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Extended Visual Fixation in the Early Preschool Years: Look Duration, Heart Rate Changes, and Attentional Inertia

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Visual fixation in infants from 6 months to 2 years of age was examined for its fit to the theory of "attentional inertia." A children's movie ("Sesame Street" movie, "Follow that Bird") or an extended audiovisual stimulus (computer-generated patterns) was presented to 40 children for a minimum of 20 min while fixation was videotaped and heart rate (HR) was recorded. Consistent with attentional inertia theory, fixations toward the stimuli had a lognormal distribution, HR decreased over the course of a look, and HR returned to prestimulus levels immediately before look offset. Older children (18 months, 24 months) showed a distinction in the parameters describing the lognormal distribution for the "Sesame Street" movie and the audiovisual patterns, whereas younger children (6 months, 12 months) responded similarly to the two stimulus types. Fixation patterns of children in this age range suggest attention increases over the course of a look, and parameters consistent with attentional inertia theory differentially develop in this age range.

INTRODUCTION

The study of extended looking to audiovisual stimuli has been done to understand the nature of attentional processes that occur in young children. Extended fixations have been studied in young infants (3, 4.5, and 6 months, Richards & Gibson, 1997), in preschool children (3- and 5-year-olds, Anderson, Choi, & Lorch, 1987; 2-, 3.5-, and 5-year-olds, Anderson, Lorch, Field, & Sanders, 1981; 3.5-, 5-, and 6.5-year-olds, Hawkins, Yong-Ho, & Pingree, 1991) and in college age students (Burns & Anderson, 1993; Hawkins, Tapper, Bruce, & Pingree, 1995). These studies examined the looks of participants to audiovisual stimuli (such as television shows) in sessions lasting from 20 min to 1 hr. Several of these studies have found similar distributions (lognormal distribution) of the looks toward the television and have interpreted this distribution as supporting a theory of "attentional inertia." However, extended fixations of children aged 6 months to 2 years have not been studied in the context of the attentional inertia theory. This paper reports a study of visual fixation to extended audiovisual stimuli in children from 6 months to 2 years of age and shows the continuity in patterns of fixation and attention from infancy to the preschool years.

Studies of extended visual fixation at several ages have shown positively skewed distributions of look duration. That is, looks of short duration (<5 s) made up the largest proportion of looks toward the television program and there was a decreasing probability of occurrence of looks of longer duration. This distribution was tested in several studies (e.g., Anderson et al., 1987; Burns & Anderson, 1993; Choi & Anderson, 1991; Hawkins et al., 1991, 1995; Richards & Gibson, 1997) and was found to be similar to the lognormal distribution rather than to other distributions that may characterize look length (e.g., exponential, gamma, Weibull, normal). The lognormal distribution has been interpreted to be consistent with a model of "attentional inertia" (Anderson & Lorch, 1983; Burns & Anderson, 1993). This model hypothesizes that at the beginning of a look attention is relatively unengaged. The high probability of short looks in the frequency distribution represents a high level of distractibility in these short looks because attention is unengaged. As the duration of a look increases, attention becomes progressively engaged. If a look survives beyond the first few seconds, attentional inertia begins to hold fixation toward the stimulus and the probability of being distracted or looking away decreases, leading to extended looks. Thus, the theory predicts that frequency distributions for look durations will be positively skewed and will be distributed as a lognormal distribution rather than as some other positively skewed distribution (Burns & Anderson, 1993).

One aspect of television viewing that may affect extended viewing is the comprehensibility of the content. Anderson et al. (1981) presented preschool children with "Sesame Street" television segments in normal order, random order, or with degraded language (Greek, backward speech). They found approximately equal viewing times for normal and random order segments that were comprehensible, but far shorter viewing times for incomprehensible (language-degraded) segments. Hawkins et al. (1991) showed in

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preschool children that the look durations when viewing comprehensible stimuli had different frequency distributions than those of the incomprehensible stimuli. In unrestricted attentional situations such as television viewing, abrupt boundaries in content may serve to elicit looks or terminate looks (Alwitt, Anderson, Lorch, & Levin, 1980; Anderson & Lorch, 1983; Hawkins et al., 1995). Attentional inertia occurring in long looks may preserve looking toward the television across these boundaries for comprehensible stimuli but not for incomprehensible stimuli. These boundaries may be changes in the medium due to filming and production techniques (edits, cuts, pans, scenes) but which preserve narrative sequence, changes that do not preserve narrative sequence (e.g., Anderson et al., 1981; Hawkins et al., 1991, 1995), or even changes from dramatic material to commercials (Burns & Anderson, 1993). Such a preservation of looking is due to the increasing inertia holding fixation toward the media itself rather than toward specific narrative elements.

A recent study by Richards and Gibson (1997) examined the applicability of the attentional inertia theory in young infants. Infants aged 14 (3 months), 20 (4.5 months), and 26 (6 months) weeks were exposed to a recording of a "Sesame Street" movie ("Follow that Bird") in one session and a series of computer-generated audiovisual stimuli in the second session. Unlike previous studies that questioned the applicability of the attentional inertia theory to young infants (e.g., Mendelson, 1983), the recording intervals (session length) in Richards and Gibson were relatively long (minimum 20 min), the stimuli changed frequently (12 s to 30 s), and the stimuli were comparable to stimuli used with older children. Richards and Gibson found that the distributions of looks toward the television were similar to the lognormal distribution rather than other distributions. The *average* look length during the session with the "Sesame Street" movie was longer than during the session with the computer-generated stimulus. However, tests of the frequency distributions showed that the distribution of look durations were not different for the two sessions. The difference between sessions found with average look length but not with frequency distributions was partially caused by the existence of several extended looks to the movie relative to the computer-generated stimuli. These extended looks affected the average values but not the distributions. The similar distribution of the looks in the two sessions suggests that for very young infants attentional inertia preserves looks across scene changes for comprehensible media as well as media that do not have a comprehensible story-like character.

This study had two goals. The first goal was to determine if the markers of attentional inertia during television viewing occurred in the age range bridging "infancy" and "early childhood." Studies have found an increase in television viewing time from 1 to 2 years of age (Anderson & Levin, 1976). However, these studies have not investigated attentional inertia in this age range. Several important developmental milestones in the ages from 6 months to 2 years may be important for attention during television viewing. The most obvious change during this time that may affect television viewing is the tremendous growth of language, including receptive language understanding and expressive language use. One factor that may affect attentional inertia is the comprehensibility of the story. Story comprehensibility affects viewing by bridging transitions in the television program when looks away from the stimulus might occur (e.g., Alwit et al., 1980; Hawkins et al., 1995). Children at the beginning of this age range (6 months, 12 months) with limited language capacity may not appreciate story continuity and therefore should react similarly toward comprehensible story-like media (e.g., "Sesame Street") and abstract patterns (e.g., Richards & Gibson, 1997). Children at the end of this age range (18 months, 24 months) should comprehend parts of the story and should appreciate the use of language by the characters. They should respond differently to a story-like stimulus than to abstract audiovisual patterns.

A second reason for studying children in this age range is that there are very few studies of attention in children in the early preschool years (see Ruff & Rothbart, 1996, for review). There are many studies of the characteristics of attention in infancy (e.g., birth to about 1 year), and some studies of attention in preschool children after age two, but little is known about the development of attention between about 1 year of age and 3 years of age. It is known that fixation patterns and attention show development over this age range. For example, there is an increase in television viewing over this age range (Anderson & Levin, 1976), and the amount of time children spend in "focused attention" and on-task time increases over this age range (Ruff & Lawson, 1990; also see Ruff, Capozzoli, & Weissberg, 1998, for slightly older preschool children). Changes in attention might be expected to occur in a relatively continuous manner across the age range from 6 months to 2 years. It has been hypothesized that the basic processes of attention have their origin in the first year and that there are gradual changes in attention during early childhood. Such changes might include a lengthening of focused attention during toy play and the application of attention to a wider variety of tasks (Ruff & Lawson, 1990; Ruff & Rothbart, 1996). This age range is difficult to study because experimental paradigms that may be applied to older children often involve manual responses or the use of verbal instructions and responses, which may not be applicable for young infants. The study of attentional inertia during extended television may provide a technique that bridges this age range because it has successfully been applied to infants (3 to 6 months of age, Richards & Gibson, 1997) and children above the age of 2 years (Anderson et al., 1981; Hawkins et al., 1991).

The second goal of this study was to determine if a noninvasive measure of attention engagement, changes in heart rate during visual fixation, could be used in this age range. The attentional inertia model hypothesizes an increasing attention engagement over the course of fixation that should have behavioral, psychological, and psychophysiological consequences. For example, peripheral distractors are less effective in interrupting looks to a television program if presented after at least 15 s of fixation than if presented early in a look (Anderson et al., 1987; Choi & Anderson, 1991). Similarly, children's performance on a secondary reaction time task was longer after television viewing had been in progress for 15 s than for shorter lengths of time (Lorch & Castle, 1997). These studies suggest that engagement with the television program enhances central stimulus selectivity (attention engagement). Psychophysiological measures also have been used to evaluate attention responses during television viewing (e.g., Lang, 1990; Reeves et al., 1985; Richards & Gibson, 1997). Richards and Gibson (1997) showed that 3- to 6-month-old infants showed a large, tonic, and progressive decrease in heart rate over the course of extended looks and a quick return to prestimulus heart rate level immediately preceding the look away from the television. Heart rate changes in that study were interpreted as reflecting increased attention engagement over the course of the entire look, with a mechanism for "attention disengagement" being indexed by the return of heart rate at the end of the look. The extended heart rate change and the return of heart rate to its prestimulus level before looking away was not different for the "Sesame Street" movie and the computer-generated stimuli. If children from 6 months to 2 years of age show attentional engagement of a similar nature, they also may show such heart rate changes. Whereas heart rate has been a useful tool for indexing attention status in young infants (e.g., Berg & Richards, 1997; Richards & Casey, 1991, 1992) and through 1 year of age (e.g., Lansink, Mintz, & Richards, 2000; Lansink & Richards, 1997; Richards & Lansink, 1998), this measure has not been used frequently after this age. We expected that the increased attention engagement with increased look duration hypothesized by the attentional inertia model should be accompanied by increasing change in heart rate and that looks away from the television would be accompanied by a return of heart rate to its prestimulus level.

The current study involved the presentation of audiovisual stimuli to children at 6, 12, 18, and 24 months of age. These ages were chosen partially to bridge studies showing attentional inertia in young infants (e.g., 3 to 6 months, Richards & Gibson, 1997) and children at 2 or 3 years of age (e.g., 2, 3.5, and 5 year olds, Anderson et al., 1981, 1987; 3.5 to 6 year olds, Hawkins et al., 1991). The participants were seated on their parent's lap and the stimuli were presented continuously on a television monitor for a minimum of 20 min. The stimulus in the first session was a "Sesame Street" movie ("Follow that Bird"), which was similar to stimuli used in other studies of attentional inertia in children's television viewing (e.g., Anderson et al., 1981, 1987; Hawkins et al., 1981; Richards & Gibson, 1997). Visual computer-generated patterns accompanied by audio stimuli were used in the second session, interspersed with segments from the "Sesame Street" movie. The computer-generated abstract stimuli were similar to those typically used in studies of young infants. The "Sesame Street" movie segments were included in this second session to compare the responses to the computer-generated stimuli and the "Sesame Street" stimuli in the same session, and to compare the responses to the "Sesame Street" stimuli in the first and second session. To avoid the long repetitive stimulus presentations used in other studies of young infants' visual attention, the length of the segments for the audiovisual patterns and the "Sesame Street" movie were chosen on the basis of the length and sequence of segments from the movie played in the first session.

METHOD

Participants

Participants were recruited from birth notices published in a Columbia, South Carolina, newspaper. They 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. Forty children were each tested on two days, approximately 1 week apart (5 female and 5 male at each testing age). The participants' ages were 6 (first day: M = 184.7 days, SD = 5.31; second day: M = 192.9 days, SD = 6.24), 12 (first day: M = 361.6

days, $SD = 4.67$; second day: $M = 369.3$ days, $SD = 5.73$), 18 (first day: $M = 545.7$ days, $SD = 5.51$; second day: $M = 552.0$ days, $SD = 5.34$), or 24 (first day: $M = 732.0$ days, $SD = 4.39$; second day: $M = 737.8$ days, $SD = 5.30$) months. Seven children tested in the study did not complete the testing protocol on the second day (sleepy, fussy, not interested during protocol) and were not included in any analyses. Four of these seven children were 6 months of age, and these children showed signs of being sleepy/fussy independent of the experimental protocol. The other children not completing the second session were 18 ($n = 1$) or 24 ($n = 2$) months of age.

Apparatus

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

The stimuli for the sessions were the same as used in Richards and Gibson (1997). 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 and presented on the television monitor with audio. The stimuli for Session 2 consisted of the computer-generated audiovisual stimuli used in Richards and Gibson (1997), interspersed with segments selected from the "Sesame Street" movie. The computer-generated stimuli consisted of 16 dynamically changing visual patterns accompanied by 12 dynamically changing auditory stimulus patterns that were randomly paired for each presentation. The segments from the "Sesame Street" movie for Session 2 consisted of 12 scenes that contained two or more characters, and each scene continued without perspective shifts for at least 25 s. The scenes for Session 2 came from the second 45 min of "Follow that Bird," and had not been seen in Session 1. Two computer-generated stimuli presentations and one "Sesame Street" segment presentation were presented randomly in three-trial blocks.

Scene changes (shifts of scene to new locations or actors) and perspective changes within a scene (pans or camera shifts to new perspective within same scene) in the movie were identified. In Session 1, these scene/perspective changes were synchronized with fixation data and heart rate recording by recording the laserdisc player time code during the experiment. The average length between major scene changes was 25.45 s in length 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). In Session 2, the computer-generated stimuli and the "Sesame Street" segments were presented continuously. The duration of each computer generated stimulus or "Sesame Street" segment matched the sequence of durations of the scene or perspective changes in the "Sesame Street" movie. Thus, the sequence of times for stimulus changes in Session 2 was similar to the scene/perspective changes in the movie played continuously in Session 1. An analysis of the actual distribution of the durations in Session 2 showed that they closely matched those in Session 1 (i.e., N = 4,214 stimulus changes, $M = 16.32$ s, $Mdn = 9.2$ s, mode = 3.79 s, 90 $P = 36.09$ s). Given this average duration of each stimulus in the second session (16.32 s), in a 20 min period there would be approximately 75 stimulus changes, with the 16 computer-generated video stimuli being presented three times, the 12 computer-generated audio stimuli presented four times, and the 12 "Sesame Street" segments presented two times. The onset time (computer-based time) of each stimulus was recorded during the presentations to synchronize the change in stimuli with the videotape and heart-rate recordings.

Procedure

The parent sat in a chair in the viewing area with the infant on the parent's lap facing the television monitor. The audiovisual stimuli were presented continuously. If the infant became fussy, a short break was taken and the presentations paused. The duration of each session was set at a predetermined minimum of 20 min, but the session could continue up to 45 min (i.e., length of first side of laserdisc "Sesame Street" movie).

Measurement and Quantification of Heart Rate Changes

The electrocardiogram (ECG) was recorded with Ag-AgCl electrodes on the infant's chest and was digitized at 1,000 Hz (each ms) with a microcomputer. A computer algorithm identified the QRS complex in the ECG and inter-beat interval (IBI) was defined as the duration between successive R-waves in the ECG.

Artifact correction was done by using the Cheung (1981) and Berntson, Quigley, Jang, & Boysen (1990) algorithms along with visual inspection of suspect beats. The IBI was assigned to .5-s intervals by averaging the IBIs in each interval weighted by the proportion of the interval occupied by that beat. The inter-beat *interval* is the reciprocal of heart *rate*, so that lengthening of the IBI corresponds to heart rate deceleration and shortening of the IBI corresponds to heart rate acceleration, or the return of heart rate to its prestimulus level.

Fixation Judgments

Each session was judged off-line by two observers, and the data for the analysis came from one observer's judgments. A time code recorded on the videotapes allowed the judgement to have millisecond accuracy, though resolution was limited to a single video scan (.5 total frame length = ~16 ms). The observer judged the infant as looking toward the television, looking away from the television, or could not be judged. The time code on the videotape was synchronized with the computer clock to synchronize heart rate changes with fixation.

The agreement between observers was assessed. First, the overall time when the observers concurred the infant was looking at the stimulus was computed. The total overlap time for the 80 sessions was 2,363 min of 2,514 min of total looking time (93.9% overlap). The overlap for individual sessions ranged from 79% to 99% (M = 93.9%, Mdn = 95.0%). 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 with 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: M = .54 s, SD = 1.88, Mdn = .20 s, 90 P = .95 s; offset: M = .43 s, SD = .79, Mdn = .21 s, 90 P = .91 s). This indicates that the two observers identified the look onsets and offsets quite closely. Third, the times in the trial where the observers disagreed on a look toward the television were analyzed. Most of these looks consisted of a judgment by one observer and not the other as a brief look away from the stimulus occurred (M = .59 s, SD = 1.39, Mdn = .25 s, 90 P = 1.24 s). Finally, the distributions of the look duration judged by the two observers were compared. If the data were divided into 1-s categories for all looks less than 60 s, then the null hypothesis that coders' frequency distributions in these categories were the same could not be rejected for the looks away from the stimulus, $\chi^2(59, N = 15{,}262) = 37.31$, $p = .9897$, or the looks toward the stimulus, $\chi^2(59, N = 14{,}833) = 50.73$, $p = .7697$. These findings indicate that the two observers substantially agreed with respect to total look duration, and that the actual times the child looked toward and away from the television and the distribution of their look durations were not significantly different.

RESULTS

Look Duration

Table 1 contains the descriptive statistics for the average look duration (Table 1, Duration per look) and the total look duration (Table 1, Total duration). The infants spent the majority of the time looking toward the stimuli (from 65% to 87%). The average look duration toward the stimulus during the "Sesame Street" session was longer than average looks toward the stimulus in the mixed "Sesame Street" and computer-generated session, and the proportion of time spent looking at the stimulus was larger during the "Sesame Street" session than during the mixed stimulus session. There was an increase from 6 to 18 months in the proportion of time spent looking at the stimuli and a leveling off of looking proportion from 18 to 24 months of age. As expected, the distribution parameters for average look duration were inconsistent with a normal distribution (e.g., mean > median, large standard deviation, skew, kurtosis).

The average look duration (log-transformed) toward the stimulus was analyzed with an Age (4) × Sex (2) × Session (2; continuous "Sesame Street," and mixed "Sesame Street"/computer-generated) ANOVA.[1] There were main effects of session, $F(1, 32) = 27.23$, $p < .001$, sex, $F(1, 32) = 27.23$, $p < .001$, and an interaction between age and session, $F(3, 32) = 2.96$, $p = .047$. The average look toward the television in the "Sesame Street" session was longer than the average look toward the television in the session with mixed segments of "Sesame Street" and computer-generated

[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 by 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

	Session 1 "Sesame Street"		Session 2 Mixed "Sesame Street" and Computer-Generated	
	Toward	Away	Toward	Away
6 Months				
	(n = 1076)	(n = 1069)	(n = 1184)	(n = 1173)
Duration per look (s)	11.26	4.77	8.30	4.41
Median	4.54	2.84	4.36	2.88
Standard deviation	21.51	5.44	10.87	5.20
Skew/kurtosis	5.3/37.5	2.5/9.2	3.2/14.6	4.0/29.7
Total duration (min)	20.19	8.50	16.38	8.63
Standard deviation	8.87	3.28	3.99	2.73
Percent looking toward	67		65	
12 Months				
	(n = 707)	(n = 668)	(n = 1032)	(n = 996)
Duration per look (s)	19.72	5.06	11.49	3.92
Median	5.33	2.94	3.79	2.58
Standard deviation	38.17	6.63	21.48	4.59
Skew/kurtosis	3.4/13.2	3.8/43.9	4.6/28.1	4.2/32.5
Total duration (min)	23.24	5.64	19.77	6.51
Standard deviation	10.39	4.06	5.63	2.54
Percent looking toward	77		74	
18 Months				
	(n = 759)	(n = 730)	(n = 1130)	(n = 1104)
Duration per look (s)	21.40	3.31	10.69	3.73
Median	5.70	1.84	3.51	2.12
Standard deviation	38.51	4.20	19.32	4.77
Skew/kurtosis	2.9/9.1	3.5/18.9	3.5/17.5	4.1/29.0
Total duration (min)	27.07	4.03	21.16	6.86
Standard deviation	7.92	2.78	5.92	3.32
Percent looking toward	85		74	
24 Months				
	(n = 836)	(n = 803)	(n = 1318)	(n = 1280)
Duration per look (s)	25.10	3.51	11.78	3.63
Median	7.38	2.24	3.65	2.34
Standard deviation	43.35	3.84	20.49	4.28
Skew/kurtosis	2.9/9.2	2.8/11.5	4.2/18.3	3.6/20.8
Total duration (min)	34.94	4.70	25.88	7.75
Standard deviation	4.13	2.48	6.45	4.11
Percent looking toward	87		77	

stimuli. There also was a significant increase over the four testing ages in the average look duration toward the television in the "Sesame Street" session but not in the session with mixed stimuli. The sex main effect reflected a longer average look duration for females than males. The sex effect did not interact with testing age nor with session. An ANOVA analysis of the average look duration away from the television resulted in no significant effects. An analysis of the proportion of total looking time for each session resulted in a significant age effect, $F(3, 32) = 4.22$, $p = .012$, and a significant session effect, $F(1, 32) = 13.17$, $p < .001$. The proportion of time looking at the stimulus increased with age, and the infants looked at the stimulus a higher proportion of time during the continuous "Sesame Street" session than during the session with mixed "Sesame Street" and computer-generated stimuli.

The average look duration and proportion of total looking time were analyzed separately for session 2 with an Age (4) × Sex (2) × Stimulus Type (2; "Sesame Street" segments; computer-generated) ANOVA. There was a highly significant effect of stimulus type for average look duration, $F(1, 32) = 167.23$, $p < .001$, and for proportion of looking time, $F(1, 32) = 234.65$, $p < .001$. The average look duration toward the "Sesame Street" stimulus was longer than average looks toward the computer-generated stimuli ($M = 9.37$ s, $SD = 10.31$, and $M = 5.53$ s, $SD = 6.01$, respectively), and the proportion of time spent looking at the stimulus was larger when the "Sesame Street" stimulus was on the television than when the computer-generated stimulus was on the television (85% and 66%, respectively). There were no significant effects of sex, and average looking time did not increase over the testing ages in this session. The "Sesame Street" and computer-generated stimuli were presented in Session 2 in predetermined segment lengths so that look duration was truncated when the stimulus changed. The average look duration therefore is artificially truncated whereas the proportions are a better reflection of the children's looking behavior in Session 2.

The change in look duration across the recording session was examined to determine if habituation or fatigue effects occurred. The session was split into 5-min blocks and data from the first 25 min was examined. The average look duration (log-transformed) toward and away from the stimulus was analyzed with an Age (4) × Sex (2) × Session (2; continuous "Sesame Street," and mixed "Sesame Street"/computer-generated) × Phase (5; 5-min blocks) ANOVA. There was a main effect of phase on the looks toward the stimulus, $F(4, 127) = 9.05$, $p < .001$, and an interaction of phase and session, $F(4, 124) = 3.00$, $p = .020$. The looks toward the stimulus did not change significantly over the 5-min blocks for the looks toward the "Sesame Street" stimulus in the first session (Ms = 16.05,

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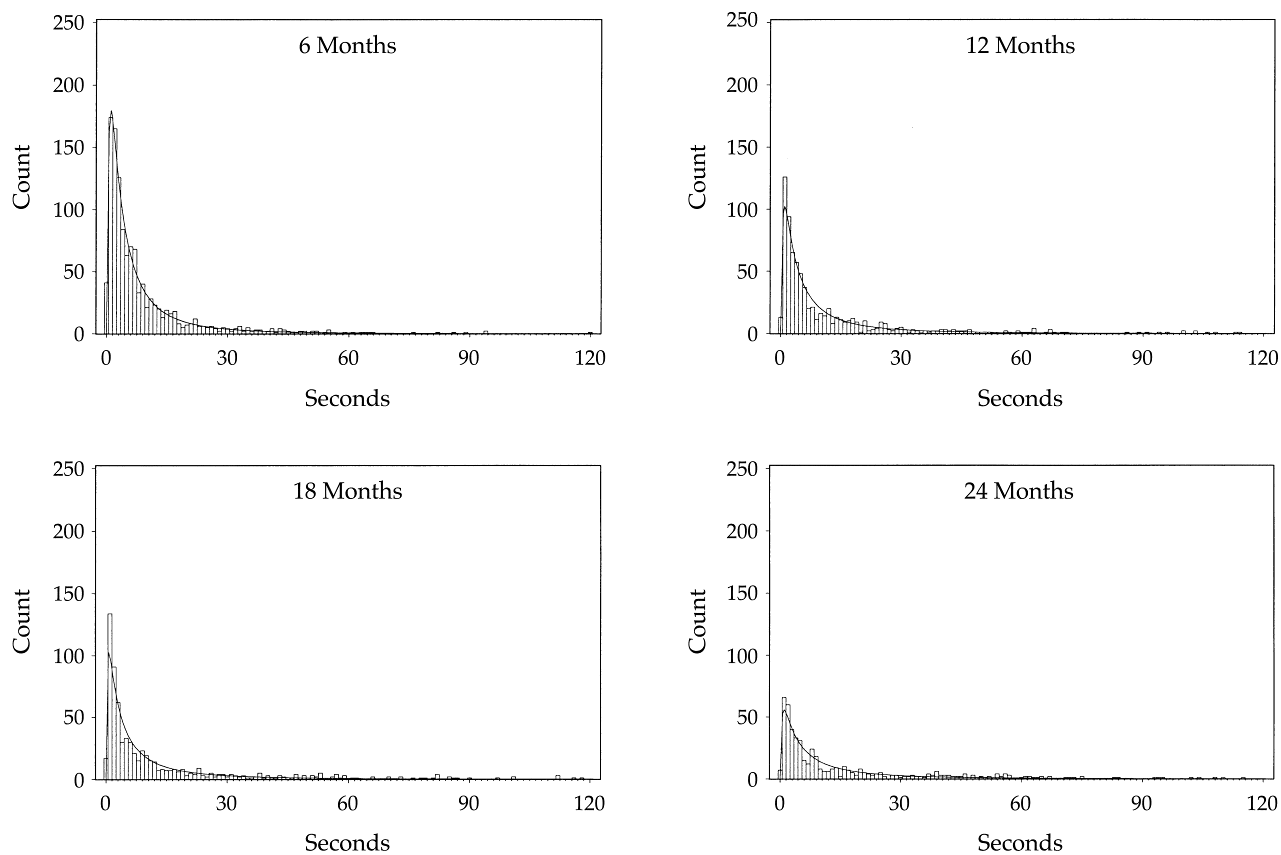

Figure 1 Frequency distribution of looking toward the stimulus in the (A) "Sesame Street" movie session and (B) mixed session containing computer-generated audiovisual stimuli interspersed with "Sesame Street" movie segments. These distributions are given separately for the four testing ages, with frequency histograms for 1-s intervals, and only for the first 20 min of the recording sessions. The solid line is the best-fitting probability distribution function (PDF) for the hypothetical lognormal distribution.

16.52, 17.63, 15.38, 20.31 s for successive 5-min blocks). The looks in the second session (mixed stimuli) decreased in the intervals from about 10 to 20 min, and then leveled off thereafter (*M*s = 13.18, 13.20, 11.93, 8.90, 8.92 s for successive 5-min blocks). There was an overall increase in average look duration away from the stimulus; *M*s = 3.16, 3.74, 3.98, 4.36, and 4.41 s for the 5-min blocks, $F(4, 127) = 12.17$, $p < .001$. These results suggest that habituation and fatigue effects did not significantly affect the characteristics of the looks toward the continuous "Sesame Street" stimulus, but may have affected look duration in the second session.

Frequency Distributions

Distribution type. The hypotheses pertaining to "attentional inertia" were examined by using the frequency distributions of the look duration. The attentional inertia model would be consistent with a lognormal distribution of the look durations (Burns & Anderson, 1993; Richards & Gibson, 1997). Figure 1 has the frequency histograms for the looks toward the stimulus, separately for the four testing ages, and separately for the "Sesame Street" session and the mixed "Sesame Street" and computer-generated stimuli session. To equate the histograms for differing session length across age, we present only the looks that occurred in the first 20 min of the session. Consistent with the values shown in Table 1, there was a large positive skew and kurtosis for each histogram, with a large proportion of short-duration looks and fewer long-duration looks. The change in average look duration for the "Sesame Street" session (Table 1) is reflected in Figure 1A as an increase in the number and duration of the extended looks with increases in age accompanied by a decrease in the number of brief looks. The shape of the histogram changed little over the four testing ages for the mixed session (Figure 1B). The peak of the distribution was relatively similar over testing ages and between sessions.

The obtained distributions were tested with statistical methods to determine if they could be character-

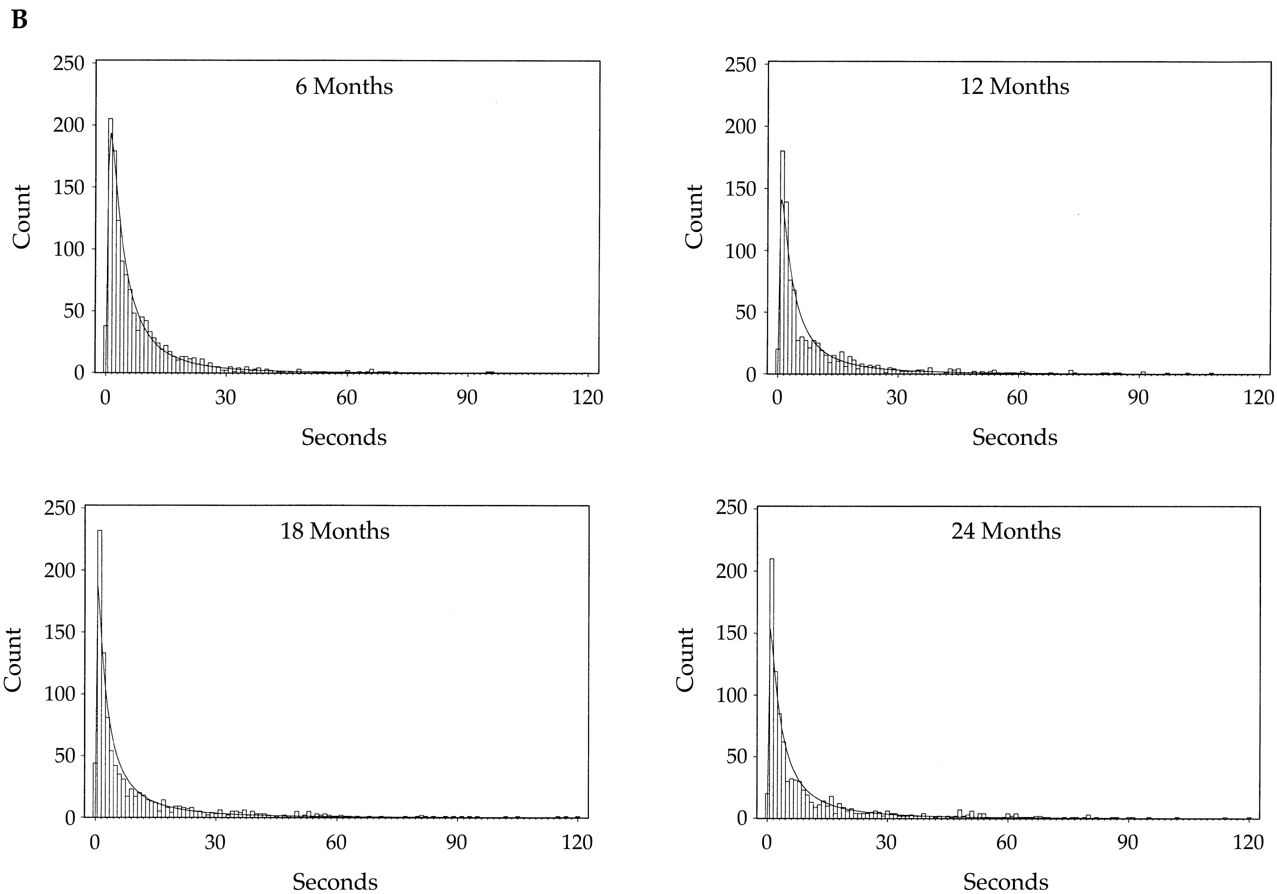

Figure 1 **(*Continued*)**

ized as lognormal distributions.[2] In addition to the lognormal probability function, we compared the obtained distributions against other theoretical distributions that conceivably would be consistent with the mean and dispersion parameters found in this study (Table 1). The obtained distributions were compared against the following hypothetical distributions: beta, exponential, gamma, lognormal, and a distribution consisting of a combination of the normal and exponential (exGaussian; Heathcote, Popiel, & Mewhort, 1991). The lognormal distribution had the closest fit to the observed data, $\chi^2(109, N = 8{,}648) = 315.97$, followed by the gamma, $\chi^2(109, N = 8{,}648) = 4{,}213.23$, exGaussian, $\chi^2(109, N = 8{,}648) = 26{,}021.26$, β, $\chi^2(109, N = 8{,}648) = 42{,}488.17$, and exponential, $\chi^2(109, N = 8{,}648) = 171{,}522.15$. The "root-mean-squared error of approximation" (RMSEA) for the lognormal distribution was significantly less than .05, indicating a very close fit of the lognormal and empirical distributions (Browne & Cudeck, 1993; MacCallum, Browne, & Sugawara, 1996). The RMSEAs for the other distributions were greater than .05 (on a scale from 0 to 1.0, see footnote 2), and most were greater than .20, indicating a poor fit of the observed distribution with those distributions. The looks away from the stimulus also were best described by the hypothetical lognormal distribution, $\chi^2(64, N = 8{,}400) = 75.90$, $p = .1465$. These analyses indicate that the lognormal distribution was an acceptable description of the look duration distributions, whereas the other distributions were not.

Lognormal distribution parameters. The effects of the experimental factors upon the distribution of look duration toward the stimuli were examined. The parameters describing the lognormal distributions were estimated and compared by using parametric statistical tests (see Appendix for details of the estimation procedures). The "scale" parameter represents the location of the distribution and is related to the apparent skew. The "shape" parameter represents the dispersion of the distribution. The scale and shape parameters that were estimated from the distribution of the empirical data were used to calculate hypothetical lognormal probability distribution functions. Figure 2A shows separately for the sessions the lognormal probability distribution functions that were calculated from the scale and shape parameters for the looks toward and looks away from the stimuli. The scale parameter for looking away was nearly identical for the two sessions (scale = 7.87 and 7.88 for "Sesame Street" and mixed sessions, respectively), as was the shape parameter (shape = 1.09 and 1.09, respectively). This is reflected in the nearly identical lognormal probability distribution functions that occurred in the looks away from the stimulus for the two sessions (Figure 2A). The scale parameter for the looks toward the stimuli in the "Sesame Street" session (scale = 8.72, $SE = .0033$) was significantly larger than for the looks toward the stimuli in the mixed stimulus session (scale = 8.38, $SE = .0025$), $t(48) = 4.46$, $p < .001$. The shape parameters were not significantly different for the two sessions, $t(48) = 1.68$, $p = .0984$ (shape = 1.47, $SE = .0048$, and shape = 1.33, $SE = .0021$, respectively, for sessions 1 and 2). This is reflected in Figure 2A as a larger number of short duration looks in the mixed-stimuli session and the increasingly larger number of long duration looks for the "Sesame Street" session. Thus, the difference in the distributions as a function of session was caused primarily by a change in the scale parameter of the distribution rather than the shape parameter.

Figure 2 also shows the lognormal probability distribution functions for the looks toward the stimuli separately for the two sessions and the four ages. The lognormal probability distribution functions for the four ages in the mixed-stimuli session were very similar (Figure 2C), whereas this function systematically differed for the looks toward the stimuli in the "Ses-

[2] The comparison of the obtained distributions and the hypothetical probability functions were made by estimating parameters of the hypothetical distribution with maximum likelihood techniques. The hypothetical distribution was then compared with the obtained distributions with χ^2. A close fit between the hypothetical and obtained distribution would be indicated by a nonsignificant χ^2. It is known that with large N, the null hypothesis of no difference between two distributions based on the χ^2 is easily rejected, so that very few comparisons would be "nonsignificant." As expected, the null hypothesis that the hypothetical distribution was not different from the empirical distribution of the looks toward the stimulus was rejected for all hypothetical distributions for the data aggregated over all participants. A measure of the closeness of the fit of the hypothetical distribution and the empirical distribution, the "root-mean-squared error of approximation" (RMSEA) was calculated for each of the tests involving the χ^2 (Browne & Cudeck, 1993; MacCallum, Browne, & Sugawara, 1996). The RMSEA ranges from 0 to 1.0, with small values indicating a good fit of the data and the hypothetical distribution, and takes into account the N of data used to estimate the χ^2. Refer to Richards and Anderson (1999) for more details of this procedure.

Individual participant's distributions also were examined. The null hypothesis that the lognormal and empirical distributions were the same could not be rejected for 46 of the 80 sessions. The null hypothesis for the gamma distribution could not be rejected for 20 of the 80 sessions. For the other distributions, less than 10 of the individual sessions could be reasonably fitted to a hypothetical distribution. The lognormal had the statistically best fit for 60 of the 80 testing sessions, the lognormal and gamma distributions fit the observations equally well for 16 of 80 testing sessions, and the gamma distribution had the statistically best fit for 4 of the 80 distributions.

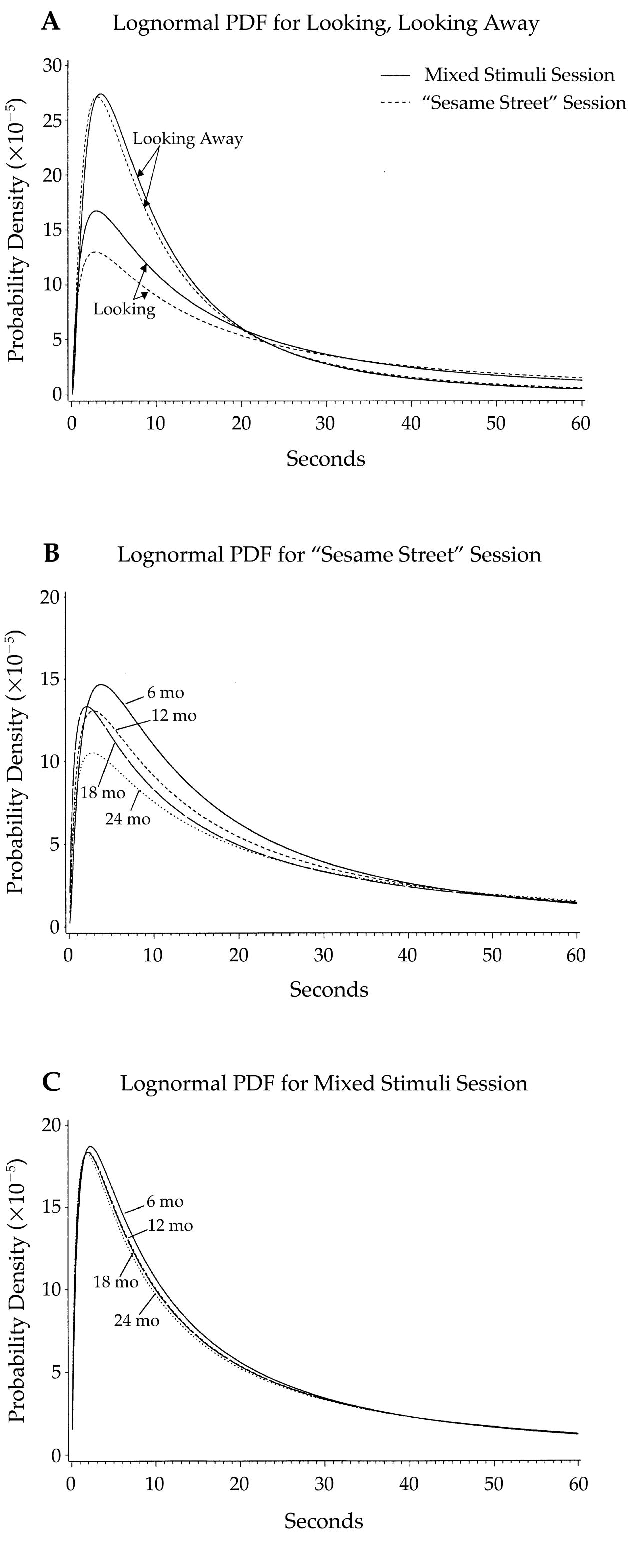

Figure 2 The hypothetical probability distribution functions (PDF) for the best-fitting lognormal function. This is shown for (A) looking toward the television and away from the television for the two sessions, and for (B) looking toward the television separately for the four testing ages and (C) the two sessions.

ame Street" session (Figure 2B). This systematic difference was characterized by a decrease in the number of short-duration looks over the four testing ages (Figure 2B). There was also a corresponding increase in the positive skew of the distributions, i.e., more long-duration looks. This may be seen in Figure 1A as an increase in the number and duration of the extended looks with increases in age, and an increase in the lognormal probability density functions for these ages in the durations from 60 to 120 s (not shown in Figure 2).

The scale and shape parameters for the looks toward the stimuli in the mixed session were at similar levels across the four ages (scale = 8.38, 8.42, 8.32, 8.38, and shape = 1.16, 1.33, 1.43, 1.4, respectively, for 6, 12, 18, and 24 months). For the looks toward the "Sesame Street" stimulus in the first session, there was a systematic increase over the four testing ages in the scale, 8.48 (SE = .0029), 8.70 (SE = .0041), 8.80 (SE = .0022), 9.02 (SE = .0054); and shape, 1.27 (SE = .0036), 1.45 (SE = .0029), 1.59 (SE = .0033), 1.57 (SE = .0049) parameters of the lognormal distributions. Stated differently, there was an increasing difference in the scale parameter between the two testing sessions over the four testing ages. The scale parameter for the two testing sessions was not significantly different at age 6 months, $t(48) = 1.31$, $p = .098$, was statistically different at age 12 months, $t(48) = 3.23$, $p = .0011$, and the difference was the largest at age 18 months, $t(48) = 6.19$, $p < .001$, and age 24 months, $t(48) = 6.82$, $p < .001$. Similarly, the shape parameter was not significantly different at the 6- and 12-month-old testing ages but was significantly different for the 18- and 24-month-old children ($ps < .05$).

Summary. In summary, the lognormal distribution was the best characterization of the distributions of look durations in this study. This was true for looks toward as well as away from the stimuli. An analysis of the look duration distributions and the parameters of the lognormal distribution functions that fit the empirical distributions resulted in two main findings. First, the differences found in these distributions as a function of session were in the scale parameter of the distribution rather than in its shape. Second, the age effects found in the "Sesame Street" session reflect a tendency for the scale and shape parameters to increase. The increase in these parameters reflects the increasing predominance of extended fixation durations with increases in age for the "Sesame Street" movie relative to the computer-generated stimuli.

Interbeat Interval Changes

The hypothesis that heart rate changes would accompany the lengthening periods of fixation was tested in two ways. First, the changes occurring during fixation and accompanying differing-length looks were examined. Second, the changes occurring at the end of each look were examined. In both cases, the looks longer than 5 s were divided into five categories on the basis of their duration: 5–10 s, 10–20 s, 20–40 s, and greater than 40 s. These divisions were made to examine the relation between the heart rate changes that occurred and the length of the look in which the heart rate changes were occurring.

First, the changes in IBI values occurring at the onset and throughout the looks were examined. The difference in the mean IBI in the 2.5 s preceding a fixation toward the stimulus and the 5 s periods during a look toward the stimulus was calculated (mean 5 s IBI − mean 2.5 s prestimulus IBI). This change score was analyzed with an Age (4) × Session (2) × Look Length (4; 5–10 s, 10–20 s, 20–40 s, >40 s) × Epochs (9; 5 s periods) ANOVA. The general linear model was used to estimate effects due to the unequal number of epochs in the look length categories. The epochs effects were adjusted by the Huynh-Feldt correction for lack of homogeneity in the covariance matrices for repeated measures (Huynh & Feldt, 1970; Jennings & Wood, 1976; Keselman & Keselman, 1988). The IBI change in the last 5 s of each look was excluded because of the expected IBI decrease at look offset (see next paragraph) and all looks over 40 s were summed into the last epochs category. There were the expected effects of epochs reflecting the heart-rate deceleration (increasing IBI levels) over time, $F(8, 284, \varepsilon = .330) = 29.66$, $p < .001$. There also was a significant interaction of age and epochs, $F(24, 284, \varepsilon = .330) = 3.54$, $p < .001$. Figure 3 shows the average IBI combined for the two sessions but separated for the four testing ages. For all ages, and in both sessions, a sudden increase in IBI length (heart-rate deceleration) at the beginning of the look was followed by a gradual increase in IBI length across most of the look. Post hoc comparisons showed the epochs effect was similar in the 6-, 12-, and 18-month-old participants and that the epochs effect in the 24-month-old participants was different from that in the three younger ages ($p < .001$). The 24-month-old participants' IBI change lasted through about 20–30 s of the looks but leveled off or began to return slightly toward the prestimulus levels in longer looks. Even with this slight return toward prestimulus levels, on the average the IBI's of the 24-month-old participants continued to be significantly longer than prestimulus levels throughout the look toward the stimulus. There were no main effects or interactions involving the look length category. This indicates that the IBI changes for the shorter looks (e.g., 5–10 s, 10–20 s) were similar to the longer looks (e.g., 20–40 s, >40 s) in the epochs where they both had IBI change data.

Second, the changes in IBI length occurring at the end of each look were examined. The time at the end of each look at the television was identified, and the

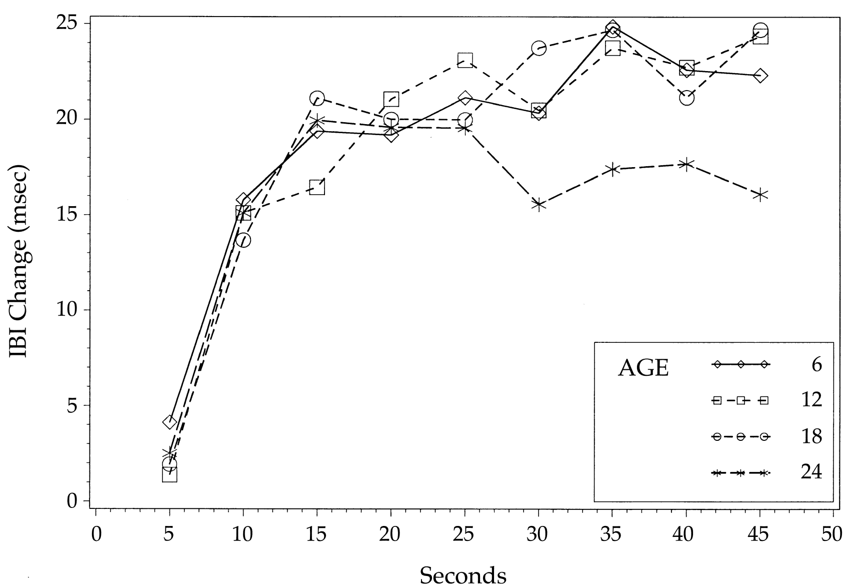

Figure 3 The change in IBI length (mean 5-s IBI − average prestimulus IBI) as a function of the duration of the fixation for the four testing ages, averaged across all look length categories. This figure is combined for the "Sesame Street" movie session and the mixed-stimuli session. The last 5 s of the look was not included in these averages (see Figure 4).

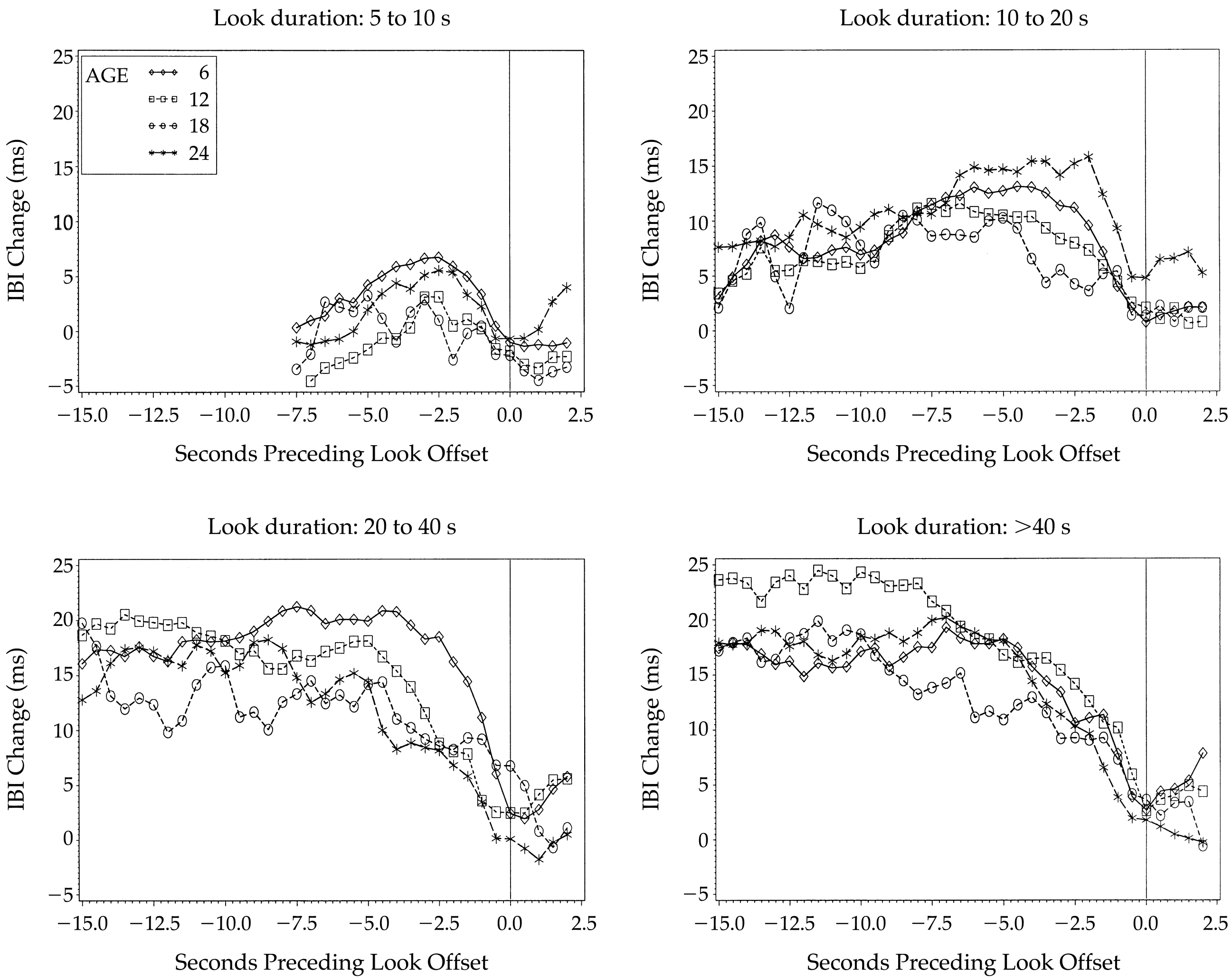

Figure 4 The return of IBI toward the prefixation level at the end of fixation (mean 0.5-s IBI minus average prestimulus IBI). The look away from the stimulus occurred at second 0, and the differing length fixations preceding the look away are in separate plots with individual lines for each testing age.

IBI changes occurring immediately before this time were computed for the different look-length categories. Figure 4 shows the IBI changes occurring at the end of the look, separately for the four testing ages, and separately for the different look lengths. The IBI values for all look lengths were returning to prestimulus levels before the ends of the looks. In the case of the longest look categories (20–40 s, and >40 s) a large tonic shift in IBI level occurred over the course of the looks (e.g., Figure 3) and a dramatic return toward prestimulus level occurred near the end of the look. This return toward the prestimulus heart-rate level did not differ for participants at the four testing ages. The IBI change at the end of the looks was analyzed with an Age (4) × Session (2) × Epochs (0.5-s intervals) ANOVA by using the general linear model to estimate effects due to the unequal number of looks in the look-length categories and then using the Huynh-Feldt correction. The different look lengths were analyzed in separate ANOVAs by using pre-offset IBIs from 5.0 s, 10.0 s, 15.0 s, and 15.0 s for the 5–10 s, 10–20 s, 20–40 s, and >40 s look categories, respectively, and 2.5 s following the look offset. The only significant effect in each analysis was that of epochs, 5–10 s looks, $F(14, 504, \varepsilon = .345) = 7.23, p < .001$; 10–20 s looks, $F(24, 864, \varepsilon = .245) = 10.61, p < .001$; 20–40 s looks, $F(34, 1224, \varepsilon = .224) = 16.46, p < .001$; looks >40 s, $F(34, 1224, \varepsilon = .236) = 14.24, p < .001$. The epochs effect in each case represents the return of the IBI intervals to prestimulus level at the end of the look. We also did tests comparing the IBI changes from differing look lengths with similar time epochs (length >40 s and length 20–40 s, seconds −15 to +2.5; and, length >40 s, length 20–40 s, length 10–20 s, seconds −10 to +2.5 s). Each of these tests showed the expected epochs effects, but no difference in the pattern of IBI change for the look-length categories. These analyses confirm the impression from the four panels of Figure 4 that the IBI changes at the end of the looks were the same for different length looks, did not differ in the two sessions, and did not change over the four testing ages.

DISCUSSION

The first goal of the study was to determine if the attentional inertia model would apply to television viewing in the age range bridging "infancy" and "early childhood." The attentional inertia model predicts that look durations will be distributed lognormally. That was the case in this study with children ranging from 6 months to 2 years of age. The distributions of look durations most closely matched the lognormal function for aggregated group data and for individuals. These empirical distributions match those found with young infants (Richards & Gibson, 1997), preschool-aged children (Anderson et al., 1987; Choi & Anderson, 1991; Hawkins et al., 1991) and adults (Burns & Anderson, 1993; Hawkins et al., 1995). The lognormal distribution shows that early in a look the likelihood of looking away from the television was high. With increasing look length, the probability of looking away from the television decreased. This finding is consistent with the attentional inertia model that hypothesizes an increasing engagement of attention over the course of a look.

The "comprehensibility" of the audiovisual presentation affected the distribution of looks toward the television for the older children but not for the younger children. The "Sesame Street" movie presented in the first session contains naturalistic language, persons and characters and a comprehensible story narrative. This stimulus was similar to stimuli used in other studies of children's television (e.g., Anderson et al., 1981, 1987; Hawkins et al., 1991; Richards & Gibson, 1997). The computer-generated audiovisual patterns used in the second session were similar to stimuli typically used in studies of young infants (Richards & Gibson, 1997), and were interspersed with segments from the "Sesame Street" movie. The average look duration seemed to be longer in the session with only the comprehensible "Sesame Street" movie than in the second session with mixed stimuli for all ages (Table 1). However, for the 6- and 12-month-old participants, the median and percentages were not substantially different between the two sessions. This lack of difference was also seen when the look distributions were compared using the parameters of the lognormal distributions (scale, shape). For the 18- and 24-month-old participants, there were differences in median look length, the percentage of time viewing the stimulus, and in the scale and shape parameters of the lognormal distributions. The differences in scale and shape were shown as a lower probability of short looks and an increased probability of extended looks for the "Sesame Street" session relative to the mixed-stimulus session. This change over age in look duration distribution occurred only for the looks in the "Sesame Street" session, whereas the look duration distribution was similar over the four testing ages for the mixed stimulus session (Figures 2B and 2C).

The change over ages in the look distributions may not have been due to comprehensibility per se, since the stimuli in the two sessions differed on more characteristics than comprehensibility. The computer-generated audiovisual stimuli do not have any language-like elements in the audio portion, do not have human (or "Muppet") characters, and do not have common situations and objects (houses, toys, and streets). Specific experiences with the movie itself may have affected the viewing patterns for the "Sesame Street" movie session for the older infants. Anecdotally, we noticed that several of the two-year-olds named "Big Bird" or "Oscar" during the "Sesame Street" movie. Productive and receptive language are well established in children at the older two ages in this study relative to the youngest two ages. The oldest infants may have been responding to the language-like elements in the "Sesame Street" movie. Language differences alone would be a sufficient condition for affecting the look distributions. Both Anderson et al. (1981) and Hawkins et al. (1991) reported that "Sesame Street" television segments showed in normal order or random order resulted in equivalent viewing times. Segments with degraded language (Greek or backward speech) had significantly shorter viewing times (Anderson et al., 1981; Hawkins et al., 1991), and the distributions of the look durations differed for normal language and language-degraded segments (Hawkins et al., 1991). Further study using the extended-viewing methodology with children in this age range might use such language-degraded stimuli, or manipulate other parameters of the movie-like stimuli, to determine more precisely what aspects of the stimulus affect changes in attention found in the current study.

The response to the stimuli presented in the mixed stimulus session was stable over this age range. This implies that some characteristics of attention may be relatively stable in this age range. The video portion and the audio portion of the computer-generated stimuli were similar to stimuli that are typically used in studies of infant attention. These stimuli also were repeated within a session. These stimuli and this presentation pattern were included to determine how older-aged children responded to such stimuli. The patterns of look duration distribution (Figure 1B, Figure 2C) were nearly identical across the four testing ages. These patterns of looking also were similar to that found with younger age infants (3 to 6 month olds, Richards & Gibson, 1997). In addition to the similarity of the look duration and distribution parameters across ages for this second session, the distribution of look durations for all stimuli was most closely approximated by the hypothetical lognormal probability density function. This was also true of the younger aged infants in Richards and Gibson (1997). This similar pattern of response over this age range implies that there are attention processes that are established early in infancy that show continuity over age. These processes ("attentional inertia," "attention engagement") affect extended viewing, result in look durations with a lognormal distribution, and result in a pattern of responding to these abstract stimuli that is established by 6 months of age and continues at least through the early preschool years. The changes in this study occurred primarily in parameters of the lognormal distribution for the "comprehensible" stimuli. This implies that the basic attention processes were not modified for viewing the "Sesame Street" movie, but that the values of the controlling parameters changed for the older two ages when viewing the "Sesame Street" movie relative to their viewing of the computer-generated stimuli.

The age changes in the difference in viewing the comprehensible and incomprehensible stimuli were not precisely predictable by the attentional inertia model, though a consistent interpretation may be possible. The attentional inertia model (Burns & Anderson, 1993; Choi & Anderson, 1991) hypothesizes that each look consists of an aggregation of "comprehension units" that last 1–2 s. A decreasing change in the probability of distraction between comprehension units leads to extended fixations, increased attention engagement, and attentional inertia. The lognormal distribution is a function of this aggregation of comprehension units and the decreasing probability of distraction (for details of this model, see Burns & Anderson, 1993; Choi & Anderson, 1991; Richards & Anderson, 1999). This model seems to assert that a stimulus needs to be comprehensible in order to result in a lognormal distribution, whereas stimuli without obvious comprehensibility would not. That was not the case in the present study. The youngest participants showed the same lognormal distribution for the comprehensible and incomprehensible stimuli. The oldest participants showed a difference in distribution parameters, but still showed the lognormal distribution of looks for the mixed-stimulus session. Thus, comprehensibility of the stimulus is not the key factor for the processes generating the lognormal distribution. Comprehensibility of the stimulus modifies the parameters of the lognormal distribution (scale, shape) without changing the underlying generating processes.

We do not believe that the theoretical positions advocated by Anderson and colleagues regarding attentional inertia (e.g., Burns & Anderson, 1993; Choi & Anderson, 1991) are totally confirmed by the results of the present study, or by other studies of extended fixation that simply show the lognormal distribution of look durations. Anderson and colleagues (Burns & Anderson, 1993; Choi & Anderson, 1991) developed a specific quantitative model based on the attentional inertia theory that generated data resulting in a lognormal distribution similar to that found empirically (Burns & Anderson, 1993). There are several theoretical models in psychological research that are consistent with nonnormal distributions (e.g., Weibull, gamma, exGaussian, lognormal). This study (and others) has affirmed that the distribution for the look durations is lognormal rather than some other nonnormal distribution. Alternative models consistent with a lognormal distribution of looking time measures have been considered in the literature (Bree, 1975; Ulrich & Miller, 1993). There also are several models in biology, economics, and the social sciences that lead to variables with lognormal frequency distributions (Crow & Shimizu, 1988). An attractive feature of some of these models is an analogy of the model with biological growth. The lognormal distribution is hypothesized to be a function of underlying growth processes that combine together in a multiplicative manner before a response (e.g., reaction time, look duration, body weight, brain size) is output or measured. Such a model for extended viewing of complex audiovisual stimuli might hypothesize that discrete cognitive activities ("comprehension units," understanding of story segments or narrative boundaries, structural boundaries in the medium) occur during extended fixations. These discrete cognitive activities affect each other in a multiplicative growth relationship, resulting in an expanding activation of attention, leading to the lognormal distribution. Such a model would be consistent with the lognormal distribution and the observations that increasing attention engagement occurs over the course of these extended fixations. A critical advance of the current article is the application of quantitative methods based on our knowledge of the underlying distribution of the variables. The scale and shape parameters of the lognormal distribution were estimated and the distributions (standard errors) of these parameters were used to test differences between the experimental factors. This advance should allow us to further quantify the processes affected by age and stimulus comprehensibility in order to determine what developmental changes in infancy and the preschool years affect extended viewing of audiovisual patterns.

The second goal of the study was to determine if the heart-rate changes occurring during visual fixation would be useful in this age range for confirming the increasing attentional engagement during extended looks. The attentional inertia model implies an increasing engagement of attention over the course of fixation that should have behavioral and psychophysiological consequences. A decrease in heart rate over the course of the look lasted through most of the look (Figure 3). This change in heart rate was similar to that found with 3- to 6-month-old infants (Richards & Gibson, 1997). We interpret this progressive decline in heart rate to indicate increasing attentional engagement to the television program. Research with infants through 12 months of age has shown that heart-rate deceleration indicates that sustained attention is occurring (Richards & Casey, 1992; Richards & Lansink, 1998). Infants are less distractible by other stimuli during these periods of sustained heart-rate change (Lansink & Richards, 1997; Richards, 1987), indicating that the heart-rate change shows attention engagement to the central stimulus and central stimulus selectivity. The interpretation of the heart-rate change in the current study is consistent with the studies showing that behavioral measures of distractibility during television viewing in older preschool children (Anderson et al., 1987; Choi & Anderson, 1991) or performance on a secondary reaction time task (Lorch & Castle, 1997) decline during these extended looks. The heart-rate changes in the extended periods of the look may have covaried with other factors known to influence resting heart-rate level (e.g., quiet sitting, body movement quieting, relaxation). The attention interpretation we favor would be more directly confirmed by a measure of attention to the television (e.g., distractibility by a second stimulus, Richards & Lansink, 1998) occurring in conjunction with the heart-rate changes found in the children in this age range. The return of heart rate to its prestimulus level immediately preceding the look away from the television (Figure 4) also replicates findings with 3- to 6-month-old infants (Richards & Gibson, 1997). The return of heart rate reflects the operation of a mechanism for attention disengagement that ends the inertial control held by attention over look direction (i.e., "attention termination," Casey & Richards, 1988, 1991; see discussion in Richards & Gibson, 1997).

The interpretation that the progressive decline in heart rate indicates increasing attentional engagement has implications for the interpretation of the changes in look duration distribution over the ages in the present study. The consistency of the lognormal frequency distribution across stimulus types and testing ages was interpreted as showing the modification of attentional processes that already existed in young infants. This interpretation is consistent with the lack of an effect of stimulus type on the extended heart-rate changes (Figure 3) and the heart-rate change occurring at the look away from the television (Figure 4). The heart-rate response during both sessions was similar. This implies that when an extended duration fixation occurred during the mixed stimuli session, it was accompanied by an appropriate heart-rate change indicating a progressive engagement of attention. Similarly, for short duration fixations—whether to the continuous "Sesame Street" movie or the mixed stimuli—there was a briefer heart-rate change that was not different for the two stimuli. Thus, attention engagement per se may have changed little over this age range, but the frequency with which attention was deployed for extended periods of attention engagement, particularly for the comprehensible "Sesame Street" movie stimulus, increased from 6 months to 2 years in the current study.

It is possible that some of the effects found in this study may be due to the testing sequence. The "Sesame Street" movie was used in the first session for all participants and the mixed computer-generated audiovisual and interspersed "Sesame Street" movie segments was used in the second session. This may lead to an overall familiarity with the "Sesame Street" movie, the presentation situation, and the need to sit in this situation for extended periods of time. If the results were due to the confounding of session and stimulus type, the overall shorter duration of looking in the second session may be due to "fatigue" or "habituation" effects rather than to the stimulus presentation. Given this explanation, it could be that the difference between look duration distributions found between the two sessions in the 18- and 24-month-old participants was due to a better "situation" memory of the older participants and the session or sequence effects happening only at those two older ages.

We do not think, however, that a "fatigue" or "habituation" explanation is the most reasonable one for the difference between looking toward the "Sesame Street" movie in the first session and the mixed stimuli in the second session. Average looking duration did not decrease over the 5-min epochs in the first testing session, and, if anything, increased slightly. There was a decrease in look duration in the second testing session in a limited period of testing time (e.g., minutes 10–15), but otherwise no appreciable decline in look duration occurred in the second session. The difference in average look duration between the "Sesame Street" movie in the first session and the mixed stimuli in the second session was evident in the first 5-min block of the second session, and did not depend on habituation or fatigue occurring in the first session or in the second session. The look duration differences (or similarities) over the 5-min epochs of the session also did not vary with the participants' age. Similarly, there were no session effects on heart-rate responses, no interaction of age and session on the heart-rate response, and no difference in the heart-rate changes over the 5-min epochs. The extended decreasing heart rate during extended viewing (Figure 3) occurred for both the continuous "Sesame Street" movie and the mixed stimulus session. This indicates that when long duration looks occurred in the second session they were accompanied by the appropriate heart-rate change and, by inference, the increased attention engagement occurring over the course of the look. Thus, habituation of attention to the stimuli over the extended viewing situation of the test sessions did not occur. These lack of habituation effects lead us to believe that the differences between looking toward the "Sesame Street" movie in the first session and the mixed stimuli in the second session were due to their stimulus characteristics (e.g., comprehensibility) rather than fatigue or habituation effects.

The results of the current study lead to a different picture of the visual attention of infants and young children than is typically held. Most accounts of infant visual attention are based upon episodes of attention to relatively uninteresting single stimuli presented in isolation with relatively short duration presentations (Richards & Gibson, 1997; see Ruff & Rothbart, 1996). These accounts suggest that infant attention rapidly declines with repeated exposures to visual stimuli ("habituation") and that young infants do not engage in visual attention for extended periods of time. An example of this interpretation of the distribution of looking durations was given by Mendelson (1983). The mixture of long and short duration looks in the extended viewing situation was explained by Mendelson (1983) as a result of habituation and a preponderance of long looks in the beginning of the session followed by a preponderance of short looks late in the session. This habituation explanation is inconsistent with the lack of habituation effects found in the present study in the first session, the limited change in look duration found in the second session, and the complete lack of habituation effects in look duration found in Richards and Gibson (1997) with infants aged 3 to 6 months. The findings from this study and from Richards and Gibson, and the attentional inertia theory, implies that infants and young children become increasingly engaged with interesting, varied stimuli within the course of a single look. In addition, over the course of a testing session, infants and young children may remain engaged with the stimuli, look durations do not necessarily decrease, heart-rate changes may continue to occur for extended duration looks, and the children may continue to participate in experimental sessions for extended viewing times.

This application of the attentional inertia theory and the extended-viewing methodology to children in this age range completes the link showing that this methodology is useful in examining attention over a wide range of ages. Previous studies have shown the applicability of this model in infants, preschool children, and college-age adults. This study provides the link in the age range bridging "infancy" and "early childhood." Some findings in this study suggest a continuity in many of the processes affecting extended viewing of audiovisual material. These similarities included the peak of the empirical distribution of looks, heart-rate changes at the onset and offset of looks, and the nature of the underlying statistical distribution of the look durations. Alternatively, dramatic developmental changes occur in the age range used in this study. These include the onset of self-produced locomotion, increased mobility and dexterity, receptive and productive language use, and interpersonal communication and relationships. These developmental changes have the possibility of profoundly affecting television viewing so that this age range serves as an important transition from infancy to early childhood in this behavior. This methodology should continue to be important in studying the development of attention throughout the childhood years.

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ADDRESSES AND AFFILIATIONS

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APPENDIX

One advance in the current study was the use of parameters implied by the lognormal distributions of the frequency distributions for testing the differences between experimental factors. The lognormal distribution of looks found in the studies of extended viewing (Anderson et al., 1987; Burns & Anderson, 1993; Choi & Anderson, 1991; Hawkins et al., 1991, 1995; Richards & Gibson, 1997) is an empirical marker that is consistent with the predictions of the attentional inertia model (Burns & Anderson, 1993). Some of these studies have used numerical and statistical methods to compare the fit of the empirical distribution of look durations with hypothetical distributions in order to show the distribution was lognormally distributed. However, the quantitative comparisons between groups (e.g., ages, comprehensible versus incomprehensible) typically have used log-transformed variables with ANOVA-based methods.

The lognormal distribution is one in which the log of the values is normally distributed (Aitchison & Brown, 1957; Crow & Shimizu, 1988; Johnson & Kotz, 1970; Johnson, Kotz, & Balakrishnan, 1994). There are three parameters that can be used to describe these distributions: scale, shape, and threshold. The scale parameter primarily describes the range of numbers in the distribution and is related to the positive skew of the distribution. The shape parameter represents the shape of the dispersion of the distribution. The threshold parameter is the location of the minimum value of the distribution, which was set to 0 ms in this study. The distribution of these parameters (and associated standard errors) may be estimated with Monte Carlo methods and maximum likelihood techniques (Ratcliff, 1993). The parameters describing the lognormal distributions that best fit the observed distributions were estimated with maximum likelihood techniques. A "simplex minimization method" (Nelder & Mead, 1965; Press, Teukolsky, Vetterling, & Flannery, 1992) was used to estimate the scale and shape parameters for the maximum likelihood estimates, and Monte Carlo methods were used to estimate the standard errors of the parameters (Press et al., 1992; Ratcliff, 1993). Richards and Anderson (1999) has a complete description of these procedures.

Using these parameters explicitly for comparisons rather than the log-transformed variables has the advantage of specifically acknowledging the underlying distributions of the variables. This should result in more appropriately sensitive and discriminative analyses for experimental factors than methods based on transformations (see Heathcote et al., 1991; Levine & Dunlap, 1982, 1983; Ratcliff, 1993) or truncation of outliers that do not seem to fit the normal distribution (Miller, 1991; Ratcliff, 1993; Ulrich & Miller, 1994; Van Selt & Jolicoeur, 1994).

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