge in the second year and develop throughout the preschool years. However, the link between visual attention in early infancy and later childhood has some important deficits. Dissimilar experimental paradigms, the study of different theoretical constructs, and the problem of other developing competencies have limited the comparison of attention between infants and preschool children. This study attempts to link research on attention in preschool children with attention in 3- to 6-month-old infants by studying a theoretical construct in infants assessed in a paradigm similar to that which has been used with older children.

Extended looks have been studied by Anderson and colleagues with 3-year-old (Anderson, Choi, & Lorch, 1987) and 5-year-old (Anderson et al., 1987; Choi & Anderson, 1991) children and college-age students (Burns & Anderson, 1993). These studies have included television program viewing (Anderson et al., 1987; Burns & Anderson, 1993) and toy play (Choi & Anderson, 1991). Short duration (<5 s) looks made up the largest proportion of looks, and longer duration looks occurred with much lower frequency. The frequency distribution of look duration in these studies had a lognormal shape, in contrast to other possible distributions (e.g., exponential, gamma, normal, Weibull). The lognormal frequency distribution was true for individual infants as well as for aggregated data. The distributions were further examined with "survival analysis" and "hazard functions." The hazard function is the conditional probability that a look will terminate in a given interval given the probability of its surviving to that interval. The hazard function found in these studies (e.g., Anderson et al., 1987; Burns & Anderson, 1993; Choi & Anderson, 1991; Hawkins, Yong-Ho, & Pingree, 1991) was that typically associated with the lognormal distribution. There was an increase from 0 s to a peak at some short interval (i.e., 1–2 s), and then a decrease with increasing look duration. In other words, at very short intervals there was a high probability of looking away, but at longer look intervals it was much less likely that a look away from the stimulus would occur.

Look duration distributions in these studies were explained with a model of "attentional inertia" (Anderson & Lorch, 1983; Burns & Anderson, 1993). This model posits that attention is relatively unengaged at the beginning of each look and increases continuously over the course of a look toward that stimulus. The explanation for the increasing attention is based on the hypothesis that each look consists of the aggregation of a series of brief "comprehension units" lasting 1–2 s. Single comprehension units involve intensive cognitive activity and are resistant to distraction. Between comprehension units, the look is vulnerable to distraction. Because attention engagement is weak

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at the beginning of look, fixation is easily terminated between comprehension units. This results in a predominance of short looks. If a look survives past the first few comprehension units, attention engagement increases, and the probability of being distracted between successive comprehension units decreases. Attentional "inertia" holds attention across successive comprehension units as the look continues. The look durations in an extended-viewing session, generated by these comprehension units with changing probability of termination, should aggregate to form lognormal distributions. The lognormal distribution of look durations found in these studies (e.g., Anderson et al., 1987; Burns & Anderson, 1993; Choi & Anderson, 1991; Hawkins et al., 1991), and the associated "hazard function," are empirical markers consistent with the model's predictions.

The increasing attention engagement hypothesized to occur over the course of the look should have behavioral or psychological consequences. Anderson reported that with increasing look length there was a decreasing probability that a peripheral distractor would interrupt fixation and an increasing latency to respond to the distractor if such a response occurred (Anderson et al., 1987; Choi & Anderson, 1991). Similarly, others have reported that children's reaction times on a secondary task were longer after television viewing had been in progress for 15 s than for shorter lengths of time (Lorch & Castle, in press). These studies were interpreted as showing an increased selectivity for the central stimulus (increased attention engagement) compared to a competing distractor. An increase in the memory for scenes and information presented in the longer parts of the look has been shown (Burns & Anderson, 1993). Thus, comprehension of stimulus content increases as the length of the look progresses.

It is unknown whether the attentional inertia model applies to infant visual attention. Most theoretical accounts of infant visual attention deal with episodes of attention to single stimuli presented in isolation, with relatively short duration presentations (e.g., Colombo & Mitchell, 1990; Richards & Casey, 1992). Stimulus presentations in studies of infant attention often last only as long as the length of a single look (e.g., "infant control procedure," Cohen, 1972; Horowitz, Paden, Bhana, & Self, 1972). Similarly, the length of the sessions in these studies is typically limited to 5 to 10 min, even with infants in the second half of the first year (e.g., Oakes & Tellinghuisen, 1994; Ruff, 1986; Ruff, Capozzoli, & Saltarelli, 1996). The theoretical accounts of visual attention derived from these experimental paradigms would have limited usefulness to the study of attentional inertia due to these limited exposure conditions. The lack of studies of extended stimulus presentation in young infants limits the study of the development of fixation and attention from infancy through preschool ages. It also limits the study of infant attention in environments where episodes of attention may last longer than 5 min.

One study (Mendelson, 1983) has questioned the applicability of the attentional inertia model to infant attention. Mendelson (1983) analyzed data collected in previous studies of 4- and 7-month-old infants viewing a film of a moving puppet. First, Mendelson found that most of the long looks came from one group of infants ("long lookers"), and that the short looks came from a different group of infants ("short lookers"). The typical hazard functions reported by Anderson did not occur in the long-looking infants (Mendelson, 1983, Table 2). Second, Mendelson reported that most of the long looks were from the beginning of stimulus presentation, and that most of the shorter looks were looks later in the stimulus duration. Thus, he argued, a pattern of habituation of fixation could account for the distribution patterns found by Anderson and colleagues. Typical of studies of infants in this age range, the recording intervals in the Mendelson (1983) report were short (1.5, 3, or 6 min) relative to research with older children and consisted of the repetitive presentation of a single stimulus. The use of a repetitive stimulus presentation, and the relatively short recording intervals, limit the usefulness of this study in its critique of the applicability of the attentional inertia model to infant attention.

This study investigated the attentional inertia model in infants using methodology similar to that used with preschool-aged participants, namely, longer recording sessions (>20 min), stimuli that changed relatively frequently (12–30 s), and comparable stimuli ("Sesame Street" movie). There were two goals of this study. One goal was to determine if the markers of attentional inertia could be found in young infants. The attentional inertia model predicts that the probability of looking away from the stimulus decreases with increases in look duration. Thus, look duration should be lognormally distributed and should have a characteristically shaped hazard function (Burns & Anderson, 1993). This was examined with distribution characteristics of infant looks during the presentation of audiovisual stimuli in an extended session.

The second goal was to determine if attention engagement increased over the course of looks in infants. Because of the descriptive nature of the first goal, we did not want to use experimental manipulations such as a distraction paradigm or memory test to evaluate this. Some studies have used physiological measures to assess attention responses in television viewing (e.g., Lang, 1990; Thorson & Lang, 1992). These have not been done with regard to the attentional inertia hypothesis and have typically been limited to looking at transient responses to specific types of scene changes. The physiological measures may be useful because they allow a nonintrusive assessment of attention engagement without explicit experimental manipulations.

A potential attention-engagement measure is heart rate (HR) changes occurring in response to the visual stimulus. Heart rate changes have been used to distinguish attention engagement level in young infants (Berg & Richards, in press; Graham, 1979; Graham, Anthony, & Ziegler, 1983; Richards & Casey, 1991, 1992). There is a large HR deceleration occurring at the beginning of fixation that is hypothesized to reflect attention engagement, and is sustained throughout attention engagement. Conversely, when attention is disengaged, the HR returns to its prestimulus level. Several studies have shown that infants are relatively difficult to distract from central stimulus viewing (Richards, 1987) or toy play (Oakes & Tellinghuisen, 1994; Ruff et al., 1996) when engaged in active attention. This period of active attention may be specifically defined with HR deceleration (Casey & Richards, 1988; Lansink & Richards, 1997; Richards, 1987, 1997). The increased attention engagement with increased look duration hypothesized by the attentional inertia model should be accompanied by increased HR slowing. This could occur as a decrease in HR level during the entire look, or as increasingly larger or more sustained HR deceleration to stimulus changes occurring within a single look. We also examined HR changes for looks of differing duration and determined whether HR changes were tied to look onset and offset.

This study involved the presentation of audiovisual stimuli to infants at 14, 20, and 26 weeks of age. These ages were chosen because HR changes have been shown to be related to visual attention in this age range (e.g., Richards, 1987). The infant was seated on the parent's lap and the stimuli were presented continuously for a minimum of 20 min. A "Sesame Street" movie ("Follow That Bird") was used in the first session as a stimulus that involved speaking, communication between people, and typical "naturalistic" stimulus situations. Thus, this study could be compared directly to those used to study attentional inertia in children's television viewing (e.g., "Sesame Street" TV program; Anderson, Lorch, Field, & Sanders, 1981, Anderson et al., 1987; Hawkins et al., 1991). Abstract visual patterns generated by a computer and accompanying audio stimuli were used in the second session. These patterns are typical of those used in infant visual attention research and could be contrasted with those typically found in young children's television viewing. These stimuli were presented continuously with a change to a new pattern about every 30 s, to avoid the long repetitive stimulus intervals used by Mendelson (1983; e.g., 90 or 180 s).

METHOD

Participants

Infants were recruited from birth notices published in a Columbia, SC, newspaper. The infants were term, defined as having birthweight greater than 2,500 g and gestational age of 38 weeks or greater based on the mother's report of her last menstrual cycle. The infants had no acute or chronic pre- or perinatal medical complications and were in good health at the recording sessions. There were 15 infants tested on 2 days, five at each testing age. The age of the infants on the first testing day was 14 (three female and two male, $M = 98.4$ days, $SD = 2.70$), 20 (two female and three male, $M = 139.8$ days, $SD = 3.49$), or 26 (two female and three male, $M = 183.8$ days, $SD = 2.16$) weeks postnatal age. The second testing day was in the next week, making the age of the infants on the second testing day 15 ($M = 106.0$ days, $SD = 4.18$), 21 ($M = 147.2$ days, $SD = 3.11$), or 27 ($M = 189.0$ days, $SD = 3.00$) weeks postnatal age. Three infants were tested in the study who did not complete the testing protocol on the second day (sleepy, fussy, not interested during protocol) and were not included in any analyses.

Apparatus

The infant was held on the parent's lap approximately 55 cm from a 49 cm (19 inch) TV monitor. The TV subtended 44° visual angle. A Yamaha Power Amplifier (MX-35) amplified the sound that was played through two Radio Shack "Realistic" audio speakers that were placed at the edges of the TV. A neutral color material covered the surrounding area. A video camera was above the TV, and in an adjacent room an observer judged infant fixations on a TV monitor. The session was recorded on videotape with a time code to synchronize fixation changes with physiological and stimulus information for analysis.

The stimulus for Session 1 was a "Sesame Street" movie (selected from the first 45 min of "Follow That

Bird") played on a laserdisc player, presented on the TV monitor with audio. Scene changes (shifts of scene to new locations and/or actors) and perspective changes within a scene (pans or camera shifts to new perspectives within same scene) in the movie were identified. These scene/perspective changes were synchronized with fixation data and physiological recording by recording the laserdisc player time code during the experiment. The average length between major scene changes was 25.45 s and was positively skewed (*Mdn* = 15.02 s, *mode* = 4.99 s, 90 *P* = 65.02 s). Shifts between scenes or perspective changes within a scene had an average length of 14.88 s and were skewed (*Mdn* = 7.6 s, *mode* = 5.99 s, 90 *P* = 32.32 s).

The stimuli for Session 2 consisted of 16 dynamic computer-generated patterns (e.g., a series of concentric squares of varying size, a flashing checkerboard pattern, a small box shape moving across a diamond) accompanied by 12 auditory stimulus patterns. The audio stimuli were generated by Colbourn "Precision Signal Generator" and "Voltage Controlled Oscillator" modules. The audio stimuli consisted of 12 different changing patterns of sound (e.g., a pulsed 1200 Hz tone, a pulsed 1400 Hz tone, a pulsed tone alternating 1200 Hz/1400 Hz, a sliding frequency from 0 to 1200 Hz or from 400 to 1600 Hz, random frequencies across the range of 0 to 1600 Hz). The dynamic changes in the audio stimuli were synchronized to the movement/dynamic aspects of the visual stimuli. The visual stimuli previously have been found to elicit first-look durations greater than 10 s and significant HR decelerations, and were easily discriminable by each of the three age groups (Richards, 1997). The auditory patterns elicit significant HR decelerations in infants in this age range (Richards, 1994).

The computer-generated stimuli in Session 2 were presented continuously, with stimulus changes occurring at 20, 25, 30, 35, or 40 s. The pairing of the visual and auditory stimuli was random on each presentation. The 16 visual patterns were presented randomly without replacement in 16-stimulus blocks, and the 12 auditory patterns were presented randomly without replacement in 12-stimulus blocks. The stimulus durations were randomly presented with the restriction that each duration occur in each 5-stimulus block. An inspection of the actual stimulus durations showed nearly equal numbers of presentations of each duration. The onset time (computer-based time) of each stimulus was recorded during the presentations to synchronize the change in stimuli with the videotape and physiological recordings.

Procedure

The parent sat in a chair in the viewing area with the infant on the parent's lap facing the TV monitor. The audiovisual stimuli were presented continuously as long as the infant maintained an alert, awake state (eyes open, no fussing or crying, looking at the visual stimuli). If the infant became fussy, a short break was taken and the presentations paused. Testing was continued only if the infant returned to and maintained an alert, awake state. The duration of the presentations was set at the predetermined minimum of 20 min, and some sessions were continued for several minutes longer (maximum duration of 26 min).

Measurement and Quantification of Physiological Variables

The ECG was recorded with Ag-AgCl electrodes on the infant's chest and was digitized at 1000 Hz (each ms) with a microcomputer. A computer algorithm identified the QRS complex in the ECG, and interbeat interval (IBI) was defined as the duration between successive R-waves in the ECG. Artifact correction was done using the Berntson, Quigley, Jang, and Boysen (1990) and Cheung (1981) algorithms along with visual inspection of suspect beats. The IBI was assigned to 0.5 s intervals by averaging the IBIs in each interval weighted by the proportion of the interval occupied by that beat. The interbeat *interval* is the reciprocal of heart *rate*, so that lengthening of the IBI corresponds to HR deceleration and shortening of the IBI corresponds to HR acceleration, or the return of HR to its prestimulus level.

Fixation Judgments

Each session was judged off-line by two observers, and data for the analysis came from one observer's judgments. A time code recorded on the videotapes allowed the judgment to have millisecond accuracy, although resolution was limited to a single video scan (0.5 * total frame length = ~ 16 ms). The observers judged the infant as looking toward the TV, looking away from the TV, or could not be judged. The time code on the videotape was synchronized with the computer clock to synchronize HR changes with fixation.

The agreement between the two observers for the look judgments was assessed for 27 of the 30 recording sessions (the time code was restarted for three sessions, and the two observers' times could not be synchronized). The concordance between the two observers was assessed in three ways. First, the overall time when the two observers concurred that the infant was looking at the stimulus was computed. The total overlap time for the 27 infants was 473.33 min of 500.08 min of total looking time (94.6% overlap). The overlap for individual infants ranged from 84% to 99% ($M = 94.1\%$, $Mdn = 95.1\%$). Second, the difference in look onset and offset for the two observers was compared. The beginning and end of each look judgment for one observer were compared to a look judgment for the second observer that uniquely overlapped the first observer's beginning time or end time. The average and median of the absolute difference between look judgments were less than 1 s (onset: $N = 1{,}663$ looks, $M = 0.86$ s, $SD = 1.073$, $Mdn = 0.56$ s, $90\ P = 1.88$ s; offset: $N = 1{,}764$ looks, $M = 0.62$ s, $SD = 1.072$, $Mdn = 0.25$ s, $90\ P = 1.59$ s). This indicates that the two observers identified the look onsets and offsets quite closely. Third, however, approximately 15% of the judgments of the second observer did not uniquely overlap the start or end time of the first observer's judgments. Most of these looks consisted of a judgment that was coded by one observer and not the other that a brief look away from the stimulus occurred ($N = 201$ looks, $M = 1.38$ s, $SD = 1.247$, $Mdn = 0.93$ s). The remaining look judgments that did not overlap had a large range of times, but accounted for only 3% of the total looks ($N = 50$ looks, $M = 8.27$ s, $SD = 10.301$, $Mdn = 5.09$ s, *range* = 0.67 to 63.14 s) and had varying degrees of overlap between the first and second observers. The two observers substantially agreed with respect to total look duration and the actual times the infants looked toward and away from the visual stimuli.

The distributions of the look duration judged by the two observers were compared. The effect of the coder on the hazard function was calculated (i.e., do one coder's judgments show an accelerated hazard function). Given a lognormal distribution for look duration (see Results), the null hypothesis that the two coders had the same hazard function could not be rejected, $\chi^2(1, N = 5{,}621) = 1.62$, $p = .202$. Similar results were obtained by assuming other underlying distributions for the look times (e.g., exponential, Weibull). Similarly, if the data were divided into 2.5 s categories for looks between 0 and 60 s, then the null hypothesis that coders' frequency distributions in these categories were the same could not be rejected, $\chi^2(23, N = 5{,}621) = 29.12$, $p = .176$. These findings indicate the coders' distributions were not significantly different.

RESULTS

Look Duration

Table 1 contains the descriptive statistics for the average look duration and total look duration. The infants spent a majority of the time looking toward the stimulus (from 48% to 84%). The distribution parameters for the average look duration were inconsistent with a normal distribution (e.g., mean > median, large standard deviation, skew, kurtosis). The inconsistency of these distribution parameters with the normal distribution implies that another type of distribution (e.g., lognormal, Weibull) will be necessary to fit the look duration distribution (see next section). On the other hand, the skewness/kurtosis parameters for the total look duration were between 1.0 and 2.0 for each condition (not presented in Table 1). The average look duration was longer for the looks toward the "Sesame Street" stimulus than for looks toward the computer-generated stimuli. The median look duration was close for the two type of stimuli because the mean for each group for the "Sesame Street" looks was inflated by a small percentage of extremely long looks (>90 s).

The average look duration toward and away from the stimulus was analyzed with an age (3) × stimulus type (2; "Sesame Street," computer stimuli) × look direction (2; look toward, look away) ANOVA.[1] The only significant effects were look direction, $F(1, 12) = 61.71$, $p < .001$, and an interaction between age and look direction, $F(2, 12) = 7.05$, $p = .009$. The average look toward the TV was longer than the looks away from the TV. The interaction between age and look direction reflected the larger difference between the looks toward and away from the stimulus for the 14-week-old infants relative to that at either of the older two ages. A similar analysis for the total look duration resulted in a significant look direction main effect. The interaction between look direction and stimulus type for total look duration approached statistically significanct levels, $F(1, 12) = 4.11$, $p = .067$. Overall, the infants looked longer at the "Sesame Street" stimulus, although this was primarily due to a few extremely long looks.

The possibility that look duration changed across the recording session was examined to determine if habituation or fatigue effects occurred. This was done by splitting the session into 5 min blocks and using

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[1] The ANOVAs for many of the analyses were done with a general linear models approach using nonorthogonal design because of the unequal distribution of looks across factors, and because of the different epoch numbers for the look duration categories (see Hocking, 1985; Searle, 1971, 1987). The sums of squares (hypothesis and error) for the nested effects in the design were estimated using "subjects" as a class and nesting repeated measures (e.g., stimulus type, look direction) within this class variable. The "PROC GLM" of SAS was used for the computations. The duration dependent variables (e.g., look duration per stimulus) were log-transformed before analysis to obtain a variable consistent with a normal distribution.

Table 1 **Descriptive Statistics for Duration of Each Look and Total Duration of Looking, Separated by Age and Stimulus Type**

	"Sesame Street" Movie		Computer Stimulus	
	Toward	Away	Toward	Away
14-week-old infants:				
n	468	494	496	541
Duration per look(s)	12.50	5.04	11.92	5.98
Median	5.89	2.14	5.88	3.26
SD	19.615	7.691	15.996	8.113
Skew/kurtosis	4.4/27.8	4.5/29.0	3.0/13.9	3.1/12.8
Total duration (min)	14.34	5.77	13.07	7.18
SD	1.59	.98	2.21	2.27
Percent looking toward	71.2		64.5	
20-week-old infants:				
n	536	576	341	396
Duration per look(s)	10.04	4.79	7.89	5.73
Median	4.37	2.64	4.15	3.50
SD	15.938	16.602	9.915	6.89
Skew/kurtosis	3.6/16.0	21.6/49.0	2.6/8.5	3.0/13.1
Total duration (min)	13.40	6.81	10.52	9.05
SD	2.43	3.27	1.23	1.27
Percent looking toward	66.8		53.7	
26-week-old infants:				
n	402	458	399	470
Duration per look(s)	11.89	6.21	10.38	6.76
Median	5.64	4.03	4.40	4.35
SD	18.056	8.949	17.422	9.240
Skew/kurtosis	3.4/14.99	7.5/86.1	4.7/33.9	6.6/74.6
Total duration (min)	12.23	7.45	11.30	8.94
SD	1.32	.84	3.31	2.78
Percent looking toward	62.0		55.4	

the data from the first four blocks (all participants had at least 20 min in each session). The duration of the looks toward and away from the stimulus was analyzed with an age (3) × stimulus type (2) × look direction (2) × phase (4; 5 min blocks) ANOVA. The only significant effect involving the phase factor was a look direction × phase interaction, $F(3,36) = 6.26, p = .002$. There was no change in the average look duration toward the stimulus over the four 5 min intervals (*M*s = 10.25, 9.67, 11.07, and 9.83 s, respectively), whereas the average look duration away from the stimulus increased (*M*s = 4.16, 4.90, 5.37, and 7.26 s, respectively). An analysis of the total look duration in each 5 min period showed a similar decrease in total looking over time. These results suggest that habituation and fatigue effects did not significantly affect the characteristics of the looks toward the stimulus.

Frequency Distributions

The hypotheses pertaining to "attentional inertia" were examined using the frequency distributions of each look. The attentional inertia model would be consistent with lognormal distributions of the look durations (Burns & Anderson, 1993). A lognormal distribution is one in which the log of the values is normally distributed. Figure 1 has the frequency histogram separately for the looks toward and away from the stimulus, and separately for the "Sesame Street" and computer-generated stimuli sessions. Consistent with the descriptive data presented in Table 1, there was a large positive skew and kurtosis in each condition, predominated by short duration looks, and a few extremely long looks. The individual infants' distributions looked similar to the aggregate distribution.

The obtained distributions were examined with statistical methods to determine if they could be characterized as a lognormal distribution.[2] Other distribu-

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[2] The obtained frequency distributions were compared against the hypothetical distributions by (1) estimating parameters of the hypothetical distributions with maximum likelihood techniques and (2) comparing the obtained and estimated-hypo-

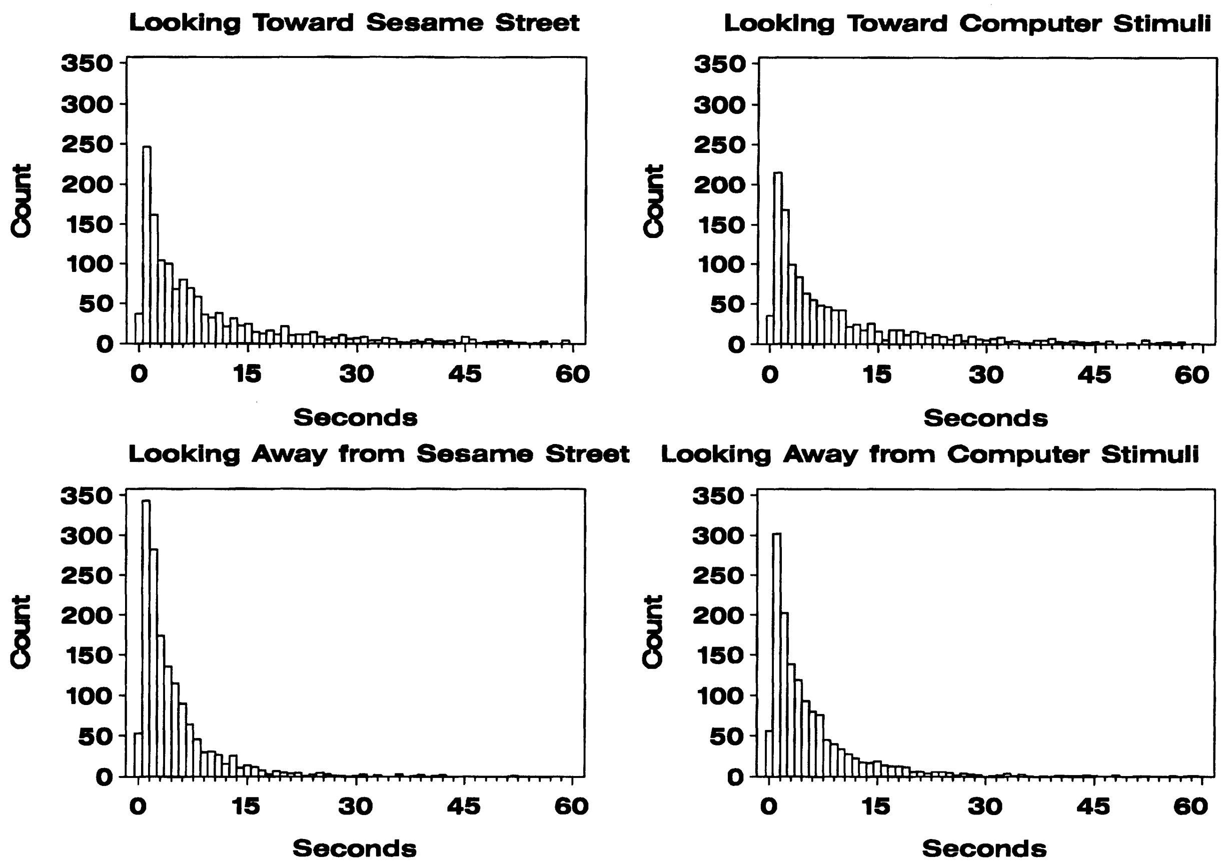

Figure 1 Frequency distribution of looking toward the stimulus and looking away for the stimulus, separately for the "Sesame Street" session and the computer-generated stimuli session. These frequency histograms were for 1 s intervals.

tions (e.g., exponential, Weibull, gamma) conceivably could account for the distribution of look durations with the parameters found in this study (e.g., Table 1). The obtained distributions were compared against the following hypothetical distributions: exponential, gamma, logistic, lognormal, normal, and Weibull. The hypothesis that the empirical distribution of looks toward the stimulus was not different from the hypothetical distribution was rejected for all hypothetical distributions for the data aggregated over all infants. Of the distributions, the lognormal had the closest fit to the observed data, $\chi^2(57, N = 2{,}574) = 151.00$, followed by the logistic, $\chi^2(57, N = 2{,}574) = 350.28$, Weibull, $\chi^2(57, N = 2{,}574) = 362.59$, gamma, $\chi^2(57, N = 2{,}574) = 440.57$, and exponential, $\chi^2(57, N = 2{,}574) = 569.92$. The normal distribution had the poorest fit to the observed distribution, $\chi^2(57, N = 2{,}574) = 10976.30$. The null hypothesis that the distribution of the looks away from the stimulus was the same as the lognormal distribution could not be rejected, $\chi^2(57, N = 2{,}910) = 66.80$, $p = .176$, whereas the null hypothesis was rejected for the other distributions ($ps < .001$). Figure 2 shows the distribution of the aggregate data along with the closest fitting lognormal distribution, separately for the looks toward the stimuli and the looks away from the stimuli. The lognormal distribution most closely characterized the distribution of look durations.

Individual infants' distributions were examined. Each infant's observed look duration distributions were compared against the hypothetical distributions, as was the aggregate data. The lognormal dis-

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thetical distributions with chi-square. The null hypothesis of no difference between an observed and hypothetical distribution would show that the hypothetical distribution is a good fit, and a statistically significant chi-square value would show that the observed distribution is not well described by the hypothetical distribution. The null hypothesis was rejected for all of the observed-hypothetical distribution comparisons for look duration, but this is likely due to the large number of observations and the sensitivity of this test to small differences. The best fit in each case was the lognormal distribution. Goodness-of-fit indices showed that the lognormal distribution was an acceptable description of the look durations in each case.

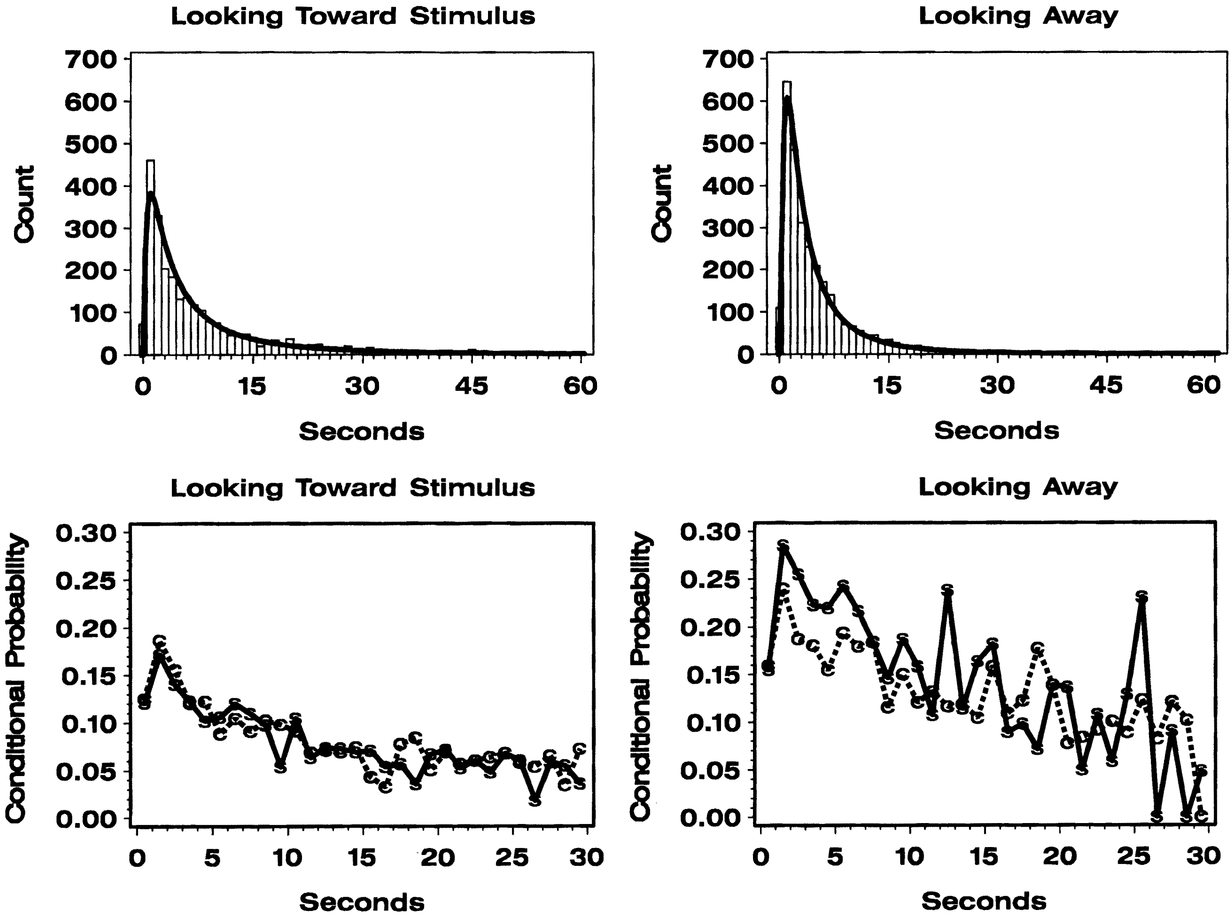


Figure 2 Frequency distribution for looking away and looking toward the stimulus, with the best-fitting lognormal function (top figure). Hazard functions for looking toward and away from the stimulus, separately for the "Sesame Street" session ("S") and computer-generated stimuli session ("C"). The conditional probability of the hazard function is the probability of the "hazard" that a look will terminate at interval "$t + 1$" conditional on the probability of the look having survived to time t.

tribution was the best fit for all except one. In addition, for 14 of the 30 infants, the null hypothesis that the hypothetical and observed distributions were the same could not be rejected for the lognormal distribution. For most of the participants, the Weibull and gamma distributions were a closer fit than the exponential distribution. The null hypothesis that the Weibull and observed distributions were the same was rejected for 28 of the 30 infants. Thus, in addition to the aggregate data, data for individual infants were also best described by the lognormal distribution.

The final analysis of the distributions was to examine the "survival" or "hazard" function for the look durations. The hazard function is the conditional probability that a look will terminate in a given interval given the probability of its surviving to that interval, that is, the "hazard" that a look will end. The hazard function for look duration found in studies with children and adults (e.g., Anderson et al., 1987; Burns & Anderson, 1993; Choi & Anderson, 1991; Hawkins et al., 1991) was that typically associated with the lognormal distribution. The obtained hazard functions for the looks toward and away from the stimulus showed the expected quick rise to a peak at about 1–2 s, followed by a decline toward zero with increasing look duration (Figure 2). A smaller unit of analysis (0.1 s) resulted in the peaks occurring near 1.1 s. This hazard function is that typically associated with the lognormal distribution, and is further evidence of the underlying hypothetical distribution being lognormal.

A test that the hazard functions were differentially affected by the experimental factors showed several things. For the looks toward the stimuli, the hazard functions of the look durations to the "Sesame Street" stimulus were not significantly different from those to the computer-generated stimuli, $\chi^2(1, N = 2{,}642) = 1.16$, $p = .280$ (Figure 2). This indicates that the underlying duration distributions of the two stimuli were similar. The hazard functions of the duration of the looks away from the stimulus were significantly different from the looks to the stimulus, $\chi^2(1, N = 5{,}577) = 189.97, p < .001$. The looks away from the stimulus showed a much larger peak on the short duration looks followed by larger conditional probabilities of terminating than the looks toward the stimulus (Figure 2). This indicates that the looks away were more vulnerable to termination early in the look (shorter duration looks) than were the looks toward the stimulus. Finally, the hazard functions were significantly affected by age. The functions of the 14-week-old infants were significantly different than those of the 20- and 26-week-old infants, $\chi^2(1, N = 1{,}841) = 18.87, p < .001$, and $\chi^2(1, N = 1{,}765) = 6.34, p = .012$, for 14/20 week and 14/26 week comparisons, respectively, whereas the distributions of the 20- and 26-week-old infants were not significantly different, $\chi^2(1, N = 1{,}678) = 2.09, p = .147$. The predominant characterization of the differences was that the peak of the hazard functions for the short duration looks was smaller in the 14-week-old group than in the older age groups. The conditional probabilities of the longer duration looks were also smaller for the 14-week-old infants. This difference reflects the tendency of these infants to have longer overall looks than the two older ages (Table 1).

In summary, the attentional inertia model (Burns & Anderson, 1993) posits that the processes controlling look length result in look duration distributions that are lognormally distributed. The best-fitting hypothetical distribution for the data in this study was the lognormal distribution. In almost all comparisons, the null hypothesis that the obtained distribution was the same as the lognormal distribution could *not* be rejected. This was true for the distributions aggregated across infants as well as for the distributions of look duration for individual infants. The 14-week-old infants had a tendency to have longer overall looks than the older two ages, reflected in smaller conditional probabilities for the younger infants' longest looks.

Interbeat Interval Changes

The hypothesis that HR changes along with lengthening periods of fixation was examined in several ways. In each case, an important variable in the analyses was the duration of the look in which the HR changes occurred. If HR changes were related to factors determining look duration (e.g., attentional inertia, habituation), then look duration and HR changes should be related. In general, for these analyses, looks were divided into five categories: 0–5 s, 5–10 s, 10–20 s, 20–40 s, and greater than 40 s. The lengthening of the IBI corresponds to HR deceleration, whereas IBI shortening corresponds to HR acceleration or the return of HR to its prestimulus level.

First, an examination of the change in IBI values accompanying differing length looks was done. The difference in the mean IBI in 2.5 s preceding a fixation toward the stimulus and the mean IBI from 5 s periods during fixation toward the stimulus (mean 5 s IBI minus mean 2.5 s prestimulus IBI) was calculated. Figure 3 shows this average IBI change for the different length looks separately for the "Sesame Street" and computer-generated stimuli sessions. Two things are immediately apparent. First, there was a gradual increase in IBI level (HR deceleration) over a substantial period of time (up to 250 s displayed). Second, this change was similar for all durations of looks. That is, the relatively brief looks (<20 s) showed the same pattern of IBI lengthening during their occurrence as did the extended looks (>20 s) for the first 20 s of their occurrence. This change score was analyzed with an age (3) × stimulus type (2) × look length (5; 0–5 s, 5–10 s, 10–20 s, 20–40 s, >40 s) × epochs (20; 5 s periods) ANOVA, using the general linear model to estimate effects due to the unequal number of epochs in the look length categories. There were expected effects of epochs reflecting the increased IBI lengthening over time, $F(21, 205) = 9.10, p < .001$, and a corresponding main effect of look length, $F(4, 38) = 10.77, p < .001$. There was no interaction between epochs and look length, supporting the observation that the IBI change pattern was similar for differing look lengths. There were no significant effects involving stimulus type or age. There seems to be a difference in the deceleration on the brief looks and the extended looks (Figure 3). This occurred only for the last average that was calculated, and may be due to unequal numbers of observations in this interval due to the look ending in that interval.

Second, the relation between IBI lengthening, stimulus change, and look duration was examined. For each look toward the TV, we identified when there was a scene or perspective change in the "Sesame Street" recording, or when there was a change in the computer-generated stimulus. The change in IBI from the 2.5 s preceding each occurrence of the stimulus change was examined for each 0.5 s interval (for looks at the new stimulus exceeding 5 s; 0.5 s IBI level minus mean 2.5 s prestimulus IBI). This change score was analyzed with an age (3) × stimulus type (2) × prior length of look (5) × epochs (20; 0.5 s periods) ANOVA. There were several significant effects, including epochs, $F(19, 266) = 6.36, p < .001$,

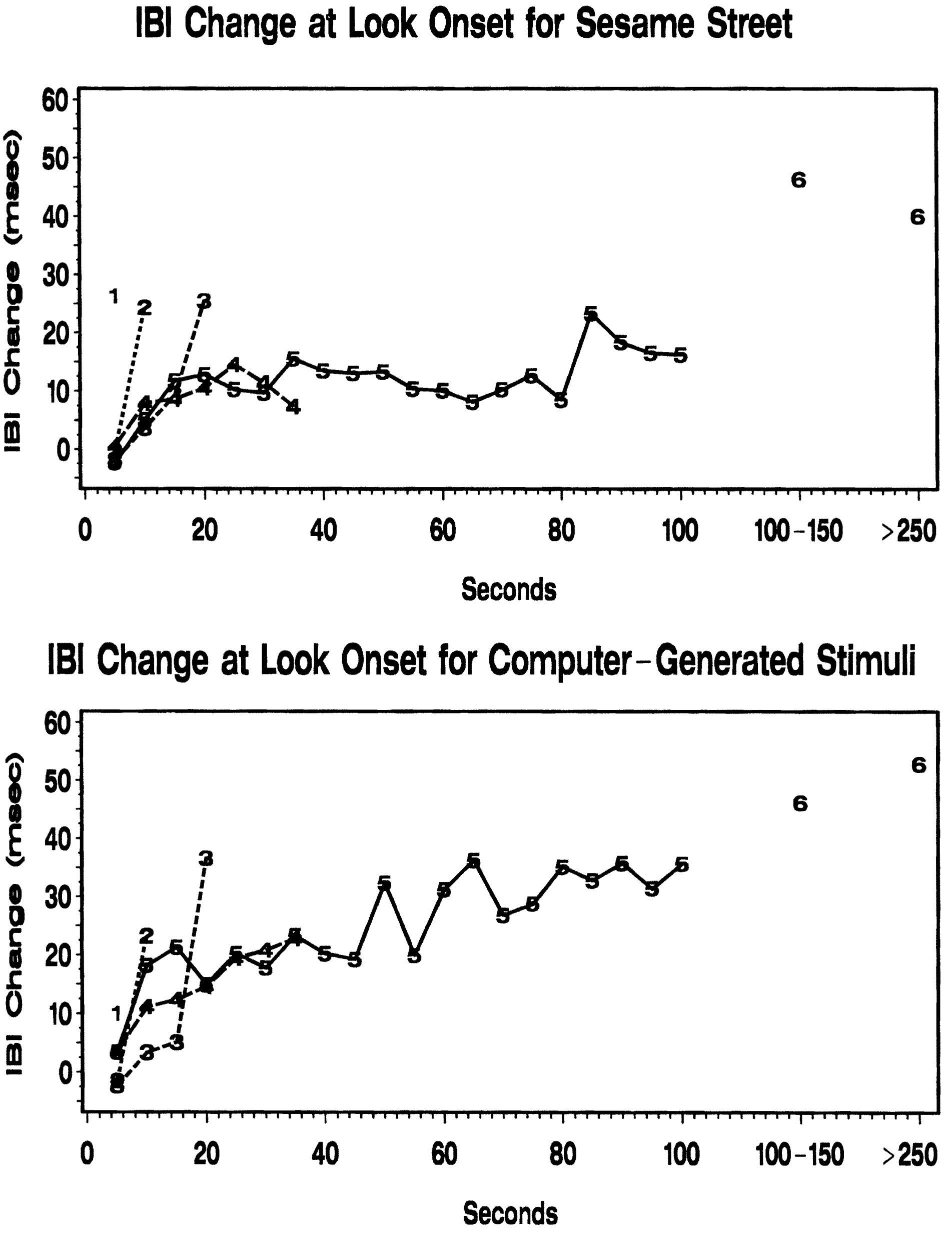
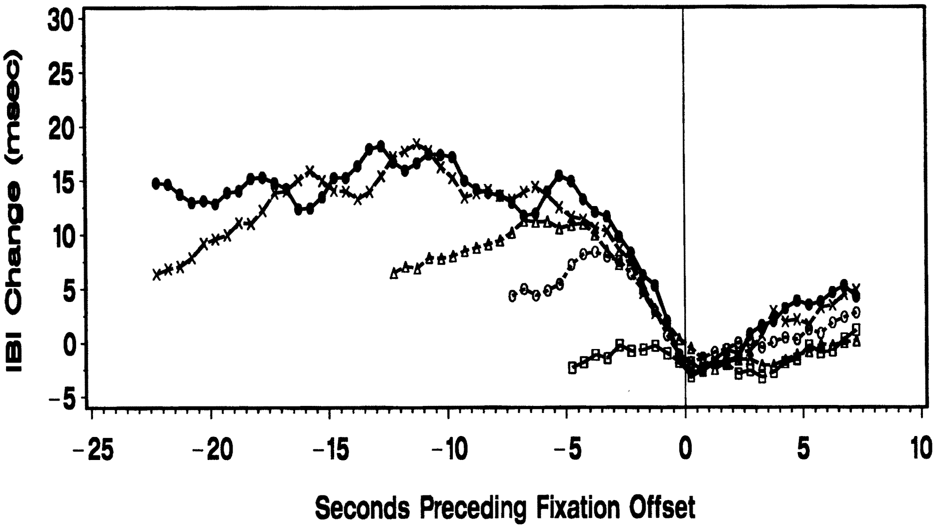
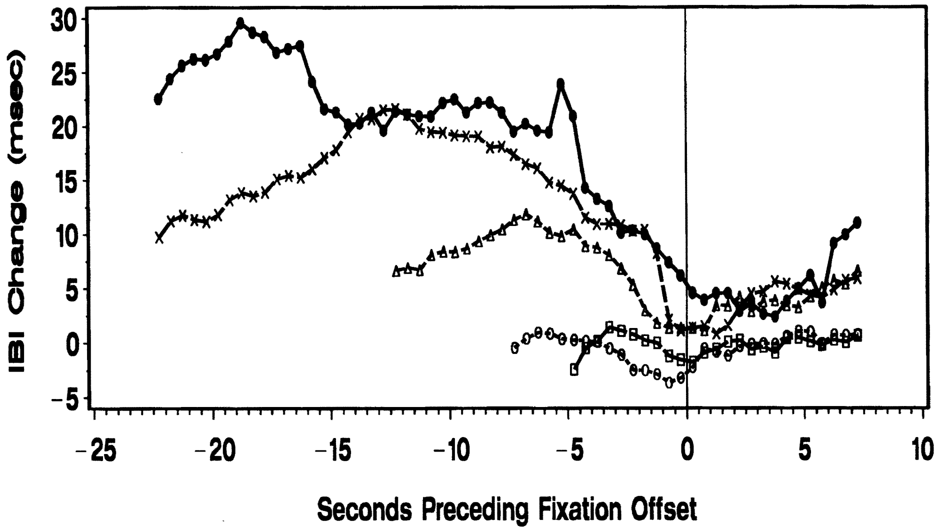


Figure 3 The change in IBI length (mean 5 s IBI minus average prestimulus IBI) as a function of the duration of the fixation (1 = 0–5 s; 2 = 5–10 s; 3 = 10–20 s; 4 = 20–40 s; 5 = >40 s). The average IBI change on extremely long looks (6 = 100–150 and >250 s) is also displayed. This figure does not include the last 5 s of fixation (see Figure 4).

prior length of look, $F(4, 55) = 2.71$, $p = .039$, and stimulus type × epochs, $F(19, 208) = 3.37$, $p < .001$. For the computer-generated stimulus, there was an immediate IBI lengthening (HR deceleration) at the onset of the new stimulus. The IBI increase appeared to be independent of the immediately preceding length of the look. For the "Sesame Street" movie the lengthening of the IBI was not as large overall, with an immediate change for those looks that had been in progress for a short time (<10 s) and little change for longer-length looks. Thus, even in the context of a steadily decreasing "tonic" HR level (Figure 3), the computer-generated stimulus produced significant HR deceleration. The scene/perspective changes for the "Sesame Street" movie produced such "phasic" changes if the look had been in progress a short time, but not in the context of longer duration looks and a large "tonic" change.



Sesame Street Fixation Offset



Computer-Generated Stimuli Fixation Offset

Figure 4 The return of IBI toward the prefixation level at the end of fixation (mean 0.5 s IBI minus average prestimulus IBI). The look away from the stimulus occurred at second 0, and the differing length fixations preceding the look away are separately plotted. (■: 0–5 s; ○: 5–10 s; ▲: 10–20 s; ×: 20–40 s; ●: >40 s).

The third way that HR changes were examined in relation to look duration was to plot the IBI changes that occurred near the termination of a look. The offset time of each look toward the TV stimulus was identified. The IBI changes occurring immediately prior to look offset were computed for the differing look length categories (0.5 s IBI minus mean 2.5 s prestimulus IBI). Figure 4 shows IBI changes occurring at the end of the look, separately for the "Sesame Street" and computer-generated stimuli sessions. The IBI values for all look lengths were returning to prestimulus levels before the look offset occurred. This was particularly striking on the look lengths between 20 s and 40 s and looks greater than 40 s. In these cases, HR returned toward prefixation levels precipitously from the large "tonic" shift in IBI level that had occurred on those extended looks (e.g., Figure 3). This shift back to prefixation IBI level then matched the shift for the shorter duration looks at approximately the time that the look duration on those shorter looks was beginning to terminate (Figure 4, seconds -5 to -1). This effect was clear in the IBI changes occurring at the end of looks toward the "Sesame Street" stimulus, where all look duration categories joined the acceleration toward prestimulus level (Figure 4). This effect was clear in the three longest look categories for the computer-generated stimuli (Figure 4).

The IBI change occurring at the end of fixation was analyzed with an age (3) × stimulus type (2) × look length (5) × epochs (50; 0.5 s periods) ANOVA, using the general linear model to estimate effects due to the unequal number of epochs in the look-length categories. There were expected effects of look length, $F(4, 48) = 7.59$, $p < .001$, epochs, $F(49, 686) = 16.20$, $p < .001$, and an interaction between look length and epochs, $F(111, 920) = 2.44$, $p < .001$. These effects represented the differences in the pattern of the return of IBI to prefixation level for the five look-length categories. Post hoc tests comparing the IBI changes from similar time epochs of differing look lengths (e.g., IBI from seconds -15 to $+2.5$ for look lengths of 20–40 s and >40 s; IBI from seconds -7.5 to $+2.5$ for look lengths of 10–20 s, 20–40 s, and >40 s) showed expected epoch effects but no differences in the look-length categories. This pattern of significant effects confirms the observation evident in Figure 4 that IBI changes on differing look lengths return in a similar manner toward prestimulus levels prior to look termination. There was a significant main effect of stimulus type reflecting the larger IBI increase to the computer-generated stimuli, but no difference in the pattern of acceleration toward prefixation IBI level for the stimuli. There were no significant effects involving age.

To summarize, there were several findings showing that HR change occurred across lengthening periods of fixation. The IBI lengthening typically found at the beginning of stimulus onset (HR deceleration) continued to occur over a substantial period of time. This IBI lengthening was continual over the entire course of the look and did not just represent sudden HR deceleration at the beginning of a look (Figure 3). In addition to this tonic change over extended looks, the computer-generated stimuli continued to produce "phasic" HR deceleration in addition to the tonic level. Finally, look termination was found to be preceded by a return of IBI toward its prestimulus level. This return of IBI to its prestimulus level occurred in a similar fashion for brief, intermediate, and extended duration looks (Figure 4). Thus, the extent of the tonic HR change over the course of a look does not affect how the HR returns to its prestimulus level near the look away from the stimulus.

DISCUSSION

The first goal of this study was to determine if the markers of attentional inertia could be found in young infants. The distributions of look duration toward the visual stimuli were consistent with those predicted by the attentional inertia model. In this study, the distribution of look duration most closely matched the lognormal function. The hazard function, that is, the conditional probability that a look will terminate in a given interval given the probability of its surviving to that interval, was that typically associated with the lognormal distribution (Figure 2). The empirical distributions of look duration with older children (Anderson et al., 1987; Choi & Anderson, 1991; Hawkins et al., 1991) and adults (Burns & Anderson, 1993) fit a lognormal distribution most closely and showed hazard functions similar to those found in this study. These distributions show that early in each look there was a high likelihood that the look would end. As the look progressed, the probability of termination decreased. This finding is consistent with the hypothesis that attention engagement was increasing over the course of the look and that distractibility by other stimuli was decreasing.

The peak of the hazard function in this study was similar to that reported for older children and adults. The peak of the hazard function for television viewing has been reported by Burns and Anderson for adults (1993) and Hawkins et al. for children age 3.5 to 6.5 years (1991) to be around 1 to 2 s. In the present study, the peak of the hazard function occurred in the second interval (1–2 s; or 1.1 s with 0.1 s frequency bins). The theoretical explanation for the attentional inertia model is based on the hypothesis that each look consists of the aggregation of a series of brief "comprehension units" lasting 1–2 s. The average length of the comprehension unit is hypothesized to be approximately the same as the peak of the hazard function (Burns & Anderson, 1993; Choi & Anderson, 1991). There is an initial low probability of termination of the look during the first comprehension unit, corresponding to the initial low conditional probability in the hazard function. The end of the first comprehension unit is marked by the high probability of termination at the time of the hazard function peak because attention engagement is still weak. Whether the theory regarding the comprehension units is acceptable or not, this stability in the peak look duration over the entire course of childhood is remarkable (cf. Figure 2 with 3.5- to 6-year-old children in Hawkins et al., 1991).

The criticisms raised by Mendelson (1983) regarding the existence of attentional inertia in young infants were inconsistent with the findings of this study.[3] The criticism that the short duration fixations and the long duration fixations come from different groups of infants ("short lookers," "long lookers"), and that the long lookers do not show the typical hazard functions of the aggregate data, was not the case in this study. Individual participants' data in this study, as well in studies of older children (Anderson et al., 1987; Choi & Anderson, 1991) and adults (Burns & Anderson), show similar shaped fixation distributions as aggregate data. Mendelson's criticism that Anderson's findings might be due to habituation or fatigue effects also was unsupported in this study. The habituation explanation is also inconsistent with the findings of the HR data that showed increased attentional engagement across the course of single fixations. The short recording sessions (1.5, 3, or 6 min) used by Mendelson, and the use of a single repetitive stimulus presented for 90 or 120 s, probably account for the pattern of results reported in his research (Mendelson, 1983). Such temporal parameters of stimulus change are not typical of those found in children's television programs and are unlikely to match the pattern of children's fixations in naturalistic environments. The explanation that habituation of looking could account for these types of data was therefore inconsistent with the findings of this study.

The second goal of the study was to determine if the attention engagement increased over the course of fixation in infants. The attentional inertia model posits that attention to the visual stimulus increases over the course of a look to that stimulus. Some of the findings in this study with the HR change were consistent with that hypothesis. There was a decrease in HR over the course of the looks, lasting through most of the look (Figure 3), and returning to prestimulus levels only at the very end of the look (Figure 4). This decrease was continual and did not simply reflect changes in the beginning of the interval. This research with young infants in this age range has interpreted HR deceleration as indicative of sustained attention (Richards & Casey, 1992). During these periods of deceleration, infants are less distractible by other stimuli than in other periods (Lansink & Richards, 1997; Richards, 1987) and show better recognition memory for stimuli presented during these periods than other periods (Richards, 1997). Given this interpretation of the HR change over the course of a single look, one may interpret the finding of a gradual HR slowing as an increase in attention engagement.

The HR change preceding the termination of a look (Figure 4) provided novel information about the course of attention engagement. The return of the IBI level to that of the prestimulus period immediately preceding the look away from the stimulus was consistent with a shift in attention engagement that led to looking away. The attentional inertia model describes an increase in attention engagement across a single look, but does not provide a specific mechanism for terminating looks. The findings in this study imply increasing attention engagement across a look (Figure 3) followed by the beginning of attention disengagement preceding look termination (Figure 4). The change in attention engagement at the end of the look precedes look termination independent of prior look duration or prior level of attention engagement. Such an attention phase labeled "attention termination" has been hypothesized to exist in young infants (Casey & Richards, 1988, 1991; Richards & Casey, 1991, 1992). Following a sustained HR deceleration (indicating sustained attention), when HR returns to prestimulus levels, the infant is more easily distracted or may voluntarily look away from a visual stimulus (Casey & Richards, 1988; Lansink & Richards, 1997; Richards, 1987). During this time, the infant is less responsive to new stimulus information (Casey & Richards, 1988, 1991; Richards, 1997; Richards & Casey, 1991). This study suggests that a specific change in state, arousal, or attention level precedes the termination of looks in these extended stimulus presentations as well as in more traditional experimental protocols studying infant attention.

This HR-defined phase of "attention termination"

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[3] The applicability of the attentional inertia model to infant visual fixation was questioned by Mendelson (1983). Several analyses were done to investigate these claims, but the claims were not supported. First, Mendelson claimed that most of the long looks came from one group of infants ("long lookers") and that the short looks came from a different group of infants ("short lookers"). However, as reported in the results, individual participants' distributions were distributed similar to the group results. Second, Mendelson claimed that most of the long looks might be from the beginning of stimulus presentation and that most of the shorter looks were looks later in the stimulus duration. Thus, he argued, a pattern of habituation of fixation could account for the distribution patterns found by Anderson and colleagues. There was no evidence of habituation of the look durations toward the stimuli (see Results), no evidence of look duration declines over the course of multiple looks for the "Sesame Street" stimulus, and evidence for declines in look duration for the computer-generated stimuli only in a small portion of the time spent viewing the computer-generated stimuli (7.0%). The IBI changes did not decline significantly over the course of the session. A more detailed report of these analyses is available upon request to the first author.

occurring prior to look termination qualifies the "comprehension unit" analysis of Burns and Anderson (1993) and Choi and Anderson (1991). That analysis assumed that the comprehension act itself was engaging and that fixation was indistractible during these across the course of a look. Conversely, at the termination of each comprehension unit, the probability of look termination was initially at high levels due to weak attention engagement. Attentional inertia occurred due to increasing resistance to distraction in the periods between the comprehension acts. In this study, the beginning of the return of the IBI levels to prefixation level occurred well before the look termination (e.g., 5–6 s). If this HR shift represents "attention termination," then there must be a shift in the probability of distraction immediately prior to look termination. If the "comprehension unit" was approximately 1 s in length and retained its indistractibility, then there must be a dramatic increasing probability of termination in the interact intervals immediately preceding look termination. A change in attention may be the specific mechanism that was responsible for termination of fixation following attentional inertia.

The increasing attention engagement over the course of a look, hypothesized by the attentional inertia model and the HR changes in this study, should have behavioral or psychological consequences. Studies in older children and adults of distractibility (Anderson et al., 1987; Choi & Anderson, 1991), performance on a secondary reaction time task (Lorch & Castle, in press), and memory for scenes and information (Burns & Anderson, 1993) support the hypothesis that increased attention engagement occurs during the course of fixation. This type of experimental demonstration of attention engagement with extended viewing with infants would be possible. There are several studies showing that infants are relatively indistractible from central stimulus viewing (Richards, 1987) or toy play (Lansink & Richards, 1997; Oakes & Tellinghuisen, 1994; Ruff et al., 1996) when engaged in active attention. Conversely, when disengaged, infants are easily distracted. These periods of attention engagement and disengagement may be specifically defined with HR deceleration and the return of HR to its prestimulus level (Casey & Richards, 1988; Lansink & Richards, 1997; Richards, 1987, 1997). Thus the patterns of IBI change found during extended looks (Figure 3) would imply that infants would be less distractible during the course of these extended looks, as was the case with older children. The return of HR to its prestimulus level at the end of a look (Figure 4) implies that distractibility increases immediately before look termination. The distraction paradigm is useful in that it experimentally controls fixation termination, can be used with an a priori definition of HR changes (Richards, 1987), and would make the study of attention engagement during extended viewing comparable to that done with young children and adults. This study, although primarily descriptive, provides a convincing rationale for such studies of distractibility to examine the hypothesized increasing attention engagement across long looks and the attention disengagement occurring immediately prior to fixation termination.

There were differences in the responses to the "Sesame Street" movie and the computer-generated patterns. A rationale for using these stimuli was to compare those stimuli typically found in children's television viewing (e.g., "Sesame Street"; Anderson & Levin, 1976; Anderson et al., 1981, 1987; Hawkins et al., 1991) with those used in infant visual attention research. There were slight differences in the total percentage of looking time. Infants looked longer on average at the "Sesame Street" stimulus than at the computer-generated stimuli. This was most apparent in the average looking time, whereas the medians were similar. This was due to a small number of long looks to the "Sesame Street" stimuli. The frequency distributions were not significantly different (Figure 1). The distributions of looking to either the "Sesame Street" stimulus or the computer-generated stimuli were similar to distributions found with older children. Thus, for infants, the stimulus type makes little difference for the fixation patterns. However, the HR responses were larger to the computer-generated stimuli. This occurred for the tonic HR change (Figures 3, 4) and for the phasic HR response at stimulus change within a look.

The differences in the HR response between these stimuli have some implications. Attentional inertia is relevant primarily for stimuli that evoke sustained attention responses and involve comprehension. Research with children has shown some differences in look distributions for "normal" "Sesame Street" movies and incomprehensible movies with altered language content (Anderson & Burns, 1991; Anderson et al., 1981; Hawkins et al., 1991). One might expect the "naturalistic" "Sesame Street" movie, involving human and puppet characters, speaking, communication between people, and typical "naturalistic" stimulus situations, to be more attractive than the computer-generated stimuli. Rather, the HR changes occurring over fixation and the phasic responses to the scene changes imply that greater attention engagement was shown to the computer-generated stimuli. The computer-generated stimuli may have resulted in a "reactive" attention response because of a more discrete change in both audio and visual components of the stimulus. Thus, even in the context of a steadily decreasing shift in HR, the computer-generated stimuli produced significant HR responding. The scene/perspective changes for the "Sesame Street" movie produced such "phasic" changes if the look had been in progress a short time, but not in the context of longer duration looks and a large "tonic" change. It may be that attention was becoming more engaged to the "Sesame Street" stimulus (Figure 3), but that scene/perspective changes were not discrete enough to elicit phasic HR responses after attention was suitably engaged. An important comparison in this regard might be with children between 6 months and the middle-preschool age (e.g., 2–3 years old). Television viewing becomes more frequent in this age range (Anderson & Levin, 1976), and comprehension may come to be based on language and social communication. A finer differentiation of the changes in the "Sesame Street" movie should occur in these older children similar to changes occurring to the computer-generated stimuli.

The successful application of the attentional inertia theoretical model, and the extended-viewing quantitative methodology and experimental situation to infants, suggest that this methodology may be useful in examining attention over a wide range of ages in the infancy and preschool eras. This study showed that a model of attention primarily derived with preschool children could be profitably adapted to infant visual attention. The theoretical aspects of attentional inertia and its empirical manifestations were found in this extended-viewing situation with young infants. Conversely, several aspects of attention studied in infants used in this study might be profitably applied to preschool children. For example, the return of the IBI levels to prestimulus values at the end of a look (Figure 4) implies increased distractibility at the end of the look. This phenomenon has been studied primarily in infants (e.g., Casey & Richards, 1988, 1991; Richards & Casey, 1991) but might be applied to studies of attentional inertia in young children. Similarly, the distraction method, used in 3- to 6-month-old infants (Richards, 1987), 6- to 12-month-olds (Lansink & Richards, 1997; Ruff et al., 1996), and 3- to 5-year-old children (Anderson et al., 1987; Choi & Anderson, 1991) might be a common method that could be applied across a wide range of ages in this extended-viewing paradigm. Finally, most theoretical accounts of attention in infants younger than 1 year of age revolve around attention episodes occurring in response to single, briefly presented stimuli. These theories are limited in analyzing the organization of attention over extended periods of time, and in naturalistic settings. Using a comparable experimental situation such as was done in this study may show greater similarities between early infant visual attention patterns and attention in the early preschool years (e.g., peak of the hazard function) and show where the significant response differences occur (e.g., differential response to "Sesame Street" and computer-generated stimuli).

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