



Infancy, 1–23, 2011

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ISSN: 1525-0008 print / 1532-7078 online

DOI: 10.1111/j.1532-7078.2011.00109.x

 WILEY-BLACKWELL

Peripheral Stimulus Localization by Infants of Moving Stimuli on Complex Backgrounds

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This study examined the effect of attention in young infants on the saccadic localization of dynamic peripheral stimuli presented on complex and interesting backgrounds. Infants at 14, 20, and 26 weeks of age were presented with scenes from a Sesame Street movie until fixation on a moving character occurred and then presented with a second segment in the scene in which the character movement occurred in a new location. Localization of the moving character in the new location was faster when the infant was engaged in attention than when inattentive, for scenes in which the character moved from one location to another, or scenes in which the character stopped moving and characters in new locations began moving. However, localization of the character was slower during attention when the first character disappeared and a different character appeared in a new location. We also found a decrease in the linear component of the main sequence in the saccade characteristics over the three testing ages, and attention affected the main sequence for infants at the two oldest ages. These results partially replicate prior findings showing that attention to a focal stimulus affects localization of peripheral stimuli, but suggest that the nature of the stimuli being localized modifies the role of attention in affecting eye movements to peripheral stimuli.

[Correction added after online publication 12/8/11: Author Brittany M. Mallin's name was incorrectly listed as "Brittany A. Mallin." This has been corrected.]

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An area of research that has received much work is the localization of peripheral stimuli by young infants. Work in this area has examined the extent of the peripheral visual field, the latency to look from a focal to a peripheral stimulus, characteristics of the eye movements themselves, and age changes in these behaviors (Ashmead, 1984; Aslin & Salapatek, 1975; Butcher, Kalverboer, & Geuze, 2000; Goldberg, Maurer, & Lewis, 1997; Hainline, Turkel, Abromov, Lemerise, & Harris, 1984; Harris & MacFarlane, 1974; Finlay & Ivinskis, 1982, 1984; Hicks & Richards, 1998; Hunter & Richards, 2003; Richards, 1997; Richards & Hunter, 1997). An important finding in this work has shown that attention to a stimulus located in the focal visual field attenuates the responses (localization percentage and localization latency) to the stimulus in the peripheral visual field (Finlay & Ivinskis, 1982, 1984; Hicks & Richards, 1998; Hunter & Richards, 2003; Richards, 1997; Richards & Hunter, 1997). Some relatively recent studies (Hunter & Richards, 2003; Richards & Hunter, 1997) have found that the “main sequence” relation between eye movement velocity and saccade amplitude changes with testing age and during attention. This study examines peripheral stimulus localization of moving characters placed on complex, dynamic background. We show that attention to the dynamic display enhances or attenuates peripheral stimulus localization partially dependent on the nature of the stimuli being localized.

Several studies have shown that the presence of a stimulus in the focal visual field affects the response to stimuli in the peripheral visual field. For example, Aslin and Salapatek (1975) found higher localization proportion and faster localizations of peripheral stimuli when a peripheral visual stimulus replaced a focal visual stimulus (replacement condition) than when the peripheral stimulus was presented in addition to the focal visual stimulus (addition condition). Several studies have shown that it is not simply the presence of the central visual stimulus that impedes peripheral stimulus localization, but engagement of attention to the focal stimulus. Several studies have used the presence of heart rate deceleration as an index of attending to the central stimulus. If the infant is attending to the focal stimulus, then longer latencies or fewer localizations occur, whereas if the infant is fixating the visual stimulus but is inattentive or attention has waned, localization latency and probability occur at levels similar to when no focal visual stimulus is present (Finlay & Ivinskis, 1982, 1984; Hicks & Richards, 1998; Hunter & Richards, 2003; Richards, 1997; Richards & Hunter, 1997).

The studies examining the role of attention on peripheral stimulus localization have used relatively simple geometric patterns to elicit attention and peripheral stimuli presented once on each trial. For example, Richards and Hunter (1997) presented infants with simple computer-generated geometric

patterns on a television monitor with a blank background. This pattern was presented until heart rate changes occurred that indicated attentiveness (heart rate deceleration) or inattentiveness (return of heart rate to prestimulus levels; see Richards, 2007, 2010; Richards & Hunter, 1998). At that point, a peripheral stimulus was presented, and the localization latency was recorded, and the “trial” ended. Heart rate changes were re-elicited by leaving the television monitor blank for several seconds, followed by a new presentation sequence.

Two lines of reasoning suggest that attention may operate somewhat differently with complex and dynamically changing stimuli than with simple geometric patterns. First, the level of heart rate change in infants to static or dynamic *geometric* patterns is much smaller and less sustained than the heart rate change to stimuli with audio and visual components (Richards, 1998, 2000; Richards & Cronise, 2000; Richards & Gibson, 1997). Phasic changes in HR are thought to correspond to different levels of attention engagement (Berg & Richards, 1997; Richards, 2007, 2010; Richards & Casey, 1992; Richards & Hunter, 1998). Thus, complex and dynamically changing stimuli may elicit larger amounts of attention.

Second, the pattern of looking toward complex audiovisual displays shows a different developmental course than looking toward simple geometric patterns. For example, Courage, Reynolds, and Richards (2006) examined changes in infants’ attention to video-like stimuli (“Sesame Street” movie) and faces or geometric patterns. They presented infants from 3 to 12 months of age with visual stimuli and recording looking and heart rate changes. They found longer looking times at all ages to the video stimuli than to either faces or geometric patterns. Infants between 6 and 12 months of age increased in looking time and heart rate deceleration to the complex dynamic stimuli but not to the other stimuli. Similarly, several studies have shown that there is an increase over these ages in looking and in attention to audio–visual video programs such as “Sesame Street” or “Blues Clues” or “Teletubbies” (Barr, Zack, Garcia, & Muentener, 2008; Pempek et al., 2010; Richards & Cronise, 2000; Richards & Gibson, 1997). Alternatively, simple static patterns or simple dynamic patterns do not elicit the same level of attention as complex video stimuli. Colombo (2001, 2002; Colombo, Harlan, & Mitchell, 1999a; Colombo et al., 1999b) has suggested that there is a gradual decrease from about 2 to 12 months in the average duration of looking toward simple static or dynamic visual patterns. Video programs are not only more complex than the simple geometric stimuli often used in peripheral stimulus localization research, but have human and human-like characters, movement and activity within a scene, and changes in scenes over time. The primary goal of this study, therefore, was to examine the effect of attention

on infants' peripheral stimulus localization of complex, dynamically changing visual stimuli.

The presentation procedure for the stimuli in this study is described as follows. The stimuli were derived from a "Sesame Street" movie, "Sesame Street 25th Anniversary Movie." The movie contained human and Muppet characters, dance and action scenes, and several scenes with humans and/or Muppets talking, but did not contain a complete story line. The participants were presented with scene segments from the movie that had single or multiple characters but which had only a single character moving in the scene. After fixation was directed to the first moving character in a particular location, a second segment from the scene was presented that had a character moving in a new location. Thus, the character in the second segment constituted movement in a location in the visual periphery, and we expected that infants would localize these peripheral stimuli in a manner similar to studies with central and peripheral visual stimuli. Work on peripheral stimulus localization often has contained "addition" and "replacement" conditions (Aslin & Salapatek, 1975; Hunter & Richards, 2003; Richards & Hunter, 1997). We attempted to mimic the addition condition by having some scenes in which a single character was present in the first segment, and the second segment consisted of that character and other characters "added" to the scene. Our replacement condition consisted of a single character in the first segment and a different character in a different location in the second segment. We also presented scenes that had a character move from one location to another in the first and second segment and scenes in which all characters were present in both segments but only the movement shifted from one location to another.

Studies that have examined the role that attention plays in peripheral stimulus localization latency or probability (Finlay & Ivinskis, 1982, 1984; Hicks & Richards, 1998; Hunter & Richards, 2003; Richards, 1997; Richards & Hunter, 1997) have used heart rate as an index of attentiveness. Changes in HR may be used to assess different phases of attention (Berg & Richards, 1997; Richards, 2007, 2010; Richards & Casey, 1992; Richards & Hunter, 1998). Stimulus orienting is defined as the time period before heart rate deceleration occurs, in which fixation is directed toward a moving stimulus and stimulus novelty is evaluated. Sustained attention occurs after a target has been localized and involves stimulus processing. Heart rate remains below prestimulus level during this period. Attention termination refers to the period when heart rate returns to prestimulus levels, while the infant continues to look at the stimulus. At this point, it is assumed that the infant is no longer processing the stimulus information because the infant can be easily distracted or may voluntarily look away.

One goal of the study was to examine the relation between attention and the latency to move the eyes from one moving character to the same or a different moving character in a different location. Heart rate changes indicating attentive and inattentive periods were elicited in this study by presenting the “Sesame Street” movie continuously for 55-sec periods. We expected to find periods of stimulus orienting and sustained attention indicating attentiveness to the “Sesame Street” movie and periods when heart rate indicates that inattention is occurring even though fixation continues. The scenes containing the first character to be localized and the second peripheral character were presented by shifting to that portion of the “Sesame Street” movie. Thus, the peripheral stimulus localization could occur during periods of attentiveness to the visual stimulus or during periods of inattention. This is in contrast to prior methods in which heart rate changes were elicited in discrete trials (e.g., Hunter & Richards, 2003). As the infant could look away from the television monitor during these presentations, we also compared the heart rate changes occurring at the onset of the “Sesame Street” stimulus with the heart rate changes occurring when an infant looked away and looked back to the television monitor. Using these heart rate changes, we therefore could evaluate the effect of the heart rate–defined attention phase on localization latency for the character with movement in the peripheral field of the infant.

A second goal for the study was to examine effect of attention on eye movements that occurred during peripheral stimulus localization. One characteristic of eye movements that has been studied in young infants is the relation between saccade velocity and amplitude, the “main sequence” (Bahill, Clark, & Stark, 1975). The main sequence is represented by a relation between maximum saccade velocity and saccade amplitude that is linear up to about 20° , with maximum velocity leveling off near 20° – 25° . At least three studies have suggested that the main sequence in young infants is modified during attention. For example, Hainline et al. (1984) reported that during scanning of interesting, complex scenes, infant main sequence relations were equivalent to those of adults; however, in response to simple, uninteresting stimuli, there was a decrease in slope. This decrease in slope of the velocity–amplitude function was interpreted as a decrease in attention. Richards and Hunter (1997) and Hunter and Richards (2003, 2011) found age changes and effects of attention on the main sequence. From the ages of 5 to 14 or 20 weeks, there is a decrease in the slope of the main sequence when infants are making eye movements from focal locations to peripheral stimuli. The slope of the main sequence in those studies was larger during sustained attention than during inattention, suggesting that more rapid eye movements for the same saccade amplitude were made during attention than during inattention. The effect of testing age and attention phase upon the main

sequence relation was tested for the eye movements made from the first segment to the new location with movement in the second scene.

Infants were tested at 14, 20, and 26 weeks of age. These ages were used because they cover a similar range of ages that have been used previously to study the effects of attention on peripheral stimulus localization (e.g., Hicks & Richards, 1998; Hunter & Richards, 2003; Richards, 1997; Richards & Hunter, 1997). A “Sesame Street” movie was presented that was known to elicit heart rate changes indicating attentiveness and inattentiveness. Scenes were presented so that the infants localized a moving character (alone, or among other characters), the character movement was shifted to another location, and infants moved their fixation to the movement in the periphery. The electrooculogram (EOG) was used to measure saccade onset, velocity, and amplitude. The latency to localize the peripheral character was obtained from saccade onset and was examined as a function of the attention status to the “Sesame Street” stimulus. The EOG recording provided the opportunity to examine the effects of testing age and attention on the relation between saccade velocity and saccade amplitude, the main sequence.

METHOD

Participants

Infants were recruited from their birth notices in the Columbia, South Carolina newspaper. Participants were full term, defined as having a birth weight >2500 g and a gestational age of at least 38 weeks based on the mother’s report of her last menstrual cycle. All infants were in good health at the time of the experiment and had no acute or chronic pre- or perinatal medical complications. There were 44 infants sampled cross-sectionally at 14 ($N = 14$, $M = 105.3$ days, $SD = 7.94$, eight males), 20 ($N = 14$, $M = 143.4$ days, $SD = 5.28$, 11 males), and 26 ($N = 16$, $M = 185.1$ days, $SD = 3.95$, eight males) weeks postnatal age. An additional seven infants were tested who did not complete the experimental protocol (fussy, uninterested).

Apparatus and Stimuli

Infants were placed on his/her parent’s lap approximately 55 cm from the center of a 49-cm (19 in) color monitor. The monitor subtended a 44° visual angle, and the plane of the television monitor was parallel to the infant’s eyes. The area around the monitor was covered in dark fabric so the infant would not be distracted easily from the screen. A video camera was centered above the monitor to allow the experimenter in an

adjacent room to judge infant fixations online and for recording of the sessions with a time code to synchronize physiological and experimental information for analysis. The video was digitized and saved in computer-based AVI movie files.

The peripheral localization stimuli were chosen from the movie, "Sesame Street's 25th Anniversary Celebration" (no sound). Scenes were chosen that contained backgrounds and single or multiple characters in different locations in the scene. The presentation sequence involved presenting a segment with the first character in the scene until the infant looked at it and then presenting the second character in the scene. We extracted 35 scenes with single or multiple characters in which there was movement restricted in a single location and for which an alternate segment with the same scene/background could be found that had the same or a different character moving in a different location. In each case, the overall background (scene, setting, trees, roads, buildings, and rooms) was the same in both the first and second segments. This insured that the background information did not change across the first and second characters. The segments could be roughly characterized according to the following four categories: (i) movement: a single character is in the first segment, and the character shifts from one location to another in the second segment; (ii) replacement: a single character is in the first segment, and the character is replaced with a different character in another location in the second segment; (iii) addition: a single character is in the first segment, and a second segment with that character in the same location and other characters in new locations is added, and movement shifts from the single character to another character; and (iv) shift: multiple characters are in the first segment, and the movement shifts from one character to a different character in a different location in the second segment. Table 1 contains sample combinations of the different stimulus types used. The table also includes the stimuli locations on the screen, measured in degrees from the center, with negative degrees being to the left and positive degrees being to the right side of the center. For example, the first shift condition listed had a baby alligator and a daddy alligator in the first segment with the baby alligator moving, and the second segment contained the same two characters but the daddy alligator was moving. Several of the chosen sequences were transitive (i.e., replace character one with character two, or replace character two with character one).

Selected scenes from the "Sesame Street" movie also were chosen. These were presented at the beginning of the peripheral localization trials to elicit heart rate changes and between the first segment and second segment presentations to sustain heart rate changes. We chose scenes that had several characters, and each scene included extensive movement.

TABLE 1
Sample Scene Presentations for the Four Experimental Conditions: Movement,
Replacement, Addition, and Shift

<i>First Stimulus</i>	<i>Width</i>	<i>Location</i>	<i>Second Stimulus</i>	<i>Width</i>	<i>Location</i>	<i>Type</i>
Big Bird thinking	18.4	1.87	Big Bird bouncing	27.94	2.89	Movement
Big Bird bouncing	27.94	2.89	Big Bird sitting/standing	19.09	-11.36	Movement
Small Kermit the Frog	9.67	-14.03	Large Kermit the Frog	19.47	5.17	Movement
Large Kermit the Frog	19.47	5.17	Small Kermit the Frog	6.74	-13.5	Movement
Grover	21.21	1.41	Grover near a mirror	19.66	-15.31	Movement
Oscar talking	24.35	6.69	Grover	21.21	1.41	Replacement
Cookie Monster	17.46	-1.39	Small Kermit the Frog	9.67	-14.03	Replacement
Kermit	16.67	5.6	Grover near a mirror	18.55	-5.62	Replacement
Big Bird thinking	18.4	1.87	Large Kermit the Frog	19.47	5.17	Replacement
Grover	21.21	1.41	Big Bird bouncing	27.94	2.89	Replacement
Baby Alligator	9.53	-12.1	Baby Alligator with hat	15.04	-9.34	Addition
Daddy Alligator	26.06	3.83	Baby Alligator with Daddy Alligator	9.53	-12.1	Addition
The Count talking	11.93	17.03	Big Bird talking to The Count	31.98	-4.92	Addition
Big Bird sitting/standing	19.09	-11.36	The Count talking to Big Bird	11.93	17.03	Addition
The Count waving his wand	14.07	18.11	Big Bird with the Count	27.88	-0.96	Addition
Baby Alligator	11.38	-11.17	Daddy Alligator	26.06	3.83	Shift
Big Bird	35.63	-14.16	Big Bird scratching	28.32	-17.81	Shift
Big Bird talking	37.46	-13.24	Little Girl	12.46	28.18	Shift
Big Bird scratching	31.98	-15.99	Little Girl	12.46	28.18	Shift
Big Bird talking	33.77	-1.98	The Count	27.08	20.87	Shift

Calibration trial stimuli were used to calibrate the EOG signal. A rectangular bar was presented that measured 2° horizontal width and 6° vertical width and had a constantly changing sine wave pattern, which gave the appearance of a blinking bar. After the infant was judged to be looking at the presentation, the bar was moved to peripheral locations (0, 5, 10, 15, or 20°) on either side. A detailed discussion of this calibration procedure may be found in Richards and Holley (1999) or Richards and Hunter (1997).

Measurement and Quantitation of Physiological Variables

The electrocardiogram (ECG) was recorded using Ag-AgCl electrodes with disposable adhesives that were placed on the infant's chest. The ECG was digitized online at 1000 Hz (1 ms). The R-wave of the ECG was identified, and the inter-beat intervals (IBIs) were computed within 1 ms of the R-wave

occurrence for the online evaluation of heart rate changes. Attention phases were defined according to a sequence of heart rate–defined changes. These changes were quantified at the beginning of the presentation of the “Sesame Street” movie, or following a look toward the stimulus when the look away was > 2 sec. Stimulus orienting was defined as the period in the first 5 sec occurring at the onset of the stimulus or look. Sustained attention was defined as a significant deceleration of heart rate, when five successive beats each had longer IBIs than the median of the five prestimulus or prelook beats. Inattentiveness was defined as occurring in two ways: first, after the first 5 sec of stimulus onset or a look onset, but before a deceleration occurred, represents looking without engagement of sustained attention and second, after the return of heart rate to its prestimulus level following a heart rate deceleration (“attention termination”), defined as five beats with IBIs shorter than the median of the five prestimulus beats. This inattentive phase continued until another heart rate deceleration occurred.

The EOG was recorded using 6 mm Ag-AgCl electrodes with disposable adhesives placed on the outer canthus of each eye. The EOG was digitized online at 1000 Hz, and a DC recording was made. Saccades were identified and separated from the composite EOG recording. The beginning and end of the saccades were identified with a third-order differential equation that identifies acceleration changes (increases for beginning; decreases at end; see Hunter & Richards, 2003; or Richards & Hunter, 1998). Saccades are characterized by a sudden shift in this parameter both at the beginning and the end of the saccade.

A computer-based editing program was used to judge the onset and offset of saccades. The maximum speed of the saccade was quantified from the EOG recording with 1 ms resolution, and the EOG amplitude was recorded at the beginning and end of the saccades. The saccade speed and amplitude were calculated on the basis of the EOG signal (μV) and calibrated into degrees. On the calibration trials, the degree of eye rotation necessary to move from one calibration stimulus to another is known, along with the difference in EOG amplitude for this change in fixation. The amplitude of saccades and the speed of the saccades were calibrated by using the subsequent fixations on the calibration trials in a separate calibration procedure (Richards & Holley, 1999; Richards & Hunter, 1997).

Procedure

Once the parent gave written consent, the infant was placed on his/her lap facing the monitor. The computer randomly chose which of the four scene types to present, and throughout the experiment, the segments specific to that particular scene type were randomized. The length of the localization trials was 55 sec. Each trial consisted of a first segment/second segment

localization followed by a randomly chosen Sesame Street segment, repeated approximately four to five times during one trial. At the beginning of the trial, a scene was randomly chosen from the scenes and was played to the infant. Once the infant localized the first stimulus and the infant was judged to be looking at the character(s) in the first segment, the second segment was presented. After the infant was judged to move his/her eyes to the second segment, a random section of the "Sesame Street" movie was shown for 5–10 sec. Four 55-sec trials with the localization scenes were given, followed by calibration trial of 55-sec duration. This was repeated as long as the infant was alert and cooperative for a maximum of ten trials.

Testing was carried out only if the infants remained alert and awake throughout the entire procedure, that is, their eyes were open, they did not fuss or cry, and they responded to protocol. Trials could be paused or restarted if the infant looked away or was uncooperative.

Stimulus Localization Judgments

A single observer judged the infant's fixations on a television monitor in an adjacent room during the experiment to control the experimental protocol. Each session was judged offline as well. The frame time of the video file was synchronized with the times of stimulus presentation and change. The video digitizing worked at 30 fps, so resolution was about 33 msec. The observer judged offline if the infant was looking toward the first segment when it was presented and then judged an eye movement to the second segment when it was presented. The calibration trials were judged similarly. In addition, a pass was made of online judging for looks toward and away from the television monitor for establishing when the infant was looking and when heart rate attention phases could be calculated. Computer programs used the video frame of the judgments to synchronize the infant looking, first and second segment occurrence, and heart rate changes. These offline judgments provided an assessment of the integrity of the experimental protocol and established whether stimulus localization had occurred. The judgment gave the approximate time of the localization that assisted in identifying the saccades used to localize the character in the second segment stimulus.

RESULTS

Heart Rate Changes for Heart Rate–Defined Attention Phases

We examined the changes in heart rate as an index of attentiveness. The IBI is the inverse of heart rate, so that a heart rate deceleration is measured by

the lengthening of IBI values, and the return of heart rate to prestimulus level, by the shortening of IBI values. Figure 1 shows the average IBI changes when the criterion was reached for a particular phase. The stimulus orienting phase occurred at the first presentation of the “Sesame Street” stimulus or following a look toward the stimulus when the infant had been

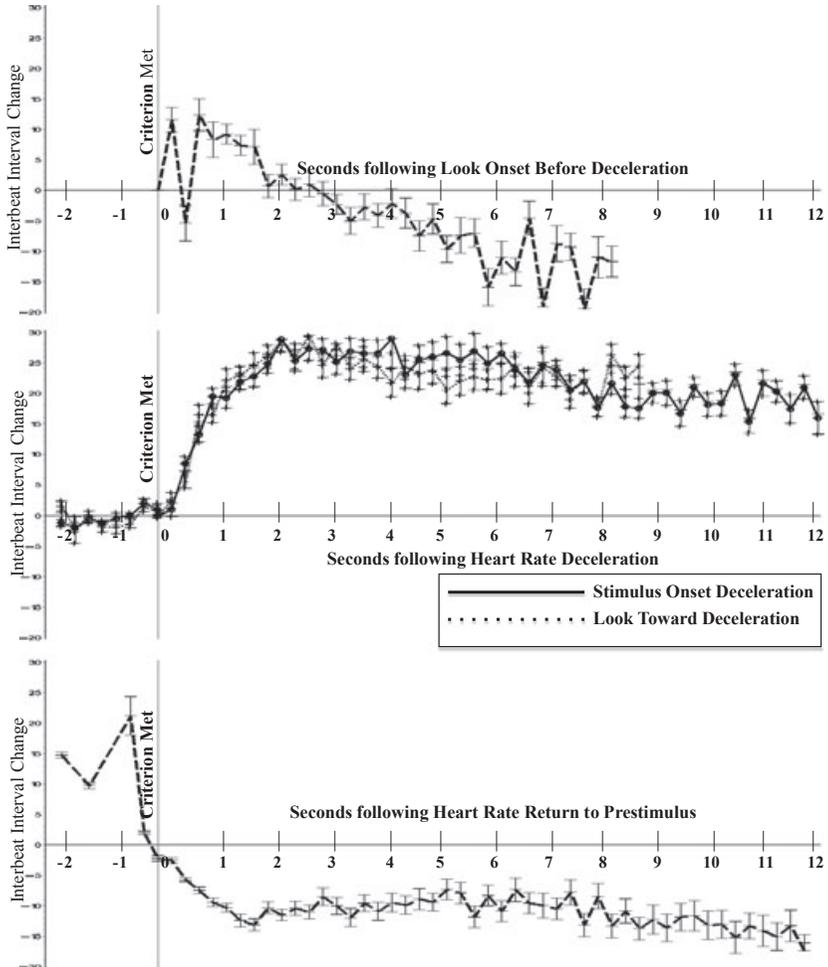


Figure 1 Changes in heart rate (IBI interval) upon reaching the criteria defining stimulus orienting, heart rate deceleration (lengthening of IBI, i.e., sustained attention), and the return of heart rate to the prestimulus level (shortening of IBI, i.e., attention termination). The line length is the average duration of that attention phase.

looking away. For this analysis, the IBI data until the onset of the first heart rate deceleration were analyzed. The criterion for this phase included the lack of a significant heart rate deceleration, and it can be seen in Figure 1 (top panel) that IBI changes did not occur during this time. The sustained attention phase occurred at the beginning of a significant deceleration in heart rate following either the onset of the “Sesame Street” stimulus (“Stimulus Onset Deceleration”) or a look toward the ongoing “Sesame Street” stimulus (“Look Toward Deceleration”). It can be seen in Figure 1 (middle panel) that the decelerations occurring at stimulus onset were nearly identical in amplitude to those occurring after a look toward the ongoing stimulus. The inattentive phase showed the typical return of heart rate toward the prestimulus level (i.e., attention termination; Figure 1, bottom panel).

The length of each attention phase and the average IBI change during the attention phase were analyzed with an age (3: 14, 20, and 26 weeks) \times attention phase (3: stimulus orienting, sustained attention, and inattentiveness) ANOVA.¹ This analysis was performed to examine the changes that occurred in the attention phases. There was a statistically significant effect of attention phase on the length of the attention phase, $F(2, 78) = 9.40$, $p < .001$, $\omega^2 = .258$, but no significant effects involving age. The average lengths of stimulus orienting, sustained attention, and the inattentiveness phase were 8.5, 12.6, and 12.8 sec. *Post hoc* tests showed that the stimulus orienting duration was shorter than the sustained attention and inattentiveness durations. Additionally, the average length of the deceleration occurring at stimulus onset (14.7 sec) was significantly longer than the length of the deceleration occurring following a look back toward the stimulus (10.9 sec). The average IBI change during the attention phases was significantly affected by the attention phase, $F(2, 78) = 149.321$, $p < .001$, $\omega^2 = .875$, and age, $F(2, 39) = 3.19$, $p = .052$, $\omega^2 = .095$. The average IBI change was -8.3 , 20.4 , and -8.0 msec for stimulus orienting, sustained attention, and inattentiveness, respectively. The difference between the deceleration and other phases was expected based on the a priori criteria defining these phases. In addition, the average IBI change during the deceleration to the onset of the stimulus (25.1 sec) was larger than the deceleration occurring when the infant looked back toward the stimulus (16.1 sec), even though the pattern of the heart rate deceleration was similar (Figure 1). The

¹The ANOVAs for the analyses were performed with a general linear models approach using nonorthogonal design because of the unequal distribution of the number of trials in the cells of the stimulus types \times attention phases \times subjects factorial design (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 (attention phase, stimulus type) within this class variable. The “PROC GLM” of SAS was used for the computations. *Post hoc* tests were carried out with the Scheffe method with the $p < .05$.

effect of age on the average IBI change occurred for the stimulus orienting and inattentive phases. The IBI change during the sustained attention phase was not significantly different for the three testing ages.

Peripheral Stimulus Localization Latency

The latency for the participant to make a saccade from the location of the character in the first stimulus to the moving character in the second stimulus was analyzed. An age (3) \times phase (stimulus orienting, sustained attention, and inattentiveness) \times stimulus type (35: first–second scene combinations) was carried out. There was a significant effect for heart rate phase type, $F(2, 55) = 9.50$, $p < .001$, $\omega^2 = .288$. The interaction effect of age and heart rate phase was close to significant, $F(4, 55) = 2.42$, $p = .059$, $\omega^2 = .119$. Table 2 shows the means and standard deviations of localization latency for age-groups and phase type. *Post hoc* tests showed that during the inattentive phase, there was a significant increase over the testing ages in localization latency, whereas there were significant decreases over testing ages in localization latency during stimulus orienting and sustained attention.

Within the same ANOVA, the effect of stimulus type was next examined to evaluate its effect on localization latency. A significant main effect of stimulus type was found, $F(34,102) = 1.91$, $p = .006$, $\omega^2 = .424$. The interaction of attention phase and stimulus type was also found to have a significant effect on localization latency, $F(89,180) = 1.40$, $p = .029$, $\omega^2 = .459$. The stimulus type effects represent the 35 first–second scene combinations. The scene effects were further examined with *post hoc* tests

TABLE 2
Latency to Localize the Character in the Second Scene (Peripheral Stimulus Localization)

	<i>Stimulus Orienting</i>	<i>Sustained Attention</i>	<i>Inattentiveness</i>
14-week-olds			
<i>M</i>	681.1	619.1	577.7
<i>N</i>	31	73	43
<i>SD</i>	111.81	71.44	86.18
20-week-olds			
<i>M</i>	463.6	600.1	685.9
<i>N</i>	18	92	25
<i>SD</i>	85.08	62.67	139.37
26-week-olds			
<i>M</i>	464.0	465.6	767.3
<i>N</i>	26	62	16
<i>SD</i>	90.69	55.53	227.29

that use the four scene categories (movement, replacement, addition, and shift) as categories. Figure 2 shows a bar graph representing reaction time for these specific analyses. For the shift of movement from one character to another character, reaction times slow from stimulus orienting to sustained attention to inattentiveness. For addition and movement types, stimulus orienting and sustained attention did not differ statistically and were significantly faster than during inattentiveness. For the replacement type, it took longer for the infants to move fixation to the replacing stimulus during stimulus orienting and sustained attention than during inattentiveness.

Characteristics of Localization Saccades: Main Sequence

The main sequence is a relation between maximum saccade velocity and saccade amplitude. We examined the main sequence relation by doing plots of the maximum saccade velocity as a function of saccade amplitude for the different ages and heart rate phases. The saccades that were chosen were the saccades to move from location of the moving character in the first segment to the location of the character in the second segment. Figure 3 shows the main sequence plots and best-fitting linear regression line for the 14-, 20-, and 26-week-old infants, and the linear regression lines for the three ages combined. There was a decrease in the linear coefficient (beta weight relating saccade velocity to saccade amplitude) over the three testing ages, from 34.1, 31.5, to 31.1 for the 14-, 20-, and 26-week-olds, respectively.

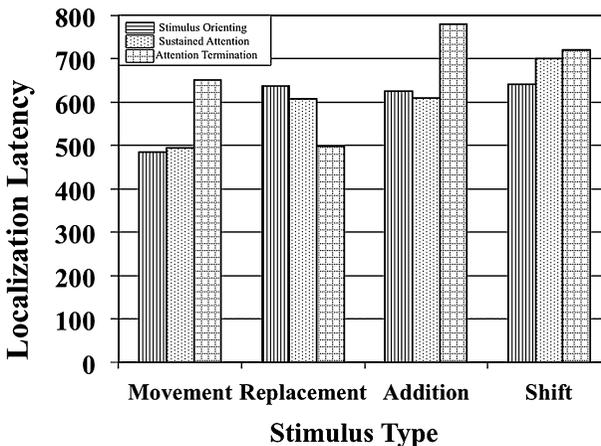


Figure 2 Latency to localize the character in the second scene for the four stimulus types and the attention phases.

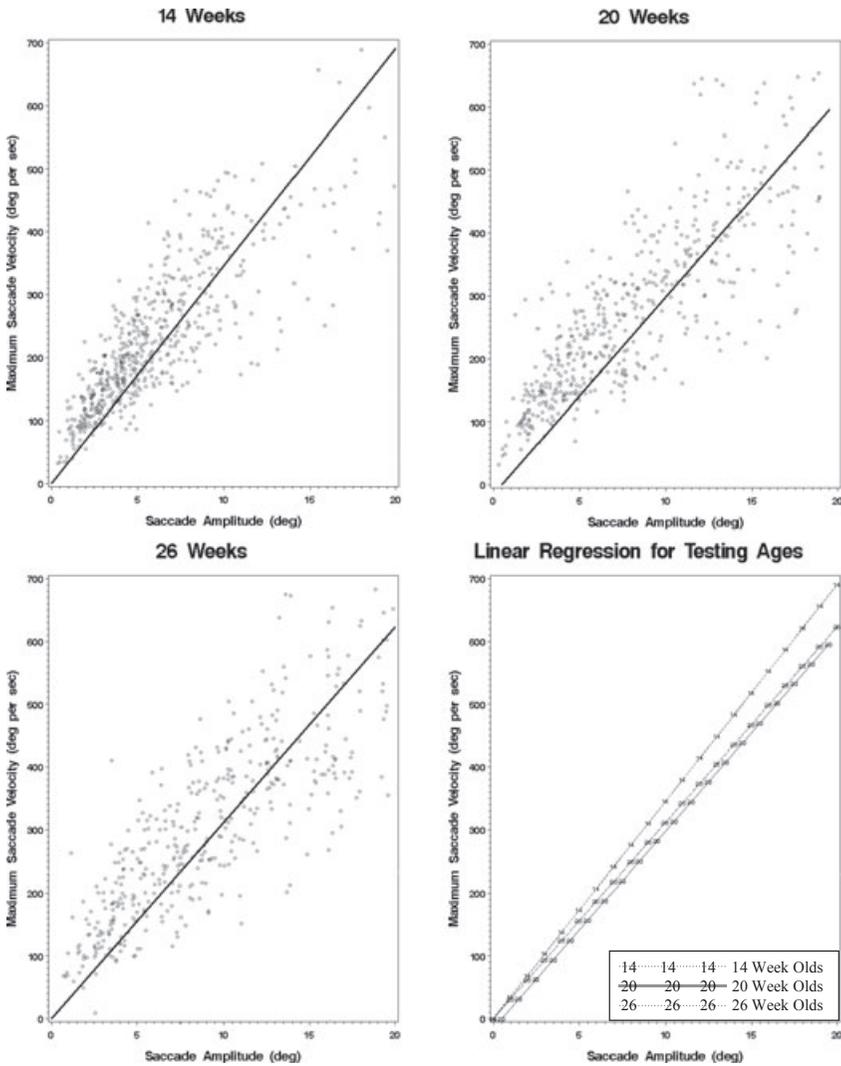


Figure 3 Main sequence relation between maximum saccade velocity and total amplitude of saccade for the three testing ages, with the best-fitting linear regression line. The regression lines are shown for saccades up to 20° in amplitude. The bottom right panel shows the linear regression lines from the other three panels.

Figure 4 shows the main sequence plots for stimulus orienting, sustained attention, and inattentiveness. The coefficient for inattentiveness was smaller (30.16) than that for stimulus orienting (32.7) or sustained attention (33.0).

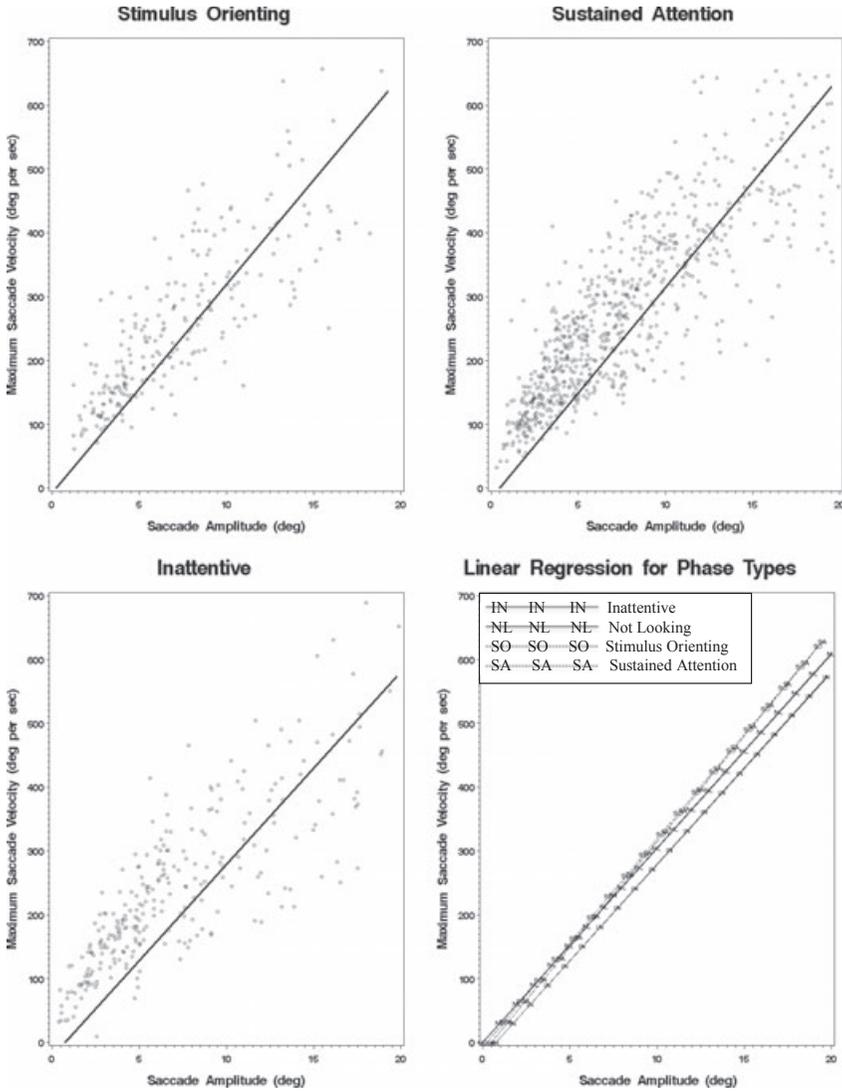


Figure 4 Main sequence relation for stimulus orienting, sustained attention, and the inattentive attention phases. The bottom right panel shows the linear regression lines from the other three panels and includes the linear regression line from saccades made when not looking at the television monitor.

Figure 4 also shows the linear regression lines for these three attention phases and periods of time when the infant was judged to not be looking at the television monitor. We consider that these periods of looking away do not represent attention engagement and should be similar to the inattentive periods. The regression lines for the stimulus orienting and sustained attention period were nearly identical, and the regression line for the saccades during inattentiveness was similar to that of the saccades made while looking away from the television monitor.

Finally, we estimated the linear regression coefficient separately for the three testing ages and for the three attention phases and saccades when looking away. Figure 5 shows the linear regression line for these effects separated by the three testing ages. The three attention phases and looking away saccades resulted in regression lines nearly identical for the 14-week-old infants. The 20- and 26-week-old infants had similar linear regression lines for the periods of stimulus orienting and sustained attention, and similar linear regression lines for the periods of inattentiveness and saccades occurring when not looking at the television monitor.

DISCUSSION

The goals of this study were designed to examine the effect of attention on infants' peripheral stimulus localization of complex, dynamically changing stimuli. The first goal was to determine whether attention to a focal stimulus affected the latency to localize a stimulus in a different location. The stimulus in the first segment, on which the infant fixated, affected the latency to localize the peripheral stimulus dependent on attention level and type of fixation shift. When a fixated stimulus was removed and then replaced by a new stimulus in a different location, it took longer to shift fixation to the new stimulus when in an attentive state than if the infant was inattentive. Alternatively, when the same character shifted from one location to another, the localizations were faster in the attentive conditions. Similarly, when a character was added to the display or the movement was shifted from one character to another, localizations were faster during attention than during inattention. The second goal of the study was to determine whether attention affected eye movement characteristics for peripheral stimulus localization of these complex stimuli. There was a difference in the main sequence between attentive and inattentive conditions for the 20- and 26-week-old infants but not the 14-week-old infants. The regression coefficient relating saccade velocity to saccade amplitude was larger during attention than during inattention for these two older ages.

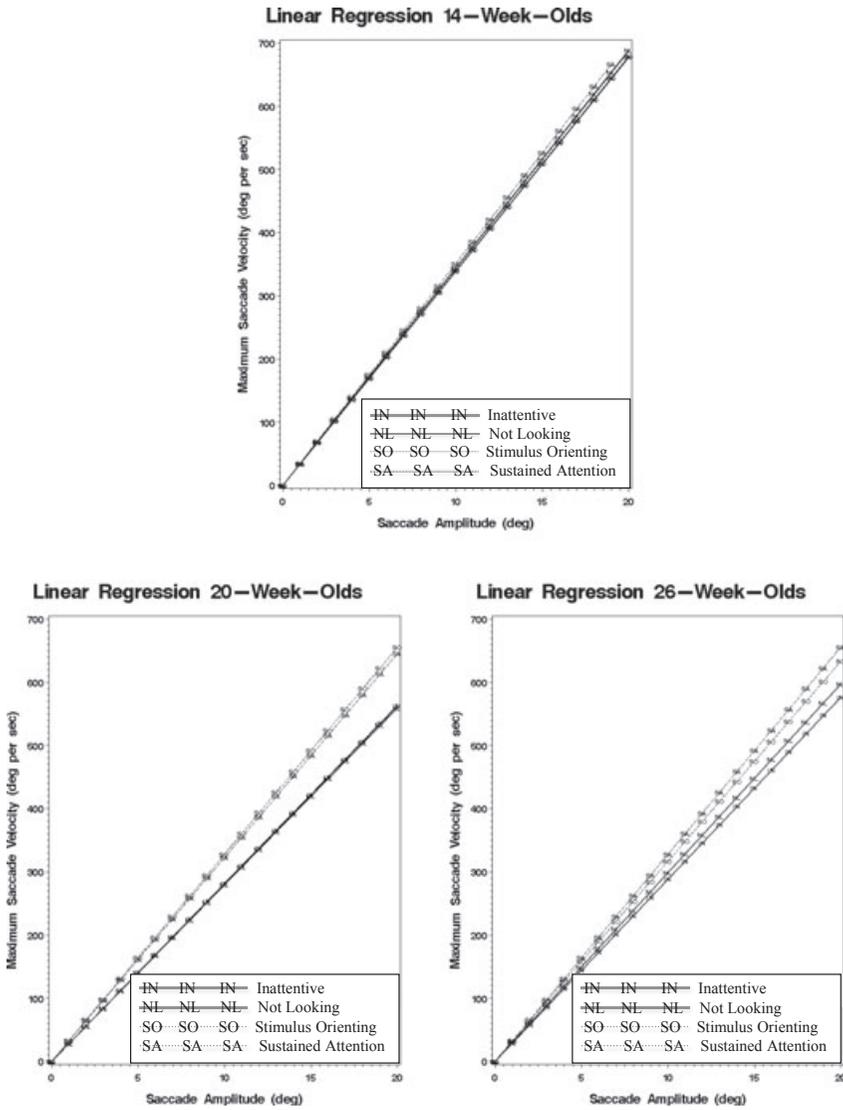


Figure 5 Linear regression lines for the main sequence relations for the stimulus orienting, sustained attention, inattentiveness, and not looking, performed separately for the three testing ages.

The effect on localization latency of attention and inattention toward the fixated stimulus was surprising. Several studies report that the presence of a foveated stimulus either increases the latency to make a localization to a

peripheral stimulus (Goldberg et al., 1997; Hicks & Richards, 1997; Richards, 1987) or decreases the probability of localizing a stimulus presented for a fixed interval of time (Aslin & Salapatek, 1975; Hicks & Richards, 1998; Hunter & Richards, 2003; Richards & Hunter, 1997). It also has been shown that localization latency and probability are attenuated toward the peripheral stimulus only if attention is engaged, whereas during fixation and inattention, the latency or probability to localize the peripheral stimulus is similar to that when no central stimulus is present. This pattern was found in the current study only for the scenes that mimicked the replacement condition. In those pairs, the character in the first segment of the scene to which fixation was directed was replaced by a new character in a different location of the scene. Under that condition, it took longer to shift fixation to the new character when the infant was engaged in sustained attention than when inattentive. The other stimulus types (shift, movement, and addition) for the most part showed the opposite effect—faster movement from the attended character location to the character in the new location than from unattended characters to characters in the new location.

An intriguing explanation of the facilitation of the peripheral stimulus localization under conditions of attentive viewing is that the type of stimulus movement may be important for attention-directed eye movements. This is seen most clearly by comparing the scene changes that were classified as replacement with those as movement. In both conditions, the infants directed fixation toward a character that occurred alone in the first segment and then shifted fixation to a character presented alone in the second segment. For the movement scenes, the identity of the character was preserved across the segments. Sustained attention is hypothesized to be accompanied by information processing (Richards, 2007, 2010). It is possible that the infants were engaged in active processing of information of a specific character and that localization of the same character in a new location was important to the infant. Thus, eye movements were facilitated in this condition. Alternatively, localization took longer when attention was not engaged (movement scenes while inattentive) or if the character in the new position was not the one to which attention was directed (replacement scenes when attentive). This interpretation suggests that the nature of the stimulus being localized interacts with the processing presumably occurring during attention or not occurring during inattention. It also implies that attention is not just to a spatial location and that attention/fixation in other locations is inhibited. Rather, it is attention to an object in a location. In this interpretation, attention facilitates the attention shift to a new location when the object shifts to that location (“shift” condition), whereas attention inhibits the attention shift to a new location when the object remains in the current location (“addition”) or a new object appears in a new location (“movement”).

The three stimulus types (movement, addition, and shift) in which peripheral localization occurred more quickly in attention than in inattention have not been used previously in this area of research. The addition condition in prior studies (e.g., Aslin & Salapatek, 1975; Hunter & Richards, 2003) presented a central stimulus and then added a peripheral stimulus. However, in those cases, if the central stimulus had movement occurring (i.e., alternating checkerboard pattern), the movement continued. The scenes in the current study that were labeled addition had characters that were added to the scene, but the initial fixation character stopped moving when the new character was added. Similarly, for the shift scenes with multiple characters, the movement shifted from one character to which fixation was directed to another character. During attention when stimulus processing of the scene was occurring, the cessation of movement for these scenes may signal to the infant that the action is now continuing in a new location and the shifts are made more quickly. This interpretation suggests that infants respond appropriately during attention to the dynamics of movement in complex visual displays by moving fixation to the dynamically changing stimuli. It is possible that video programs are designed with this viewer characteristic in mind and that the video makers intent to move the story uses shifts of dynamic activity in the scene to move a viewer's attention from one character to another (e.g., shifting action during conversations or dyadic interactions).

There were several aspects of these stimuli that limit the unambiguous attention interpretations. The identification of the scenes was carried out to identify preexisting scenes from the Sesame Street video that were similar to prior work with peripheral stimulus localization (e.g., Aslin & Salapatek, 1975; Hicks & Richards, 1998; Hunter & Richards, 2003; Richards & Hunter, 1997). However, we could not find scenes that precisely matched conditions used in prior work (e.g., replacement, addition). One limitation to the comparison of the current study with prior work is that analogs of the addition, movement, and shift scenes have not been previously studied in work on infant peripheral stimulus localization. These scenes were not designed specifically for the current study but were simply taken from preexisting scenes in the "Sesame Street" movie. It would be beneficial to the understanding of these effects to design stimuli that more closely mimic the replacement and addition conditions. Additionally, the eccentricities of the stimuli could not be precisely controlled, and the width of the characters on the screens differed both within and across scenes. The lack of eccentricity control affects the determination whether the saccade to the second character in the scene precisely localizes the stimulus or what part of the second stimulus is localized. We have developed a method to more precisely control these aspects by extracting backgrounds from scenes of this Sesame Street

video, extracting individual characters, and randomly overlaying characters in arbitrary locations. This leads to exact duplication of replacement and addition conditions and precise control of second stimulus eccentricity. It also may be that some backgrounds or stimuli may be more effective in eliciting attention or attention-affected gaze shifts. Although in the current study the background scene elements did not change across first and second character presentations, there may have been some inadvertent attention-background-stimulus linkages. Our new method will allow the separation of “characters” and “backgrounds” from the video scenes.

The effects of attention on the main sequence characteristics replicate work done in prior studies of peripheral stimulus localization. Richards and Hunter (1997) and Hunter and Richards (2003) measured the main sequence in infants ranging in ages from 5 weeks to 6 months. They used simple geometric focal and peripheral stimuli, presented on a simple background, and used single-exposure methods to elicit attentive and inattentive periods. Infants below the age of 14 weeks (Hunter & Richards, 2003; Richards & Hunter, 1997) had approximately the same linear regression coefficient during attention and inattention for saccades to the peripheral stimulus, whereas 20- and 26-week-old infants showed a larger linear coefficient for attention than inattentive saccades. Hunter and Richards (2011) measured the main sequence in infants from 8 weeks to 26 weeks of age in a free viewing procedure for a complex video program (“Sesame Street’s 25th Anniversary”). They found changes from 8 to 17 weeks of age in the main sequence slope but not at later ages, and no changes in the main sequence slope between attentive and inattentive periods. This suggests that the effect of attention on the main sequence slope in studies of peripheral stimulus localization (e.g., the current study; Hunter & Richards, 2003; Richards & Hunter, 1997) is not a general effect on eye movement systems but specifically on the eye movements used to localize peripheral stimuli. Hainline et al. (1984) found a similar increase in the linear regression coefficient during free scanning of interesting (i.e., complex) visual scenes, relative to the slope during scanning of uninteresting (i.e., simple) scenes, although the ages over which this effect occurred were not specified. The findings of the current study using complex and dynamically changing stimuli were consistent with studies using simple geometric patterns or more complex visual scenes, and saccades occurring during free scanning or discrete peripheral stimulus localization. These results imply that the increases over age of the effect of attention on the main sequence relation are because of an increasing influence of top-down attention processes over lower-level processes that control peripheral stimulus localization (Hunter & Richards, 2003; Richards & Hunter, 1997, 1998, 2002).

ACKNOWLEDGMENTS

This research was supported by a grant from the National Institute of Child Health and Human Development, #R37-HD18942 to John E. Richards.

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