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Visual Processing and Infant Ocular Latencies in the Overlap Paradigm

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Young infants have repeatedly been shown to be slower than older infants to shift fixation from a midline stimulus to a peripheral stimulus. This is generally thought to reflect maturation of the neural substrates that mediate the disengagement of attention, but this developmental difference may also be attributable to young infants' slower processing of the midline stimulus. This possibility was tested with 3- and 7-month-old infants in 2 experiments in which the degree of familiarity of the midline stimulus was manipulated across repeated trials. The results of these experiments demonstrated that the processing of midline content does affect infants' ocular latencies to a peripheral stimulus but that developmental differences in such processing do not account for developmental differences in disengagement seen across the 1st year.

Keywords: ocular latencies, information processing, disengagement, attention, infants

The study of the development of visual attention in infancy has attracted considerable empirical interest during the last decade (e.g., Colombo, 2001, 2002; Johnson, 1995; Richards, 1998). Although the term *attention* is often used to refer to a unitary construct, recent research suggests that attention may be best conceptualized as a collection of dissociable functions or components, each with a dedicated underlying central nervous system pathway or structure (e.g., Rafal & Robertson, 1995; Webster & Ungerleider, 1998).

Disengagement of attention is one such function and can be characterized as the ability to "inhibit" or "turn off" attention to a spatial locus or visual object. In adults, disengagement is one of a number of spatial orienting functions (engagement, disengagement, and shifting attention) that have been hypothesized to be mediated by a posterior attention system composed of the superior colliculus, pulvinar, and posterior parietal lobe (Posner, 1980, 1995; Posner & Petersen, 1990; Rothbart, Posner, & Boylan, 1990). In this framework, the posterior parietal lobe is proposed to mediate disengagement, although Rafal and Robertson (1995) have also implicated the temporal–parietal junction. The construct of disengagement has been investigated widely in the context of psychopathology or clinical populations (Braddick et al., 1992; Hood & Atkinson, 1990; Landry & Bryson, 2004; Mercuri et al., 1997; Wainwright-Sharp & Bryson, 1993).

Disengagement of Visual Attention in Infancy

Developmental investigations of disengagement may be traced back to reports of *obligatory looking* (Stechler & Latz, 1966) or *tropistic fixation* (Caron, Caron, Minichiello, Weiss, & Friedman, 1977) in young infants. These terms refer to prolonged periods of fixation seen in young infants that are thought to be dissociated from actual stimulus processing. Such patterns have been observed in instances where infants appear to have finished processing but are unable to disengage (see, e.g., Diamond, 1995). It had been suggested that these periods might reflect infants' difficulty with the ability to voluntarily inhibit fixation (Greenberg & Weizmann, 1971; Hopkins & Van Wulfften-Palthe, 1985). This phenomenon has been more recently recast as immaturity in the ability to disengage attention (Atkinson, Hood, Wattam-Bell, & Braddick, 1992; Hood, 1995; Hood & Atkinson, 1993; Johnson, Posner, & Rothbart, 1991).

Disengagement of attention during infancy has recently been studied in controlled laboratory situations using the gap–overlap paradigm. Infants' gaze is first drawn to a visual stimulus at midline and then a stimulus is presented in the visual periphery, which typically draws the eye away from the midline stimulus and toward the peripheral stimulus. In the gap condition, the midline stimulus is removed prior to the presentation of peripheral stimulus; disengagement is presumably unnecessary before attention is shifted toward the peripheral stimulus. In the overlap condition, the midline stimulus remains present when the peripheral stimulus appears, thus presumably requiring disengagement of attention prior to any shift away from the midline stimulus. The primary dependent measure is the latency of the infant's ocular movement away from the midline stimulus and toward the peripheral stimu-

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lus. Such latencies are shorter in the gap condition than in the overlap condition (Atkinson, Hood, Braddick, & Wattam-Bell, 1988; Atkinson et al., 1992; Hicks & Richards, 1998; Hood & Atkinson, 1993; Johnson, 1990; Johnson et al., 1991).

Ocular latencies of younger infants (i.e., under 6 months of age) are particularly impaired in the overlap condition relative to those of older infants (Frick, Colombo, & Saxon, 1999; Hood & Atkinson, 1993). Although there is some controversy over which structures or pathways mediate disengagement during infancy (e.g., Csibra, Johnson, & Tucker, 1997; Hood, 1995; Johnson, 1990; Johnson et al., 1991), developmental changes in performance in the gap–overlap paradigms have been generally assumed to be driven by maturational change (Atkinson et al., 1992; Hood & Atkinson, 1993; Johnson et al., 1991). That is, younger infants are slower to disengage simply because those brain structures or pathways that mediate disengagement are immature. We consider here, however, an alternative to this maturational hypothesis for developmental differences in disengagement.

An Alternative Hypothesis

The processing hypothesis raised here proposes that at least some of the age-related change in infants' performance on the overlap condition of the gap–overlap paradigm may be attributable to the speed or rapidity with which infants process or encode the midline stimulus. In most implementations of the gap–overlap paradigm with infants, effort is taken to make the midline stimulus attractive and interesting so as to optimally hold infants' fixation to the central stimulus of the display (e.g., Atkinson et al., 1988, 1992). Younger infants look longer to visual stimuli than older infants, and this has been linked empirically to the speed with which they encode visual stimuli (e.g., Colombo & Mitchell, 1990; Mayes & Kessen, 1989; Pecheux & Lecuyer, 1989). Thus, it is possible that younger infants may appear to be slower to disengage in the gap–overlap paradigm simply because they are slower to process the content of the midline stimulus. Under this hypothesis, longer ocular latencies to the peripheral stimulus in the overlap condition are not due to difficulty in disengagement per se (i.e., the inability to "let go" of the stimulus) but are attributable in part to infants' continued active processing of the midline stimulus. Atkinson et al. (1992) have briefly discussed the effect of repeated exposure on latencies in this paradigm, but processing of the midline stimulus has not been widely considered as a component in the sequence leading to disengagement of attention and its influence has not been explicitly investigated.

The extant data in the literature allow for a plausible case to be made for this alternative hypothesis. Look duration, which has been the primary indicant for infants' speed of encoding (Colombo & Mitchell, 1990), has been reported to correlate with measures of disengagement in the overlap condition in 3- and 4-month-olds (Frick et al., 1999) and has been implicated in the relationship between look duration and recognition performance (Colombo, Richman, Shaddy, Greenhoot, & Maikranz, 2001). It has therefore been previously suggested that individual and developmental differences in disengagement drive individual and developmental differences in look duration (see also Cohen, 1976; Colombo, 1995; McCall, 1994; McCall & Mash, 1995). The processing hypothesis under consideration here, however, proposes that the causal direction of this association may be reversed; that is, the processing hypothesis suggests that slower stimulus processing (as indicated by longer look durations) actually drives infants' performance on ocular latency tasks.

The Current Study

The purpose of the current study was to test this possibility by contrasting the different predictions generated by the maturational and processing hypotheses under conditions in which the exposure to the content of the midline stimulus was manipulated. The processing hypothesis predicts that additional exposure to the content of the midline stimulus would produce significant improvements in ocular latencies, perhaps even to the point of eliminating developmental differences on this measure. In contrast, the maturational hypothesis predicts that the developmental differences should be consistent and maintained irrespective of exposure to the content of the midline stimulus.

Therefore, the present study examined the performance of 3- and 7-month-old infants in the overlap paradigm under conditions in which exposure to the particular midline stimulus was manipulated. In addition to the measurement of ocular latencies, heart rate (HR) was measured while infants were administered the task. The course of infants' visual processing has been shown to coincide with the course of the robust HR deceleration typically exhibited by young infants during looking (e.g., Richards, 1997; Richards & Casey, 1992). Thus, the inclusion of this measure allowed us to determine whether infants were still engaged in processing the midline stimulus when the peripheral stimulus was presented during the experiment.

Experiment 1

Method

Participants

Ninety-six infants (47 male, 49 female) were recruited by mail and telephone from the Kansas City metropolitan area. This population is predominantly Caucasian and of upper-middle socioeconomic status. Parents were college educated; the mean number of years of education was 16.1 for mothers and 16.0 for fathers. Participants were 3 months (M = 105.5 days, SD = 7.9) and 7 months (M = 216.6 days, SD = 8.3) of age. In this sample, 53 infants were first born, 29 infants were second born, and 14 were third born. Of these 96 infants, 10 were excluded for fussiness (n = 1), failure to look at midline stimuli on all attempted trials (n = 7), or failure to shift on all attempted trials (n = 2). The 86 remaining infants contributed to subsequent analyses, although not every infant completed all trials of the protocol.

Apparatus

Infants were tested in a 2 m × 2 m room with black walls and ceiling; they were placed in a car seat approximately 1 m away from a rear-projection screen. Stimuli were presented on the 1 m × 0.7 m screen by three Kodak Carousel projectors. A video camera was centered at the bottom of the rear-projection screen, and an observer located in the adjacent room observed the infant on closed-circuit television. The observer coded looking behavior online using a button press connected to a microcomputer that kept track of the length of looking during accumulation and controlled the projectors.

HR responses were simultaneously collected during the session. Ag-AgCl electrodes were placed in a triangular configuration, with two on either side of the infant's chest and one above the abdomen. Data were collected using a commercial psychophysiological data acquisition package (BioPac, Inc., Santa Barbara, CA), with the electrocardiogram (EKG) digitized at a sampling rate of 250 Hz.

Stimuli

Infants were presented with complex stimuli at midline and simpler stimuli in the periphery. The complex stimuli were eight multicolored geometric designs placed on a background of white rectangles (13.5° horizontal × 20° vertical). These were composed of different combinations of red, green, yellow, and blue circles, squares, triangles, rectangles, and crescents. Eleven adult judges had indicated that the stimuli were matched for complexity in a rating task conducted prior to the infant study.

The peripheral stimuli consisted of simpler monochromatic (i.e., red, green, yellow, or blue) geometric shapes (i.e., circle, square, rectangle, or triangle), presented on a white background. The peripheral stimuli were the same size as the midline stimuli. The location of the peripheral stimuli was balanced across trials; they were shown 10° to the left or right of midline (i.e., 20° apart).

Design

Experiment 1 was a 2 (age: 3- vs. 7-month-olds) × 2 (condition: same vs. different) between-subject factorial design. In the *same* condition, the stimulus presented at midline was the same on every trial. In the *different* condition, the stimulus presented at midline was varied from trial to trial.

Procedure

Following the completion of informed consent, the infant was placed in a car seat in the testing room. Caregivers typically remained in the room with the infant at all times and were instructed not to interfere or interact with the infant during testing. On rare occasions when necessary, the infant was held on the caregiver's lap at the same distance and height from the display as the car seat. Once the infant was placed in front of the presentation screen and was judged to be in a contented state, lights were gradually dimmed to off and the experiment began.

At the beginning of a trial, the infant was presented with a stimulus at the center–midline of the screen and his or her looking to the stimulus was recorded. Once the infant accumulated 5 s of looking at the midline stimulus, a peripheral stimulus was presented either to the left or right of the midline stimulus. When the infant shifted fixation away from the midline stimulus (or after 5 s had lapsed if the infant never moved fixation away from the midline stimulus), both stimuli were removed. The observer then pressed a button to begin the next trial presentation; the intertrial interval was 2 s.

In all trials, the midline stimulus remained on during (i.e., overlapped with) the presentation of the peripheral stimulus. The lateral position of the peripheral stimulus was randomized and counterbalanced across 16 trials, with the constraint that it could not appear in the same location for more than two consecutive trials. This was done to eliminate the possibility that the infant might become biased toward anticipatory looks to a specific peripheral lateral position.

If the infant cried during a trial, the trial was terminated and not used in the analyses. If the infant returned to a calm state during the next trial, then subsequent nonfussy trials were kept for analysis. If fussiness continued and the infant did not return to a content state, the session was terminated.

On conclusion of the session, parents were asked to complete a health questionnaire. Then parents were shown a tape of their baby in the experiment, and the experimenter offered to answer any additional questions.

Data Reduction

Coding and calculation of ocular latencies. For a trial to be coded as valid, the infant had to (a) successfully accumulate 5 s of looking to the midline stimulus, (b) be fixated on the midline stimulus at the point when the peripheral stimulus appeared, and (c) make an overt shift in the direction of the peripheral stimulus. For trials on which all requirements were met, ocular latency was calculated by coding trials on a frame-by-frame basis (33-ms resolution) using a Panasonic jog–shuttle VCR interfaced with a computer via an RS232 port. Custom software controlled the frame-by-frame presentation and the frame count. The calculation of latency started with the presentation of the peripheral stimulus and continued until the infant made an eye movement toward the peripheral stimulus.

The sessions were later coded for reliability, and the reliability of coding ocular latencies from the tapes was highly consistent, with interobserver records correlating at .99.

Derivation of look duration. We also measured the number of looks that the infant made to the midline stimulus during the accumulation phase, and this allowed us to calculate a mean look duration from the phase. This measure was taken to examine the relationship between look duration and overlap paradigm performance, as in Frick et al. (1999).

Reduction and calculation of HR. The EKG was digitized and synchronized with stimulus and looking events. This made it possible to examine infants' HR immediately before and after occurrences of interest (e.g., stimulus onsets and offsets).

Results

Ocular Latencies

Overall latency. The mean ocular latency calculated for each participant across all valid trials was entered into a 2 (age) × 2 (condition) between-subjects analysis of variance (ANOVA). Forty-four 3-month-olds and 42 7-month-olds contributed to the analysis; 47 infants completed the *same* condition and 39 infants completed the *different* condition. There was a significant main effect for age, $F(1, 82) = 50.03$, $p < .001$, $\eta^2 = .38$, as older infants had shorter ocular latencies than younger infants. This was qualified by a significant two-way interaction, $F(1, 82) = 4.54$, $p = .036$, $\eta^2 = .05$ (see Figure 1). The interaction was attributable to 3-month-olds showing longer latencies in the *different* condition, relative to the *same* condition. Seven-month-olds' latencies did not vary across condition.

Manipulation of the midline stimulus therefore affected ocular latencies in the 3-month-olds. However, it did not eliminate age differences between the two age groups. Even in the *same* condition, which imposed the least cognitive load for infants in this study, latencies for 3-month-olds ($M = 1{,}044$ ms, $SD = 548$) were still significantly longer ($p < .001$) than those seen for 7-month-olds ($M = 458$ ms, $SD = 229$). Clearly, differences in the pro-

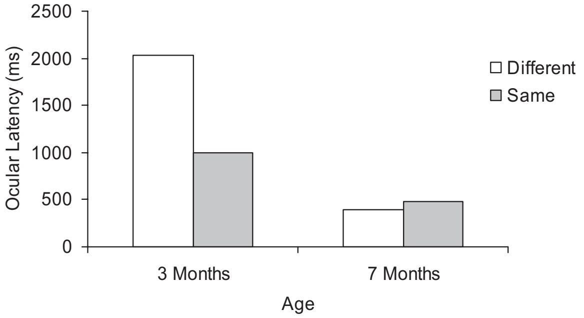


Figure 1. Ocular latencies (in milliseconds) for infants in the two conditions and age groups from Experiment 1.

cessing of the midline stimulus did not account for the developmental differences in overlap paradigm performance.

Change in latencies across trials. The overall latency analysis raised the question of whether 3-month-olds' latencies were reduced by increased familiarity with the content of the midline stimulus or were increased by the presentation of novel midline stimulus across trials. To address this, we examined the pattern of infants' performance across trials. To maximize data use, latencies for each infant were averaged from the 16 trials to create four blocks of four adjacent trials (i.e., ocular latencies were averaged across trials 1–4, 5–8, 9–12, and 12–16). A hierarchical linear model (HLM) analysis was then performed on these values using the predictors of age, condition, trial block (linear component across trials), and trial block^2 (quadratic component across trials). The HLM was chosen because many infants had missing data, even after computing the trial block averages, and this would have compromised the power and generalizability of a repeated-measures multivariate analysis of variance.

As with the analysis reported above, the HLM yielded a significant main effect for age, $F(1, 123) = 22.72$, $p < .001$, $\eta^2 = .16$. It also yielded a significant main effect for trial block^2, $F(1, 123) = 5.01$, $p < .05$, $\eta^2 = .04$. Both main effects, however, were qualified by significant higher order interactions. A Trial Block^2 × Age interaction, $F(1, 123) = 6.20$, $p < .05$, $\eta^2 = .05$, was itself further qualified by a significant Trial Block^2 × Age × Condition interaction, $F(1, 123) = 4.69$, $p < .05$, $\eta^2 = .04$. Latencies for 7-month-old infants showed no change across trials in either the *same* or *different* conditions. Latencies for 3-month-olds showed no change across trials in the *same* condition but a significant quadratic increase in the *different* condition (see Figure 2). Thus, the changing content of the midline stimulus slowed 3-month-olds' ocular latencies across trials.

Association Between Ocular Latencies and Look Duration

The current data set allowed for a repetition of the finding that the duration of infant looking was correlated with the latency of disengagement in an overlap paradigm. We calculated a mean look duration for each infant from accumulation periods across the session, and a mean ocular latency was calculated for each infant from valid trials during the session. Correlations were calculated separately for each of the ages because an Age × Condition ANOVA of look duration showed 3-month-olds looking marginally longer than 7-month-olds, $F(1, 89) = 3.43$, $p = .07$, $\eta^2 = .04$.

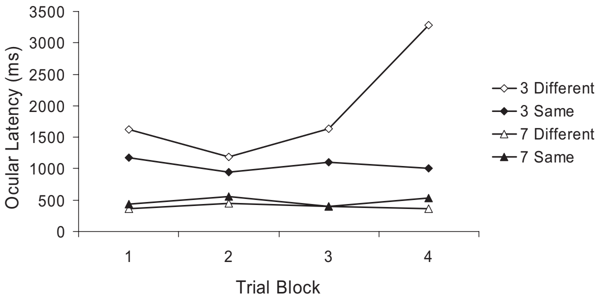


Figure 2. Ocular latencies (in milliseconds) from Experiment 1 across trial blocks as a function of age and condition.

The correlation between mean look duration and mean ocular latency was moderately strong for 3-month-olds, $r(24) = .47$, $p < .001$, but not significant for 7-month-olds, $r(35) = -.16$, *ns*. The results for 3-month-olds are consistent with Frick et al.'s (1999) report, but the current study extends those findings, suggesting that this correlation dissipates by 7 months.

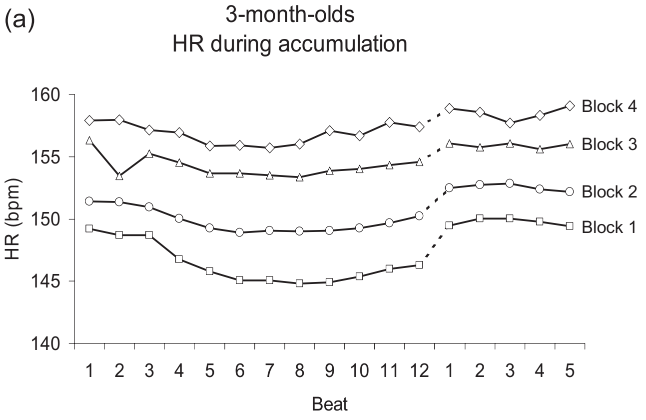
Analysis of HR During the Accumulation Phase

HR was collected in this study to provide a convergent check on infants' processing of the midline stimulus during accumulation. Infants' HR decelerates robustly during active information processing; this deceleration has been definitively linked to the processing of information (e.g., Richards & Casey, 1992).

Examination of HR was limited only to trials on which a valid shift occurred. HR was averaged for each infant across blocks of four adjacent trials, as for the analysis of ocular latencies described above. In each of the analyses run, highly significant ($p < .001$) main effects for trial block and age emerged. Infants' mean HR increased across blocks (the mean increase is about 10 bpm; see also Maikranz, Colombo, Richman, & Frick, 2000), and 3-month-olds' HR was consistently 10 to 12 bpm higher than that of the 7-month-olds. Reference to these effects is minimized in the following sections to conserve space.

HR deceleration during accumulation. A 4 (trial block) × 12 (beat) × 2 (age) × 2 (condition) mixed-design ANOVA was conducted on the first 12 beats following the onset of the midline stimulus. Twelve beats represent approximately 5 s of elapsed time and reflect a period for which data were available on all infants. Aside from main effects for age and trial block, the analysis yielded three other significant effects. A main effect for beat, $F(11, 60) = 11.97$, $p < .001$, $\eta^2 = .46$, was produced by the clear presence of an HR deceleration (quadratic effect, $p < .001$). This was qualified by two interactions (see Figure 3). A Beat × Age interaction, $F(11, 60) = 2.43$, $p = .014$, $\eta^2 = .10$, emerged, as 7-month-olds' HR decelerations were completely recovered to prestimulus levels by the end of the 12-beat period. However, 3-month-olds' HR was still decelerated at the end of this period. The difference between the ages likely reflects the difference in processing or encoding efficiency between the two age groups. A Trial Block × Beat interaction, $F(33, 38) = 2.44$, $p = .004$, $\eta^2 = .45$, resulted from decelerations during accumulation becoming progressively shallower for both age groups as the session progressed.

HR at the end of accumulation. The analysis described above was informative, but we were interested in the state of information processing for infants at the end of accumulation as well. To address this issue, we analyzed the five final beats of the accumulation phase (i.e., the five beats preceding the onset of the peripheral stimulus; it is worth noting that all infants were looking to the midline stimulus at this point). Aside from the main effects for trial block and age, three significant terms emerged. A main effect for beat, $F(3, 64) = 3.02$, $p = .024$, $\eta^2 = .12$, was qualified by two subsequent interactions. A significant Beat × Age interaction, $F(4, 63) = 3.55$, $p = .011$, $\eta^2 = .18$, occurred because 7-month-olds increased their HRs across these beats ($p = .001$) but 3-month-olds did not. A significant three-way Block × Beat × Condition interaction, $F(12, 55) = 2.17$, $p = .026$, $\eta^2 = .10$, also emerged. In the *different* condition, this HR increase was present across all trial blocks, perhaps because infants exposed to constantly chang-



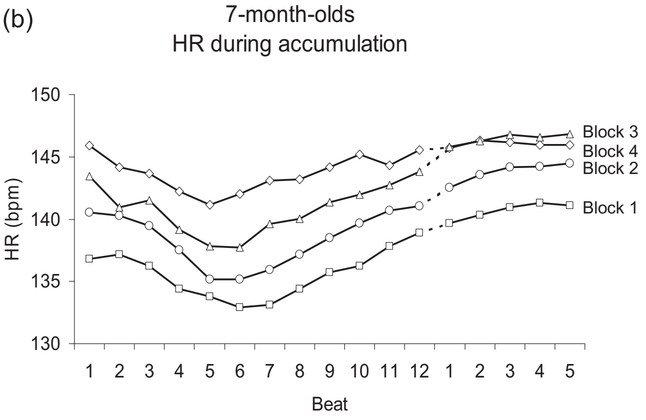


Figure 3. Heart rate (HR; in beats per minute) for 3-month-olds (a) and 7-month-olds (b) during accumulation as a function of trial block. Beats 1–12 on the left side of the *x*-axis represent the first 5 s after onset of the midline stimulus. Beats 1–5 on the right side of the *x*-axis represent the last 2 s before onset of the peripheral stimulus.

ing midline content continued to decelerate during accumulation, even into the later trials. For infants in the *same* condition, the increase was present for only the first two trial blocks.

One last analysis was conducted to evaluate whether the two age groups had completed processing at the end of the accumulation period. If processing of the midline stimulus was complete, HRs should have returned to prestimulus levels by the end of the accumulation period; if infants were still processing the content of the midline stimulus at this point, one would expect that their HRs would still be decelerated (e.g., Richards & Casey, 1992). We compared the three beats prior to the onset of the midline stimulus (i.e., prestimulus level) with the last three beats of the accumulation period (i.e., the infants' last state of processing) in a 2 (age) × 4 (trial block) × 2 (condition) × 3 (beat) × 2 (prestimulus vs. end of accumulation) mixed-design ANOVA. This analysis confirmed that neither age group of infants was decelerated at the end of the accumulation period. Indeed, infants' HR was actually above prestimulus levels at the end of accumulation, which caused a prestimulus/end-of-accumulation main effect, $F(1, 66) = 54.31$, $p < .001$, $\eta^2 = .45$. This main effect was qualified by two other interactions. Older infants increased their HRs toward the end of accumulation more than young infants, $F(1, 66) = 17.63$, $p < .001$, $\eta^2 = .21$. Finally, HRs at the end of accumulation were higher in the *different* condition than in the *same* condition, $F(1, 66) = 4.34$, $p = .04$, $\eta^2 = .06$. The fact that the *different* condition elicited higher HRs by the end of accumulation may have played a part in 3-month-olds' slower latencies in that condition (discussed below). Nevertheless, in each case, the basic finding held: Neither 3- nor 7-month-olds were decelerated at the onset of the peripheral stimulus, and thus we may infer that both groups had effectively completed processing of the midline stimulus.

Discussion

Behavioral data from Experiment 1 showed that the content of the midline stimulus affected young infants' ocular latencies; changing content produced increased ocular latencies in later trials. However, both the behavioral and psychophysiological data indicate that the developmental differences between 3- and 7-month-olds' ability to disengage from the midline stimulus cannot be attributed to changes in processing efficiency or speed. Three-month-olds' latencies remained much longer than 7-month-olds', despite increased familiarity with the midline stimulus. HR data confirmed that the young infants were no longer actively processing the midline stimulus when the peripheral stimulus was presented; thus, differences between the young and old infants cannot be attributed to 3-month-olds' slower processing of the midline stimulus.

In Experiment 1, we observed longer latencies in 3-month-olds with changing midline content in the later trial blocks. It is worth noting that the *different* condition did engender a larger HR increase at the end of accumulation than the *same* condition, and so it may be that the changing content at midline increased arousal and that this increased arousal differentially affected the two age groups' ability to disengage and shift attention.

Finally, the association between look duration and ocular latency reported first by Frick et al. (1999) for 3- and 4-month-olds was repeated in 3-month-olds. This study provides new information in showing that this positive correlation was not seen in the 7-month-olds.

Experiment 2

Rationale

Experiment 1 yielded evidence for the effect of processing on the performance of 3-month-olds in the overlap paradigm but not on the performance of 7-month-olds. It seemed likely that a 5-s accumulation period was too long for the older infants and may have obscured any effect of processing. In Experiment 2, we examined the performance of 7-month-olds on the overlap paradigm with briefer accumulation periods, coupled with the manipulation of midline stimulus content across trials. We were also interested in knowing whether the increase in ocular latency seen in the 3-month-olds in Experiment 1 might also be seen in older infants under these more challenging conditions.

Method

Participants

Sixty-six infants (42 male, 24 female) were recruited by mail and telephone from the same Kansas City area as for Experiment 1. Of these, 3 were excluded because of fussiness. The mean years of education completed for both mothers and fathers was 16.0 (i.e., college graduates). Participants were 7 months (M = 215.2 days, SD = 5.8) of age. In this sample, 30 infants were first born, 23 were second born, 9 were third born, and 4 were fourth born.

Apparatus, Design, Procedure

The methods were the same as in Experiment 1. The design used the same conditions of *same* and *different* for midline stimulus content. In addition, infants were assigned to conditions in which they accumulated either 1 s or 3 s before the presentation of the peripheral stimulus.

Results

Latency to Disengage Attention

Overall latency. As in Experiment 1, a mean latency to disengage attention was calculated for each participant across all valid trials. Twenty-seven infants completed the 1-s condition, and 37 infants completed the 3-s condition; 33 infants completed the *same* condition, and 31 infants completed the *different* condition. The mean latency was entered into a 2 (exposure) × 2 (condition) between-subjects ANOVA. Results revealed a marginal main effect for exposure, $F(1, 60) = 3.40$, $p = .07$, $\eta^2 = .05$; infants in the 3-s accumulation condition (M = 387.65 ms, SD = 76) showed shorter ocular latencies than infants in the 1-s accumulation condition (M = 435.21 ms, SD = 142). There was also a marginal effect for condition, $F(1, 60) = 3.33$, $p = .07$, $\eta^2 = .05$ (see Figure 4); infants in the *same* condition (M = 385 ms, SD = 80) showed shorter ocular latencies than infants in the *different* condition (M = 429 ms, SD = 130). Means are presented in Figure 4.

Ocular latency performance across trials. As in Experiment 1, latencies for each infant were averaged across blocks of four adjacent trials for the 16-trial protocol. An HLM analysis run on these values using accumulation, condition, trial block (linear component across trials), and trial block^2 (quadratic component across trials) as predictors yielded only a significant main effect for trial block, $F(1, 146) = 16.52$, $p < .001$, $\eta^2 = .10$ (see Figure 5). Ocular latencies decreased linearly across trial blocks.

HR Analyses During Accumulation

As in Experiment 1, HR was examined during accumulation of looking to the midline stimulus and in terms of responses to the onset of the peripheral stimulus. As before, HR was examined only for valid trials, and HR for each infant was averaged across blocks of four adjacent trials. As in the analyses for Experiment 1, significant main effects for trial block (all effects attained at least $p < .01$) emerged at each point, as infant HR increased across trials.

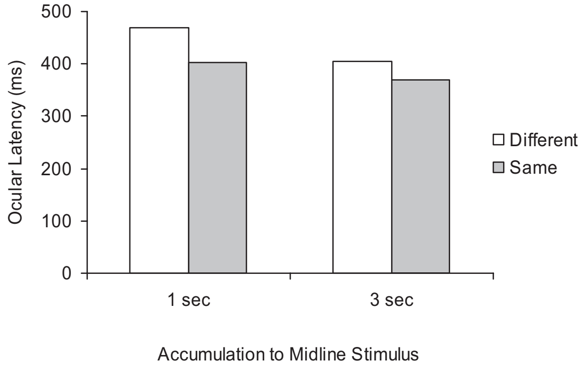


Figure 4. Ocular latencies (in milliseconds) for 7-month-old infants in Experiment 2 as a function of condition and accumulation period.

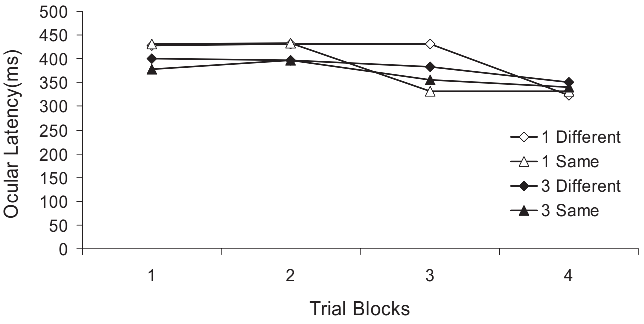


Figure 5. Ocular latencies (in milliseconds) across trial blocks in Experiment 2.

Because of the shorter accumulation phases of Experiment 2, we examined only the last five beats of the accumulation period. A 4 (trial block) × 5 (beat) × 2 (exposure) × 2 (condition) mixed-design ANOVA conducted on the last five beats of the accumulation period yielded a significant main effect for beat, $F(4, 29) = 2.80$, $p = .044$, $\eta^2 = .28$; this effect was qualified by a significant Beat × Exposure interaction, $F(4, 29) = 8.17$, $p < .001$, $\eta^2 = .53$ (see Figure 6). This analysis suggests that the exposure manipulation produced its desired result: Infants' HR in the 1-s accumulation condition was decelerating just at the end of the accumulation period. In contrast, infants' HR in the 3-s condition was returning to prestimulus levels.

Discussion

Experiment 2 provided some evidence for 7-month-olds' ocular latencies being affected by manipulations of stimulus content at brief levels of exposure. Trends toward longer ocular latencies

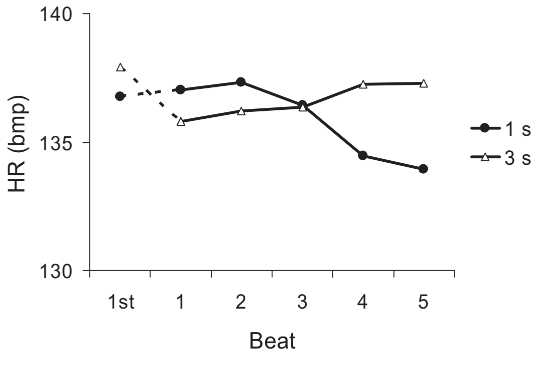


Figure 6. Heart rate (HR; in beats per minute) data from the accumulation period for Experiment 2. Analyses were conducted on Beats 1 to 5 (which immediately preceded the peripheral stimulus presentation). The beat labeled "1st" is the first beat of the accumulation period and is shown here for comparison purposes only.

were observed for conditions in which per-trial exposure to the midline stimulus was reduced and in which midline content was constantly changing across trials. The HR analyses confirmed that in conditions in which exposure to the midline stimulus was briefest (i.e., only 1 s), infants were still decelerated when the peripheral stimulus was presented. At the same time, however, the effects observed for these factors were somewhat weak, suggesting that 7-month-olds' performance in this paradigm is fairly robust to the demands of processing the midline stimulus.

General Discussion

The purpose of the present study was to examine the relationship between visual processing and ocular latencies. Taken as a whole, these data lend themselves to several conclusions with regard to the development of attention in infancy.

Visual Processing and Ocular Latencies

The current experiments provide some support for the hypothesis that ocular latencies are affected by stimulus encoding and processing in the overlap paradigm. In Experiment 1, 3-month-old infants presented with changing midline stimulus content across trials produced longer latencies across trials, especially in later trials. Although the direction of these results was somewhat unexpected, the results clearly represent an effect of processing on ocular latencies. The fact that the HR increase seen across the course of the accumulation period was significantly exacerbated in the *different* condition suggests that the changing midline stimulus may have increased arousal. It may be that 3-month-olds were differentially affected by these changes, with increased arousal leading to the longer latencies occurring in the *different* condition in the later trials of Experiment 1. The differential effect of arousal on the disengagement of infants at different ages will require closer scrutiny in future research.

In Experiment 2, we investigated 7-month-olds' performance in this paradigm more comprehensively given that the results of Experiment 1 suggested that this age group was relatively impervious to manipulations of midline content and familiarity. This experiment yielded an additive trend for longer midline familiarization and repetitive midline content to reduce ocular latencies, although these effects were not particularly strong. The ability to disengage attention appears to therefore be particularly robust in this age group, given that the 7-month-olds perform quite well despite procedural manipulations designed to affect cognitive demands or load.

Maturational Change and Ocular Latencies

These results indicate the limits of the effect of visual processing on ocular latencies at both 3 and 7 months of age; as such, the developmental differences in disengagement seen in the overlap paradigm do not appear to be attributable to differences in encoding and processing of the midline stimulus. This conclusion implies that the best extant model for interpreting and accounting for developmental differences in performance in the overlap paradigm is probably one that attributes such differences to the maturation of brain areas that mediate disengagement of attention.

Concluding Remarks

These data largely confirm that ocular latencies measured in the overlap paradigm do primarily reflect the construct of disengagement of attention. In this light, the successful repetition here of the relationship between look duration and ocular latency at 3 months lends further support for the contention that individual differences in disengagement contribute to individual variability in look duration and its cognitive concomitants in early infancy (see also Colombo et al., 2001). The current study extends the literature in demonstrating that this association is no longer evident by 7 months of age. This lends further support to the contention that there are qualitative changes in attention across the first postnatal year, with a major turning point occurring at or about 6 months of age (Colombo, 2001, 2002; Colombo, Richman, Shaddy, Maikranz, & Blaga, 2004). Indeed, the major improvement in disengagement of attention appears to occur between 3 and 4 months of age; comparison of means from the current study with those from comparable conditions (e.g., Frick et al., 1999) suggest that there is little change in overlap condition performance from 4 to 7 months of age. Studies of the process and development of disengagement in infancy, then, would be best focused on the first half of the first postnatal year.

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