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Individual and Developmental Differences in Disengagement of Fixation in Early Infancy

Janet E. Frick, John Colombo, and Terrill F. Saxon

The current study investigated whether individual and developmental differences in look duration are correlated with the latency for infants to disengage fixation from a visual stimulus. Ninety-four infants (52 3-month-olds, 42 4-month-olds) were tested in a procedure that measured ocular reaction time to shift fixation from a central target to a peripheral target under conditions in which the central target either remained present ("competition" condition) or was removed from the display ("noncompetition" condition). Look duration was correlated with disengagement latency; longer-looking infants were slower than shorter-looking infants to shift fixation to the peripheral target on competition trials, but not noncompetition trials. Results were similar for 3- and 4-month-olds, although 3-month-olds showed slower latencies on all trials. Furthermore, long-looking infants were not consistently slower, but rather showed greater variability in their response latencies under conditions that required disengagement of fixation. The results support the position that developmental and individual differences in look duration are linked to the development of the neural attentional systems that control the ability to disengage, or inhibit, visual fixation.

INTRODUCTION

In recent years, various theoretical models have been proposed to account for individual and developmental differences in measures of infant visual attention (Colombo, 1993). These measures are thought to reflect cognitive processes in young infants, such as attention (Richards & Casey, 1992), information processing (Colombo & Mitchell, 1990), memory (Rose, Feldman, & Wallace, 1988), and anticipation (Canfield, Smith, Brezsnyak, & Snow, 1997). All show considerable change across the 1st year of life. Furthermore, several measures of infant attention have been shown to correlate with cognitive measures later in childhood (Bornstein & Sigman, 1986) and adolescence (Sigman, Cohen, & Beckwith, 1997). One such measure is look duration, which has long been considered a useful indicant of infant attention and cognition (e.g., Cohen, 1969; McCall, 1975), has a clear developmental course (Colombo & Mitchell, 1990; Mayes & Kessen, 1989) and shows some continuity with cognition later in life (e.g., Rose, Slater, & Perry, 1986). In this article, we examine some of the models that have been proposed to account for developmental and individual differences in this measure.

Look Duration as an Indicator of Strategies of Visual Encoding

One theoretical model that has received recent support is that individual differences in look duration may relate to differences in strategies of encoding visual information. Bronson (1991) demonstrated that infants who encoded a visual stimulus more slowly scanned the stimulus *less* extensively and frequently engaged in prolonged fixation of one stimulus area. He concluded, "more advanced scanning is marked by a . . . relatively low incidence of prolonged fixations" (Bronson, 1991, p. 52; see also Krinsky-McHale & Hainline, 1996). Other studies have shown that infants with characteristic short look durations process stimuli in an adult-like global-to-local sequence (overall configural stimulus characteristics are processed first, followed by a more detailed analysis of the elements comprising the stimulus; see Kimchi, 1992; Navon, 1977). Infants with longer look durations, however, rely on local visual information in their processing of visual stimuli (Colombo, Freeseman, Coldren, & Frick, 1995; Colombo, Frick, Ryther, & Gifford, 1996).

The reasons why some infants maintain a tendency to cluster their looks in smaller portions of the visual field, however, remain unclear. It is possible that mature scanning and patterns of global stimulus processing depend on the ability to release fixation from a current focus and move attention to a new spatial location. Recent work in animal populations (e.g., Wurtz & Munoz, 1995) and within the realm of developmental cognitive neuroscience (see Richards, 1998) has led to increased interest in the mechanisms underlying disengagement and movement of fixation and their relevance for understanding developmental and individual differences in infant visual attention. This position has recently been elaborated by two different researchers.

Look Duration as an Indicator of Disengagement or Inhibition of Attention

McCall (1994; McCall & Mash, 1995) and Colombo (1995) have both proposed that individual differences in measures of infant visual attention (i.e., measures from visual habituation paradigms such as look duration) may relate to the ability to inhibit or disengage fixation from the current focal point and move it to another location. McCall (1994) proposed that fundamental abilities common to all infant visual attention tasks are the ability to inhibit responding to repetitive or uninformative aspects of the visual environment in a quick and efficient manner, and to direct attention toward novel stimuli, which are likely to be more informative. Inhibition also is a key concept in current models of childhood cognition (see Dempster, 1993; Harnishfeger; 1995; Harnishfeger & Bjorklund, 1993). McCall (1994) noted that support for this proposal would come from studies of infants' ability to inhibit attention to distracting and familiar stimuli. Colombo (1995) developed a similar hypothesis regarding developmental and individual differences in look duration, based on recent work in cognitive neuroscience elucidating central nervous system (CNS) pathways that mediate disengagement and shifts of attention (e.g., Posner, Petersen, Fox, & Raichle, 1988; Posner & Petersen, 1990). Both models propose that the ability to disengage fixation is essential in the development of visual attention in infancy.

Developmental changes in fixation disengagement in infants have been examined in a number of studies. Johnson, Posner, and Rothbart (1991) found that 4-month-olds showed a much greater propensity than 2- or 3-month-olds to disengage fixation from a central target and orient to ("localize") a peripheral target. In addition, the ability to make anticipatory saccades during a regular visual stimulus sequence has been demonstrated with 3-month-olds (Haith, Hazan, & Goodman, 1988), but not 2-month-olds (Canfield & Haith, 1991; Robinson, McCarty, & Haith, 1988). Older infants will shift fixation to wider eccentricities than younger infants (e.g., Harris & MacFarlane, 1974). Also, localization differs based on whether the central stimulus continues to be presented following peripheral stimulus onset. Infants are less likely to shift to a peripheral stimulus in the central stimulus's presence; furthermore, when they do localize the peripheral stimulus, latencies are longer when the central stimulus is present than when it is removed (Aslin & Salapatek, 1975; Finlay & Ivinskis, 1984; MacFarlane, Harris, & Barnes, 1976).

There are many ways in which infant visual behavior is consistent with the predictions of developmental improvements in the ability to disengage fixation. One of the most often noted characteristics of the visual behavior of young infants (1–2 months of age) is that they sometimes exhibit what has been termed "obligatory attention" (Stechler & Latz, 1966), "blank looking" (Bronson, 1982), or "sticky fixation" (Hood, 1995). That is, young infants often have difficulty disengaging fixation from a central stimulus to look to another stimulus (see also Cohen, 1976). Johnson (1990, 1995) has attributed the obligatory attention exhibited by 1 to 2-month-old infants to the developmental emergence of neural systems that inhibit peripheral eye movements. In this model, prolonged looking is believed to be due to the suppression of peripheral orienting. Similarly, Hood (1995) interpreted prolonged looking in young infants as being due to an inability to disengage from salient foveal stimuli. These models agree that early difficulties in disengaging fixation from a focal stimulus are eventually replaced by the ability to exhibit voluntary or goal-directed shifts of fixation.

Colombo (1995) proposed that infants who show characteristic patterns of long look durations ("long-looking infants") might do so because they have difficulty disengaging fixation from a stimulus, thus continuing to exhibit visual behavior that is characteristic of younger infants. There is some preliminary evidence to support this hypothesis. Look duration is negatively correlated with oculomotor reaction time in the visual anticipation paradigm (Haith et al., 1988), with long-looking infants being slower to shift fixation to a series of targets presented in a predictable sequence (Jacobson et al., 1992). However, individual differences in fixation disengagement would best be assessed with a research design that involves having participants fixate a central stimulus and then shift fixation to a peripheral target (e.g., Hood & Atkinson, 1993; Johnson et al., 1991; Richards, 1997).

Aims of the Current Study

The current study examined the latency for infants to shift fixation from a central visual stimulus to a peripheral stimulus as a function of individual differences in look duration. Three- and 4-month-old infants were tested in a peripheral stimulus localization paradigm. It was expected that 3-month-olds would be slower to shift fixation to a peripheral target than 4-month-olds and that infants would localize peripheral stimuli faster when the central target was removed than when it remained illuminated. Furthermore, it was expected that infants with longer look durations during a pretest would be slower to localize peripheral targets. If long-looking infants were slower in all conditions, whether or not the central stimulus remained illuminated, it would suggest that they simply exhibit slower oculomotor responses. If, however, long-looking infants were slower only when the central stimulus remained illuminated, this would suggest that they are slower to disengage fixation only when another target is competing for attention. In addition, the variability of infants' latencies to localize the peripheral target would indicate of the consistency of infants' response times; variability in infant reaction time has been examined in other recent work on early attention and cognition (see Dougherty & Haith, 1997).

METHOD

Participants

A total of 158 infants (86 3-month-olds, and 72 4-month-olds) were recruited by mail and telephone from a midwest suburban area to participate in the study near their 3- or 4-month birthday. Of this sample, 64 infants (34 3-month-olds and 30 4-month-olds) were excluded from all analyses due to fussiness or sleepiness ($n = 51$); experimenter error/equipment failure ($n = 6$), or prematurity (gestational age of 37 weeks or less; $n = 7$).

The remaining 94 infants (52 3-month-olds and 42 4-month-olds) provided data that were included in subsequent analyses. The average age of 3-month-olds was 95.0 days ($SD = 4.9$), and the average age of 4-month-olds was 124.4 days ($SD = 5.0$). Infants were generally from middle-class, two-parent families.

Apparatus

All infants were tested in a darkened 3m × 3m room with black walls and ceiling. Infants sat in a car seat in front of a 77 cm × 77 cm rear-projection screen. The distance from the infant's face to the screen was approximately 75 cm. Stimuli were rear-projected onto the screen by three Kodak Carousel projectors. A video camera was mounted at the bottom of the screen. In an adjacent room, an observer coded the direction and duration of the infant's fixations as they occurred using pushbuttons interfaced with a Zenith Z-159 microcomputer. In addition, the session was recorded on videotape so that the experimental trials could be analyzed off-line, frame-by-frame. A Panasonic Videocassette Recorder, Model AG-7750, and a Panasonic Editing Controller, Model AG-A750, were used to determine infants' latencies to shift fixation with 33 ms resolution.

Stimuli. The stimuli were three achromatic slides of geometric patterns and one color photograph of a female face. The two stimuli used to assess individual differences in look duration were a color photograph of a female face and a black and white checkerboard. The woman was photographed in front of a neutral background wearing a blue jacket. She had shoulder length brown hair and was smiling. The face stimulus subtended a visual angle of 10° by 15°, and the checkerboard stimulus subtended a visual angle of 15° by 15°.

The two remaining stimuli were used in the task assessing disengagement of visual fixation. These were achromatic arrays with either of two sets of figures, circles or diamonds, aligned along the vertical axis. The figures were solid black against a white background. These stimuli subtended a visual angle of 15° by 25°. The elements (circles or diamonds) within the arrays each subtended a visual angle of 6°. The peripheral stimuli were presented 25° either to the right or to the left of the central stimulus during the experimental trials; this is well within the range in which 3- and 4-month-old infants can detect peripheral stimuli (Tronick, 1972).

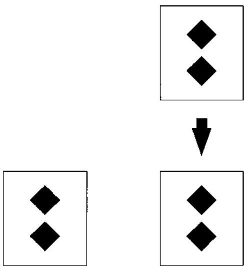
Procedure and Design

Look duration pretest. A measure of individual differences in look duration was first obtained. Infants accumulated a prescribed amount of fixation to each of two visual stimuli (the female face and the checkerboard), which were presented consecutively. The computer monitored the real-time button-presses of the observer and calculated both the total number of looks made during the accumulated looking time and the duration of the peak (longest) look. A look was considered terminated with any look away from the stimulus, but the stimulus remained illuminated until the entire amount of fixation was accumulated.

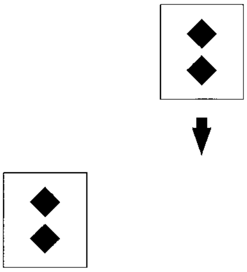
The required accumulated looking times were adjusted for the age of the infant as well as stimulus characteristics. Younger infants tend to show longer fixations than older infants; previous studies had shown a 20% drop in peak look duration from 3 to 4 months of age (e.g., Colombo, Mitchell, O'Brien, & Horowitz, 1987). In addition, infants tend to look longer at faces than at nonsocial stimuli (Dannemiller & Stephens, 1988). In previous studies in which this face stimulus had been shown along with an achromatic visual array to determine individual differences in look duration, fixations to the face were consistently longer than to any other type of stimulus (e.g., Colombo et al., 1996; Saxon, Frick, & Colombo, 1997). Based on linear interpolations of the age and stimulus effect sizes, the accumulated fixation times for the female face were set to 25 s for 3-month-olds and 20 s for 4-month-olds; the accumulated fixation times for the checkerboard were 20 s for 3-month-olds and 15 s for 4-month-olds.

In addition to the on-line measurement of look duration, a videotape record of the pretest was recoded off-line by an independent observer for 93% of the participants. Reliability estimates were obtained by calculating the correlations between the two sets of observations; all correlations for look duration variables exceeded .95.

Disengagement procedure. Following the fixation-duration pretest, infants were presented with a series of eight trials designed to measure latency of shifting fixation toward a peripheral target. The experimental procedure is illustrated in Figure 1. In this procedure, a central stimulus (either a pair of circles or diamonds vertically aligned) was presented until the infant fixated it for 1 s. Infants were randomly assigned to view either the circles or diamonds as the central stimulus; this factor was balanced across the two age groups.



Competition Condition



Noncompetition Condition

Figure 1 Illustration of the experimental procedure. In Competition trials, the central stimulus remains on during the presentation of the peripheral stimulus. In Noncompetition trials, the central stimulus is removed 750 ms prior to onset of the peripheral target. As described in the text, the lateral position of the peripheral stimulus (right or left) and the appearance of the peripheral target (novel or familiar) was balanced across trials.

As soon as the infant fixated the central stimulus for 1 s, a peripheral target was presented. The lateral position of the peripheral target (right or left) was balanced in random order across the eight trials. Two different peripheral stimuli were used: For half of the trials, the peripheral stimulus was circles, and for the other four trials, it was diamonds.

The eight trials also differed on whether or not the central target remained illuminated during presentation of the peripheral target. During four "competition" trials, the central stimulus remained illuminated while the peripheral target was presented. During the other four "noncompetition" trials, the central stimulus was removed approximately 750 ms prior to the appearance of the peripheral target. (The characteristics of this condition are similar to the "gap" condition reported in work by Hood and Atkinson (1993). Errors caused by infants looking away prior to the appearance of the peripheral target may be reduced if the length of this gap is reduced or eliminated.) This factor was balanced in random order across the eight trials. On each trial, the peripheral target was presented until the infant fixated it or until 10 s had elapsed. Following each trial, the stimuli were removed for a 2-s interstimulus interval, and then the next trial was initiated with another presentation of the central stimulus.

Coding of peripheral stimulus trials. The peripheral stimulus trials were controlled by an observer who pressed a button when the infant fixated one of the peripherally presented stimuli. The videotape record of the disengagement procedure was then coded off-line frame-by-frame to measure the direction of infants' fixations with temporal resolution of the length of a single video frame (33 ms).

Trials were classified according to whether fixation did or did not move directly from the central target to the peripheral target. Only trials in which fixation moved directly from the central target to the peripheral target or in which fixation remained on the central target during the entire trial were included in analyses. (Only two infants, both 3-month-olds, had a trial in which their fixation never left the central target during the 10 s presentation of the peripheral stimulus. It was decided to retain these two trials in analyses because such a trial represents an extreme case of a central stimulus inhibiting movement of fixation, which should be a way in which individual differences in disengagement of fixation are made manifest.) Trials were excluded if infant fixation moved from the center stimulus in some direction other than toward the peripheral stimulus, or if the infant became fussy. It was decided not to readminister unsuccessful trials because this would have led to some infants being in the testing situation longer than other infants. These infants could receive different amounts of exposure to the experimental protocol, and this potentially could skew responses on later trials. Specifically, had infants been given multiple opportunities to repeat unsuccessful trials, performance might have improved, due to familiarity with the procedure, or it might have declined, due to fatigue. To keep fatigue and practice effects constant across the sample, infants were not retested on unsuccessful trials.

Calculation of disengagement latency. The latency for fixation to move toward the peripheral target was calculated via frame-by-frame observation of video records. The dependent variable was the latency for the eye to move off the central target and begin to move toward the peripheral target. Thus, latencies reported in this study represent the latency for the eye movement toward the peripheral target to be *initiated*, not the length of time it took for fixation to actually move to and fixate the peripheral stimulus.

In previous research on visual reaction times with infants of these ages, it has been argued that 200 ms represents the lower limit of how quickly infant eye movements can respond to a stimulus presented in the peripheral visual field (Canfield & Haith, 1991; Canfield, Wilken, Schmerl, & Smith, 1995; Haith et al., 1988; see also Fischer & Breitmeyer, 1987). Response times faster than 200 ms are thought to represent anticipatory eye movements begun prior to stimulus onset. Thus, only latencies that were greater than or equal to 200 ms were included in analyses.

Reliability on these measures was obtained by having two observers independently code experimental sessions and determining the correspondence between the two sets of observations. Reliability was obtained on 20% of participants. Observers agreed within one video frame (33 ms) on when infant fixation began to move to the peripheral target on 91% of trials and within two video frames (66 ms) on 95% of trials.

RESULTS

Descriptive Statistics

Look duration pretest. For 3-month-olds ($n = 52$), the average peak fixation to the face stimulus was 12.14 s ($SD = 6.77$), and the average peak fixation to the checkerboard stimulus was 11.21 s ($SD = 5.06$). An overall average peak fixation was calculated by averaging the values for the infant's peak fixation to the two stimuli. The mean value for this average peak fixation for 3-month-olds was 11.68 s ($SD = 4.98$). For 4-month-olds ($n = 42$), the average peak fixation to the face stimulus was 9.54 s ($SD = 4.67$), and the average peak fixation to the checkerboard stimulus was 7.50 s ($SD = 3.47$). The mean value for the average peak fixation for 4-month-olds was 8.52 s ($SD = 3.19$). The value of average peak fixation was significantly longer for 3-month-olds than for 4-month-olds, $t(92) = 3.56$, $p < .001$. The overall correlation between infants' peak fixation to the face and to the checkerboard was $r(92) = .40$, $p < .001$. This significant correlation was not simply due to longer looking on the part of younger infants; the two variables were positively correlated within ages as well, and the correlation across all infants with age partialled was $r(91) = .35$, $p < .001$.

Fixation disengagement procedure. Typically, eye movement reaction time data are not normally distributed. Thus, in this article, the raw values are reported for descriptive statistics, but in statistical analyses the variables are transformed with the natural logarithm function, which results in a more normally distributed variable (see also Atkinson, Hood, Wattam-Bell, & Braddick, 1992; Richards, 1987).

Average latencies for fixation to move to the peripheral stimulus for 3-month-olds were 0.77 s ($SD = .63$), and for 4-month-olds were 0.43 s ($SD = 0.10$). This difference between the two age groups on this variable (log-transformed) was statistically significant, $t(92) = 4.08$, $p < .001$, indicating that 4-month-olds were significantly faster to shift fixation toward the peripheral stimulus.

Effect of Experimental Manipulations on Disengagement Performance

The effects of the experimental variables were analyzed in a mixed-design analysis of variance (ANOVA), with the between-subjects variables of Age (2: 3 or 4 months) and Type of Central Stimulus (2: circles or diamonds) and the within-subjects variable of Competition Condition (2: competition or noncompetition), for infants who completed at least one valid trial for each competition condition ($n = 77$; 41 3-month-olds and 36 4-month-olds). The dependent variable was infants' average reaction time to initiate an eye movement to the peripheral target. None of the main effects or interactions involving type of central stimulus (circles or diamonds) was significant, and this factor will not be discussed further. There was a main effect of age, $F(1, 73) = 12.17$,

Table 1 Correlations between Look Duration and Latencies as a Function of Age and Competition Condition

	At Least One Trial		At Least Two Trials		At Least Three Trials	
Peak Fixation	Competition	Non-competition	Competition	Non-competition	Competition	Non-competition
3-month-olds	.45**	.21	.54**	.19	.54**	.05
n	(45)	(48)	(35)	(34)	(24)	(20)
4-month-olds	.40*	−.30	.53*	−.29	.66**	.05
n	(35)	(41)	(27)	(37)	(17)	(22)
All ages	.54**	.14	.62**	.09	.60**	.14
n	(80)	(89)	(62)	(71)	(41)	(42)
Age partialled	.41**	.07	.54**	.01	.55**	.05
n	(80)	(89)	(62)	(71)	(41)	(42)

Note: Correlations are shown for infants with differing numbers of successful disengagement trials contributing to the correlation. The more trials contributing, the more reliable disengagement latency estimate is obtained. Disengagement values are log-transformed; the magnitude of the correlations is somewhat higher if the untransformed values are used.
* $p < .05$; ** $p < .01$.

$p = .001$, a main effect of competition condition, $F(1, 73) = 14.41$, $p < .001$, and an interaction between age and competition condition, $F(1, 73) = 6.48$, $p = .01$. This significant interaction was decomposed by performing separate one-way ANOVAs for each age group on the effect of competition condition on latency to move fixation toward the peripheral target. The effects of competition condition were highly significant for both 3-month-olds, $F(1, 40) = 11.39$, $p < .005$, and 4-month-olds, $F(1, 35) = 7.97$, $p < .01$.

For 3-month-olds, latencies in the noncompetition condition were 0.47 s ($SD = 0.27$) and in the competition condition, 1.16 s ($SD = 1.69$). For 4-month-olds, latencies in the noncompetition condition were 0.38 s ($SD = 0.15$) and in the competition condition, 0.50 s ($SD = 0.25$). Both age groups were faster to move fixation to the peripheral stimulus in the noncompetition than in the competition conditions. The significant interaction was due to the fact that 3-month-olds were slowed to a much greater extent in the condition that required disengagement from the central target than were 4-month-olds.

Individual Differences Analyses

Relation between look duration and disengagement performance. Because of the strong effects of age group and competition condition on peripheral stimulus localization latency, correlations between average peak look duration and this variable (log-transformed) were calculated separately for 3- and 4-month-olds, as well as for competition and noncompetition trials. Results are presented in Table 1. Three sets of correlations are presented, due to the fact that infants completed different numbers of trials successfully (because trials in which the infant looked away were not readministered; see above).[1] One 4-month-old was identified as a statistical outlier in disengagement latency (standardized residual greater than three *SD*s from the mean) and was not included in these correlation analyses. However, exclusion of this participant does not alter the conclusions drawn from these correlations.

As shown in Table 1, average peak look duration was strongly correlated with latency to move toward the peripheral target in the competition condition. This correlation was not due to one age group; it remained strong when the two age groups were analyzed separately, or when age was partialled from the correlation. However, average peak look duration was not related to latency to move fixation to the peripheral target in the noncompetition condition. This suggests that look duration does not covary with

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[1] The decision not to readminister unsuccessful trials resulted in infants completing different numbers of trials successfully. The length of time that elapsed between the attainment of the 1 s fixation criterion and the presentation of the peripheral stimulus (in the competition condition), or the 750 ms gap between the time that the central stimulus was removed and the peripheral stimulus was presented (in the noncompetition condition), is believed to have contributed to this loss of trials. Had the gap between central stimulus and peripheral stimulus been shorter, fewer infants would have looked away prior to peripheral stimulus onset (see also Hood & Atkinson, 1993). However, this loss of trials was randomly distributed across the sample, and was not related to the experimental questions. There was no relation between infants' average peak look duration and the number of trials they successfully completed, $r(92) = .06$, *ns*, even with age partialled, $r(91) = .11$, *ns*.

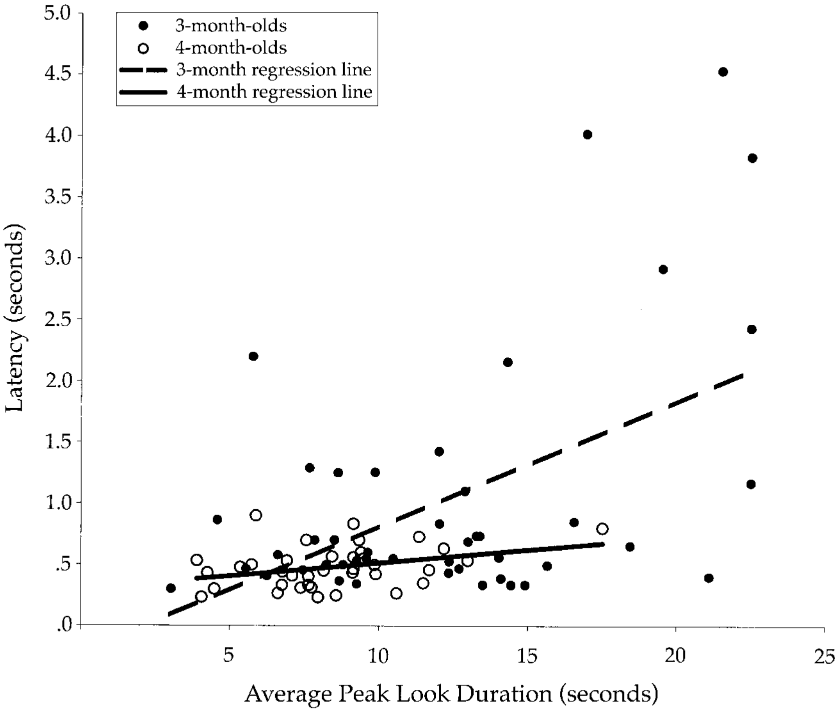

Figure 2 Scatterplot of the correlations between look duration and disengagement latency for the competition condition. Data for 3-month-olds are represented by the filled circles and the broken regression line. Data for 4-month-olds are represented by the open circles and the solid regression line.

overall latency to respond to peripheral targets, unless some process of disengagement is involved. A scatterplot of the correlation between look duration and disengagement latency in the competition condition, separated for the two age groups, is presented in Figure 2 (with the one statistical outlier mentioned above removed from the data).

Individual differences in variability of response. The previous results indicate that long-looking infants are slower to move fixation toward peripheral targets when a central target is competing for attention. This does not, however, address the *consistency* of infants' response times to the peripheral target (see Dougherty & Haith, 1997). It is not clear whether infants with longer fixations show slower latencies to move fixation to the peripheral target on a consistent basis or whether they are only slower on some trials.

This issue was addressed with an analysis of infants' fastest and slowest latencies to shift fixation to the peripheral stimulus in each condition. For infants who completed at least two trials of a given condition successfully, their fastest and slowest latencies were analyzed. The question still remains as to whether the overall distribution of disengagement latencies is shifted for long-looking infants relative to short-looking infants (i.e., whether long-looking infants are always slower than short-looking infants in disengaging from a look) or whether the correlations are due to an erratic or variable performance profile by long-looking infants. By examining the fastest and slowest disengagement performance of long- and short-looking infants, it should be possible to determine whether long-looking infants are actually capable of exhibiting disengagement latencies as fast as those shown by short-looking infants. If they are, then the groups should not differ significantly on their fastest performance, but rather only their slowest, or worst, performance (see also Larson & Alderton, 1990).

Infants were classified as long or short lookers based on a median split of their average peak look duration, as has been done in previous research (see Frick & Colombo, 1996). Infants' latencies to shift fixation were analyzed in an Age (2) × Looker (2: long and short) × Speed (2: fastest or slowest) × Condition (2: competition and noncompetition) mixed-design ANOVA. This overall analysis revealed main effects for all four variables and several two-way interactions. The analysis of interest for the current question, however, was a significant three-way interaction among looker, speed, and condition, $F(1, 50) = 4.54, p <$

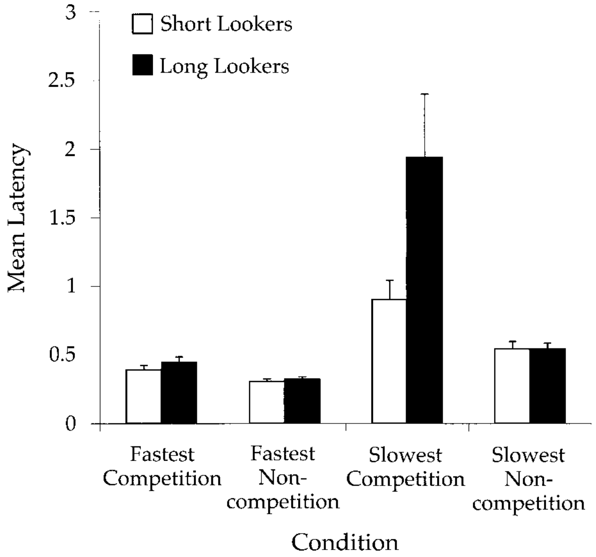

Figure 3 **Infants' fastest and slowest latencies for the competition and noncompetition condition, broken down by individual differences in look duration. Long- and short-looking infants were similar for all variables except their slowest latencies in the competition condition. Data are presented in s; error bars represent the *SEM*.**

.05.[2] This interaction is illustrated in Figure 3. Long- and short-looking infants differed in their slowest latencies in the competition condition, but not in their fastest latencies in that condition, nor in their fastest *or* slowest latencies in the noncompetition condition. Thus, long- and short-looking infants appear very similar in their response times, except that long-looking infants are much slower in their slowest latencies in the competition condition than are short-looking infants.

DISCUSSION

Peripheral Stimulus Localization in Young Infants

Consistent with many previous studies, older infants shifted fixation to a peripheral stimulus more quickly than younger infants, and all infants shifted fixation more slowly when a central target competed for attention than when the central target was removed prior to peripheral stimulus onset. The fact that a competing central target slows peripheral stimulus localization suggests that attention must be disengaged from the central target prior to moving to the peripheral target. Thus, the current findings indicate a significant improvement from 3 to 4 months of age in the latency to disengage fixation from a visual stimulus. This is consistent with previous claims that the ability to disengage attention and move fixation from one location to another undergoes rapid developmental changes in the first 6 months of life (see Hood, 1995; Johnson, 1995).

A possible alternate interpretation of the current findings is that what is being measured with this methodology is not really disengagement of attention (a capacity that is necessary for efficient cognitive performance), but rather "distractibility" (an attribute that would presumably be negatively related to such performance). Indeed, many studies in the literature with older children use prolonged manipulation or attention to a stimulus, object, or toy as a measure of "focused attention;" infants are found to shift fixation away from a stimulus more slowly when they are engaged in the most intense exploration of that stimulus (see Lansink & Richards, 1997; Oakes & Tellinghuisen, 1994; Ruff, 1986; Ruff, Cappozzoli, & Saltarelli, 1996; Tellinghuisen & Oakes, 1997). These studies have shown that focused attention (i.e., slower disengagement latencies from an object under examination) increases with age and with stimulus novelty and complexity (e.g., Oakes & Tellinghuisen, 1994).

However, the current findings can clearly be interpreted as measuring developmental improvements in attentional disengagement, due to the significant developmental trend in which 4-month-olds inhibited looking to a central stimulus much more readily than did 3-month-olds. It would not appear parsimonious to interpret this response in terms of distractibility, because one would not expect 4-month-olds to be more distractible than 3-month-olds. Rather, a theoretically consistent interpretation is that the current results and others using similar methodologies (e.g., Hood & Atkinson, 1993; Johnson et al., 1991) reflect developmental improvements in infants' ability to inhibit looking to repetitive visual information, whereas studies with older infants (e.g., Lansink & Richards, 1997; Ruff, 1986) have measured developmental improvements in infants' ability to focus attention on dynamic sources of information in their environment. It does seem likely that prolonged looking reflects different processes at different age-points during the

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[2] This full ANOVA required infants to have at least two valid trials for both the competition and noncompetition conditions, which was true for 54 infants (27 at each age). For example, an infant with four valid competition trials but only one valid noncompetition trial could not be included. Data from more infants could be brought to bear on this point by performing separate Age × Looker × Speed ANOVAs for each of the two conditions; for this analysis, infants would be required to have only two valid trials for one of the two conditions. This includes 63 infants for the competition condition and 72 infants for the noncompetition condition. The Looker × Speed interaction, $F(1, 59) = 3.81$, attains the $p = .056$ level for the competition condition analysis, but does not approach significance for the noncompetition condition analysis. Thus, essentially the same conclusions are drawn when more infants are included in these analyses, as illustrated in Figure 3.

first 2 years of postnatal life (see, e.g., Ruff & Rothbart, 1996; Saxon et al., 1997). Further work examining the relations between attentional disengagement early in infancy and focused attention later in infancy would clearly be informative.

Individual Differences in Disengagement of Fixation

The most important new contribution of this study was the finding that individual differences in look duration are correlated with the latency for fixation to move to a peripheral target, when a central target competes for attention. Look duration was not correlated with latency to shift fixation in the noncompetition condition, but only in the competition condition, in which fixation first had to be disengaged from a central target. This suggests that infants with long look durations do not consistently exhibit slower oculomotor responses, but rather are slower to *disengage* their visual attention. Thus, it appears that developmental and individual differences in look duration are linked to the development of the neural attentional systems that control the ability to disengage, or inhibit, visual fixation (Colombo, 1995; McCall, 1994). Studies indicating stability of individual differences in saccadic reaction time in young infants (e.g., Canfield et al., 1995) also are relevant to the interpretation of these findings.

The significant correlations between look duration and disengagement performance are clarified by the fact that infants with longer look durations also showed greater variability in their performance on the disengagement task (see Figure 3). It is important to note that long-looking infants were just as fast as short-looking infants in their fastest disengagement latencies. The greater variability exhibited by longer-looking infants suggests that long look durations do not reflect a pervasive attentional deficit. Rather, it may indicate a propensity toward some slower visual processing or responding, or possibly a difficulty with attentional regulation, than is typically observed for a particular population or age group. Reaction time variability has been shown to be an important cognitive variable in past work with both adult populations (Jensen, 1992; Larson & Alderton, 1990) and infant populations (Dougherty & Haith, 1997). Thus, variability in measures of infant visual attention may prove to be important for understanding the status of early attentional and cognitive processes; this remains to be addressed in future work. Furthermore, the current results were observed within a population of healthy, term infants; further work examining the same issues in infants at risk for later cognitive deficit would also be useful.

One question that remains concerns the relevance of the current findings for neuroscientific accounts of developmental changes in infant attention during the 1st year of life, including the transition from "obligatory attention" in younger infants (e.g., Stechler & Latz, 1966) to voluntary attention shifts in older infants. Johnson (1994) has proposed that obligatory attention is due to inhibition of the superior colliculus by the substantia nigra (see also Hikosaka & Wurtz, 1983); the end of the period of obligatory attention is believed to be due to a gradual emergence of cortical projections (middle temporal and frontal eye field pathways) to subcortical regions (striatum and superior colliculus), which overcome this earlier inhibition. In this model, obligatory attention is interpreted as inhibition of peripheral orienting; the influence of the nigral pathway on collicular activity is believed to "have the result that stimuli impinging on the peripheral visual field no longer elicit an orientation as readily as they do in younger infants" (Johnson, 1994, p. 246).

Obligatory attention can also be interpreted, however, as a deficit in the ability to disengage from a central target (e.g., Hood, 1995) due to immaturity in cortical systems that control disengagement of attention; the parietal lobes have been implicated in this process (Posner & Petersen, 1990). The former model would predict that the visual behavior of very young infants would be characterized by slowed latencies to shift fixation to any target presented in the peripheral visual field; the latter model, on the other hand, would predict slowed latencies only under conditions where disengagement from a central stimulus was required. To the extent that the behavior of long-looking infants (at 3 and 4 months of age) can be attributed to the same attentional processes that are observed in 1- and 2-month-olds, the current data provide more support for the latter model than for the former model.

Although obligatory attention is typically attributed to infants younger than the participants in the current study, differences in the rate of maturation of cortical attention systems would be expected to have the effect of prolonging the period during which disengagement difficulties would be observed. Still, the methodology used in the current study does not provide a definitive test of any model of the neural pathways or networks that underlie developmental and individual differences in early visual attention. Further work from the perspective of developmental cognitive neuroscience (Johnson, 1997; Richards, 1998) will undoubtedly foster continued progress toward this goal.

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ADDRESSES AND AFFILIATIONS

Corresponding author: Janet Frick, Department of Psychology, University of Georgia, Athens, GA 30602-3013; e-mail: jfrick@egon.psy.uga.edu. John Colombo is at the University of Kansas, Lawrence, KS; and Terrill Saxon is at Baylor University, Waco, TX.

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