INFANCY, *8*(3), 201–216

RESEARCH ARTICLES

Motion Popout in Selective Visual Orienting at 4.5 But Not at 2 Months in Human Infants

James L. Dannemiller
Department of XXXXX
University of Wisconsin

The effect of element density on selective orienting was examined in 2 experiments with 2- and 4.5-month-old infants. Selective visual orienting to a singleton oscillating target that appeared with other static bars was used to study the effects of element density. Increasing the set size and density of the static bars decreased selective orienting to the moving target in the 2-month-old infants, but it increased selective orienting in the 4.5-month-olds despite the fact that the overall levels of correct orienting to the target were titrated to be the same at the 2 ages. Thus, density affected the selectivity of visual orienting to movement at these 2 ages differently with popout being evident at the older age. In the 2nd experiment, motion popout for the 4.5-month-old infants was replicated using oscillating targets that had the same peak and mean speeds but different temporal frequencies and amplitudes of oscillation. Increases in the efficiency of perceptual grouping of similar elements between 2 and 4.5 months of age could overcome the lateral masking effects of increasing element density seen at the lower end of this age range.

There are processes in the mature human visual system that preattentively segregate image regions that differ from their local surrounds on one or more stimulus dimensions. These disparate elements typically "pop out" effortlessly from their surrounds and draw attention (Nothdurft, 1993, 2002). For example, the response time to detect a singleton moving object in a field of similar static objects does not depend on set

Correspondence should be addressed to James L. Dannemiller, Department of Psychology MS-25, Rice University, P.O. Box 1892, Houston, TX 77251–1892. E-mail: dannemil@rice.edu

size. Models of preattentive processing typically include an early stage in which elements are compared on various dimensions to surrounding elements, and differences produce *local feature contrast,* which tends to enhance the salience of the disparate elements (Nothdurft, 2002). The degree of local feature contrast can have large effects on the efficiency of visual search (Duncan & Humphreys, 1989, 1992).

These processes that signal local discrepancies in the image are important because such discrepancies are probably correlated with behaviorally relevant parts of the image. That is, some actions are more appropriately directed toward regions that differ in some way from their surrounds than to regions that are uniform on some dimension. This could be especially important developmentally for several reasons. First, early in development, before sufficient visual experience has occurred, it is unlikely that there is much top-down guidance of visual attention. In this case, bottom-up salience is likely to be more important in directing visual attention, and discrepancy-detecting processes would contribute to this bottom-up guidance. Second, the impact of visual experience on the development of visual pathways is likely to depend on the distribution of the infant's looking behavior. Selectively looking at regions that are discrepant in some way from their surrounds rather than at uniform regions should promote the development of those pathways (Singer, 1982). Thus, studying visual popout is important for understanding the determinants and consequences of visual attention during infancy.

Research on perceptual popout during infancy has been characterized by variations in methodology (e.g., habituation, preferential looking, forced-choice preferential looking [FPL], saccadic latency), the stimulus features manipulated (e.g., color, shape, orientation), and the size of the discrepant regions (e.g., a feature singleton or a patch of discrepant elements). It is difficult to draw firm conclusions about the developmental time course of discrepancy detection precisely because the results observed in these studies apparently depend to a great extent on variations in the methodology. Furthermore, one would not necessarily expect to find a single age after which popout occurs because it undoubtedly will depend on sensitivity to the feature (e.g., orientation, size, shape, direction of motion) under investigation. Nonetheless, these studies do show that visual attention is attracted to discrepant regions in a visual display certainly within the first 6 postnatal months.

For example, consider studies on the detection of a discrepancy in orientation. These studies typically embed a small line (singleton) or a region of small lines (patch) that differ in their orientations from a surrounding region that contains small line segments with uniform orientations. If we take the youngest age at which this kind of discrepancy detection can be demonstrated as an estimate of the lower limit for the onset of perceptual popout on the dimension of orientation, then the estimate would be 3 to 4 months (Quinn & Bhatt, 1998). Three- to 4-month-olds detected a single line that was oriented differently from the surrounding lines, but even here there were limitations on the angular differences that produce popout (Quinn & Bhatt, 1998). Other studies put the onset of popout on orientation somewhat later (Atkinson & Braddick, 1992; Bertin & Bhatt, 2001b; Rieth & Sireteanu, 1994a, 1994b; Sireteanu & Rieth, 1992), but again methodological and stimulus display variations could explain some of the differences between results in these studies.

Other features have also been shown to produce perceptual popout in young infants. Color singletons or a patch of elements with a color discrepant from the color of the surrounding elements leads to enhanced visual attention at 5.5 months (Bertin & Bhatt, 2001a; Bhatt, Bertin, & Gilbert, 1999). Discrepancies in shape, whether presented as a singleton or as a patch, produce popout by 3 to 4 months of age (Adler & Orprecio, 2005; Bertin & Bhatt, 2001a; Bhatt et al., 1999; Colombo, Ryther, Frick, & Gifford, 1995; Quinn & Bhatt, 1998). A column of moving elements that differs in direction from the motion of surrounding elements was detected at all ages across the range from 8 to 20 weeks (Bertenthal & Bradbury, 1992; Wattam-Bell, 1992). Finally, a discrepant element that interferes with grouping disparate elements into a good form attracts attention in 5.5-month-olds (Bertin & Bhatt, 2001b). This latter study points to the importance of grouping processes in enhancing the detection of a discrepant element.

In visual search with adults, surround elements that can be grouped perceptually can be suppressed as a whole, making the detection of a discrepancy more likely (Duncan & Humphreys, 1989, 1992; Nothdurft, 2000). One parameter that affects the likelihood of grouping is element density. All other things being equal, elements that are closer to each other can be grouped more readily into a texture-like background. This is generally true; however, there is also evidence that texture density affects discrepancy detection nonmonotonically (Meinecke & Donk, 2002; Nothdurft, 2000; Sagi & Julesz, 1987; Schubo, Schrogerb, & Meinecke, 2004). More specifically, increasing set size in sparse displays can actually lead to decreasing discrepancy detection, but detection once again improves as the elements appear with increasing density.

Element density is one parameter in developmental studies that could play an important role in how readily similar elements are grouped and suppressed to increase the salience of a discrepant element. Spatial integration in other visual domains certainly changes during infancy (Banton, Bertenthal, & Seaks, 1999; Hansen, Hamer, & Fulton, 1992; Kovacs, 2000), so it would not be surprising to find that the tendency of similar elements to group perceptually might also change developmentally as intracortical inhibitory connections develop (Atkinson & Braddick, 1992). Only four studies with infants to date have manipulated set size or element density,[1] and generally these studies find weak to null effects of density (Atkinson & Braddick, 1992; Rieth & Sireteanu, 1994a). The two exceptions are

[1]Set size and element density are directly correlated when the size of the display is fixed. In most visual search studies with adults, and in the studies reported here, the display size was fixed, so element density increased as set size increased.

studies by Adler and Orprecio (2005) and Dannemiller (2005). In Adler and Orprecio, the accuracy of saccades made by 3-month-olds to a discrepant element showed a positive trend as set size increased from 3 to 8, although this trend was statistically not significant. In Dannemiller, there was a significant interaction between age and set size on orienting to a singleton moving bar surrounded by static bars. The youngest infants, 7- to 11-week-olds, oriented less as set size increased from 2 to 28 bars, but the oldest infants, 17- to 21-week-olds, oriented more often toward the moving singleton as set size increased. Infants at the intermediate ages showed no influence of set size over this range.

The purpose of the work reported here was to explore the influence of set size or element density on discrepancy detection in infants in two age ranges: 7 to 12 weeks and 17 to 22 weeks postnatal. This age range spans the onset of popout in some of the studies previously listed. It also covers the ages at which negative (7–12 weeks) and positive (17–22 weeks) effects of set size were shown in Dannemiller (2005). This work had two goals. The first was to attempt to find evidence for the influence of element density on discrepancy detection in infants as has been observed in adults. Second, in Dannemiller (2005), the absolute levels of detection of the discrepant element differed between the youngest and the oldest infants, with the latter being more sensitive to the discrepancy than the former. This is not an ideal way to compare the effect of element density at the two ages because the discrepant element itself was probably not equally salient at the two ages, leading to different levels of mean accuracy at the two ages. Age differences in absolute performance can interfere with inferences regarding differential developmental processes (Chapman & Chapman, 1978; Chapman, Chapman, Curran, & Miller, 1994). To improve on this prior study, pilot testing was used to equate overall detection independently of set size at the two ages allowing for a more sensitive assessment of the effect of element density.

EXPERIMENT 1

Motion was chosen as the stimulus feature for two reasons. First, mechanisms that respond to motion are present in 8-week-olds—near the lower end of the age range tested in this study (Wattam-Bell, 1992). One could argue from data using optokinetic nystagmus that motion processing is evident even before this age (Manny & Fern, 1990). Second, the prior study on which this experiment was based used a motion singleton (Dannemiller, 2005).

Method

Participants. Infants were recruited from birth announcements in a local newspaper. Forty-nine infants were tested. Analyses were conducted on the data from 44 of these infants. The average age of the 22 younger infants (hereafter, 2-month-olds) was 64.7 days (range = 50–83 days, *SD* = 11.0 days). Data from an additional 3 infants at the younger age were not used in the analysis because 2 of them became too fussy to be tested, and 1 of them spent 2 days in the intensive care unit (ICU) and was seeing a pediatric ophthalmologist for potential eye problems. The average age of the 22 older infants (hereafter, 4.5-month-olds) was 136.0 days (range = 120–151 days, *SD* = 8.6 days). Data from an additional 2 infants at the older age were not used in the analysis because 1 of these infants was inattentive and fussy, and the other infant was born more than 2 weeks before the expected due date.

Apparatus and stimuli. The stimuli were presented on a large monitor running at 60 Hz in a noninterlaced frame mode. At the 50 cm viewing distance, the stimulus field was 40° horizontally by 31° vertically. The target and static bars were 5° vertically by 0.75° horizontally. The background color of the stimulus field was yellow ($x = .503$, $y = .439$), and the bars were black. The luminance of the yellow background was 36 cd/m^2. All of the bars on the screen were darker than the background, and their luminances were set to a nominal level of zero by setting the DAC values for the three color guns to zero. Thus, the Michelson contrasts of these bars were 100%.

The strategy in this experiment for revealing potential age differences in the effects of density on orienting to the moving bar was to titrate the amplitude and temporal frequency of movement of the target bar to equate the level of performance at the two ages in at least one condition. In other words, if it could be shown that at one density (set size) performance was the same at the two ages, then differences between the two ages at other densities could reveal age differences in the effect of density on the mechanisms that determine orienting. This strategy predicts that under the correct choice of stimulus conditions a crossover interaction between age and density (set size) should occur if there were differences in the way in which motion was processed by the mechanisms that determine visual orienting.

Based on previous studies using this paradigm, the 2-month-olds were tested with the moving bar having a temporal frequency of 4.8 Hz and an amplitude of 1.0° (mean-to-peak). The 4.5-month-olds were tested with the moving bar oscillating at a temporal frequency of 1.2 Hz and an amplitude of 0.5°. Sensitivity to this oscillating movement changes substantially over this age range (Roessler & Dannemiller, 1997), so this large difference in the parameters of the moving target was chosen with the intent of equating performance at the two ages for at least one level of density (actual or interpolated).

The display was situated at the infant's eye level in a matte black wall. To the infant's right of the display, there was a peephole that an observer used to watch the infant's eye and head movements and to make online judgments. To span a large range of density levels, and to estimate performance with no static bars in the neighborhood of the moving target, the lowest density that was used was zero, so the set size was one. In this condition, the moving target appeared on one side of the display, and an identical, static bar appeared on the other side of the display in the corresponding position. These were the only two bars on the display. The moving target always appeared at the center of the right or left sides of the display. In all conditions, an identical static bar appeared on the opposite side of the display in the same relative position. The moving target and its static foil always appeared 10° to the left or right of the center of the display, and they were always centered vertically on the display. This set size = 1 condition can be considered a classical, two-alternative forced-choice signal detection condition with the signal (moving target) on one side of the display and the "noise" (an identical static bar) on the other side of the display.

In addition to this set size of 1, two other set sizes were used: 5 and 14. With a set size of 5 (14), four (13) static bars appeared on the same side as the moving target, and five (14) static bars appeared on the opposite side of the display. The static bars appeared on the appropriate side of the display with the following constraints. The static bars for a given side were distributed randomly between seven imaginary columns that divided the horizontal extent of each half of the display into seven equal segments. For the set size of 5, two static bars never appeared in the same column. For the set size of 14, two bars appeared in each of these columns. The vertical positions of the static bars in the columns were random with the constraint that two bars could not overlap and the whole of a bar had to be visible. The goal was to simulate a situation in which the infant had multiple potential targets of attention within this portion of the visual field. The densities of the static bars in the neighborhood of the oscillating target corresponding to set sizes of 1, 5, and 14 were 0, 0.006, and 0.021 bars per square degree.

Design and procedure. Density was manipulated within subjects. Seventy-two trials were presented to each infant: 24 trials at each of three set sizes: 1, 5, and 14. For half of the trials at each set size, the moving target appeared on the left (right) side of the display. Set size was blocked so that each set size occurred once in a block of three trials. Set size within a block of trials was ordered randomly. A schematic of the display is shown in Figure 1.

The infant was seated in an infant seat approximately 50 cm from the display. Prior to the start of each trial a small blue flashing bar appeared in the center of the screen to attract the infant's attention. The observer also used various noise-making toys to encourage the infant to orient to the display. At the start of a trial, all of the bars appeared simultaneously with an abrupt onset from the uniform background field, and the moving target began to oscillate from its middle position as soon as it appeared. The observer pressed a button to initiate the trial, and she could restart a trial when the infant looked away from the display at the start of the trial. The same practiced observer was used with all of the infants.

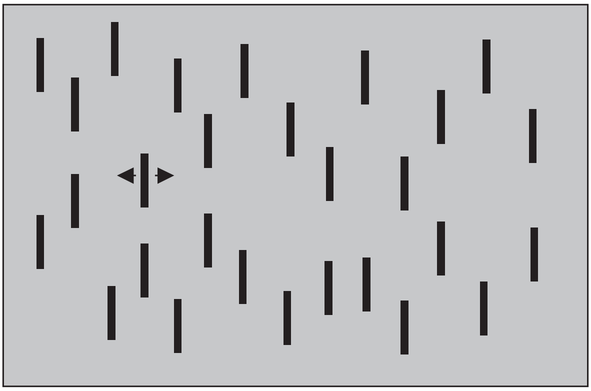

FIGURE 1 Example of a stimulus display for set size 14. The moving target is indicated by the arrows. Stimulus dimensions are not to scale (see text for actual dimensions).

Data were collected using the FPL (Teller, 1979). The adult who was observing the infant made a forced choice on each trial about the location of the moving target. This adult observer was blind to the trial type and to the location of the moving target bar on each trial. The computer provided the observer with feedback about the correctness of this judgment after every trial in the form of a brief, audible beep. The FPL observer was instructed to make these judgments as quickly as possible while maintaining reasonably good accuracy because the primary interest was in orienting or the dominant direction of regard in the seconds immediately following the onset of the motion stimulus. It is more common with the FPL technique to allow the FPL observer to wait indefinitely on each trial until enough evidence has accumulated to make a forced-choice judgment. This version of the FPL technique differed because the observer made a speeded judgment. The latencies to make these judgments were on the order of 1.5 to 2 sec, so this measure yields information primarily about orienting during the initial second or two after a strong motion stimulus appeared. Notice also that reliability is not an issue for the purposes here because there is an external stimulus (the location of the moving bar) that provides validity for the judgments.

Results and Discussion

The primary dependent variable was the percentage of correct judgments calculated from the 24 trials presented at each set size. Recall that the strategy of this experiment was to equate performance at the two ages in at least one condition (actual or interpolated set size), so that an age difference in the effect of set size/density could be tested without the interfering implications of an overall dif-

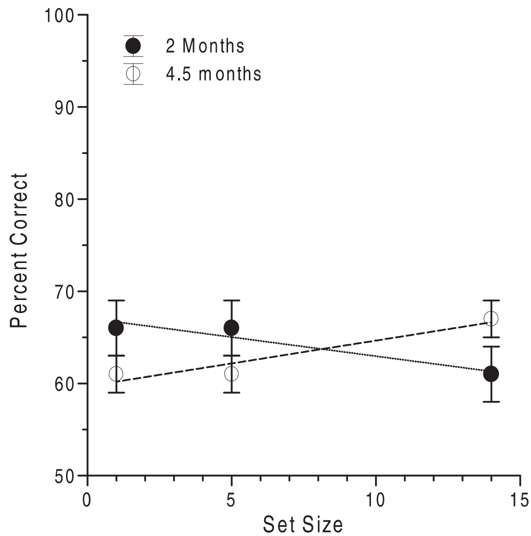

FIGURE 2 Percentages of correct judgments for 2-month-olds (closed symbols) and 4.5-month-olds (open symbols) as a function of set size. Error bars are ±1 *SEM*. The dashed lines show the best fitting regression lines through the means based on statistical analyses that revealed only significant linear trends with set size at both ages.

ference in accuracy. Figure 2 shows the percentage of correct judgments at the two ages for the three set sizes. Notice that there is a crossover in performance at the two ages between set sizes of 5 and 14. In particular, for the 2-month-olds, increasing set size and density in the neighborhood of the moving target produced less selective orienting to this target. In contrast, for the 4.5-month-olds, increasing density in the neighborhood of the moving target produced increased orienting to this target. These age differences were similar to those observed in Dannemiller (2005), but the current results permit a clearer inference about this change with age because they are not confounded by overall differences in the salience of the moving target (as assessed by the overall accuracy at the two ages).

The data were analyzed using a mixed analysis of variance (ANOVA). The between-subject variable was age group (2 months vs. 4.5 months), and the within-subjects variable was set size (1, 5, and 14). Because set size was a quantitative independent variable, it was analyzed for its linear and quadratic main effects as well as for the interactions of the age variable with these linear and quadratic effects. The percentage of correct judgments by the FPL observer served as the dependent variable.

The analysis revealed a significant Age × Set Size interaction, $F(2, 84) = 4.12$, $p = .021$, $\eta_p^2 = .089$ (partial eta-squared). Inspection of the linear and quadratic portions of this effect showed only an interaction between the linear effect of set size and age, $F(1, 42) = 5.72$, $p = .021$, $\eta_p^2 = .12$. It is notable that there was no main effect of set size, $F(2, 84) = 0.132$, $p = .877$, nor was there a main effect of age, $F(1, 42) = 0.427$, $p = .517$. The lack of a main effect of age means that overall accuracy (percentage correct) was equated at the two ages ($M = 64.5\%$ at 2 months vs. 62.9% at 4.5 months). The lack of a main effect of set size means that the linear effect of set size was approximately opposite at the two ages; at the younger age, performance decreased with increasing set size, but at the older age performance increased with increasing set size. Neither the quadratic effect of set size nor its interaction with age was significant.[2]

EXPERIMENT 2

The moving bar drove orienting more consistently at the older age as set size or spatial density in the neighborhood of the moving target increased. Why did increasing density have a facilitative effect on orienting toward the moving bar for the older infants? This effect is similar to the effects of increasing density on visual search in adults (Meinecke & Donk, 2002; Schubo et al., 2004). There were two goals for the second experiment. First, it is important to replicate and extend this facilitative effect: to test the parameter ranges over which it operates. The density effect may reflect a spatial contrast or texture effect; that is, as bars are placed closer to the moving target, the movement becomes more salient because it stands out perceptually from the static, textured background. If this were primarily a spatial, density effect, then one might expect manipulations of the amplitude of the moving target to have greater effects than manipulations of its temporal frequency. The second goal of this experiment, therefore, was to compare spatial and temporal influences on this facilitative effect of density at the older ages.

To replicate and extend the density effect found in Experiment 1, separate groups of infants were tested in Experiment 2 using displays that were identical to those used in Experiment 1 with the exception of the amplitude and temporal fre-

[2]One concern with the use of FPL is that response times might have varied between the age groups. If it took longer for younger infants to suppress the static bars at the higher densities, and the FPL observer made her judgments with approximately the same latency at the two ages, one might argue that the negative effect of set size was an artifact of terminating the trial before suppression had a chance to exert its effects at the younger age. An analysis showed that the FPL observer's responses were approximately a third of a second slower with the younger infants (1.90 sec vs.1.58 sec with younger and older infants, respectively), $t(42) = 5.17$, $p < .001$. Given that the FPL observer took significantly longer to make her judgments with the younger infants, it is unlikely that the age difference in the effect of density represents an artifact of biasing the results in favor of the older infants by terminating the trials at the same duration at the two ages. It is, of course, possible to argue that the one third of a second mean extension of trial duration for the younger infants was still insufficient to allow suppression to work, and this must remain a possibility.

quency of the moving bar's oscillation. These two movement parameters were traded against each other to produce targets with different amplitudes, but with the same peak and mean speeds. Peak and mean speed in sinusoidal movement are proportional to $A \cdot f$ where A is the amplitude and f is the temporal frequency. Two sinusoidal oscillations with the same Af products have the same peak and mean speeds. For example, relative to an oscillation with a fixed amplitude and temporal frequency, if the amplitude is doubled and the temporal frequency is simultaneously halved, the peak and mean speeds will remain constant despite the different amplitudes (and temporal frequencies).

Method

Participants. Infants were recruited from birth announcements in a local newspaper. Forty-nine infants were tested. Analyses were conducted on the data from 44 of these infants. Infants were randomly assigned to be tested in one of two groups (A vs. B). The average age of the 22 infants in Group A was 135.2 days (range = 119–151 days, SD = 9.9 days). The average age of the 22 infants tested in Group B was 134.9 days (range = 119–154 days, SD = 10.5 days). Data from an additional 5 infants were not used in the analyses because 2 of the infants became too inattentive and fussy to be tested, and 3 of the infants spent time in the neonatal ICU.

Apparatus and stimuli. In this experiment, the amplitude or the temporal frequency of the oscillating bar was changed from the values used in Experiment 1. For one group of infants the temporal frequency of oscillation was set to 1.2 Hz and the amplitude was set to 1°. For the other group of infants, the temporal frequency was set to 2.4 Hz and the amplitude was set to 0.5°. Thus, the product of amplitude and temporal frequency, Af, was constant in these two conditions, and hence, their peak speeds were constant. The condition with a temporal frequency of 1.2 Hz also afforded a between-experiment check on the effect of amplitude because this age group in Experiment 1 was tested with the same temporal frequency of oscillation but half the amplitude.

Design and procedure. The design and procedures were the same as in Experiment 1. Each infant received 24 blocks of trials with three set sizes (1, 5, and 14) each occurring once in a block, and the target appeared equally often on the left and the right sides of the display.

Results and Discussion

The percentage of correct judgments for each set size is shown for the two groups in Figure 3. Also replotted in Figure 3 are the means from the older age group in

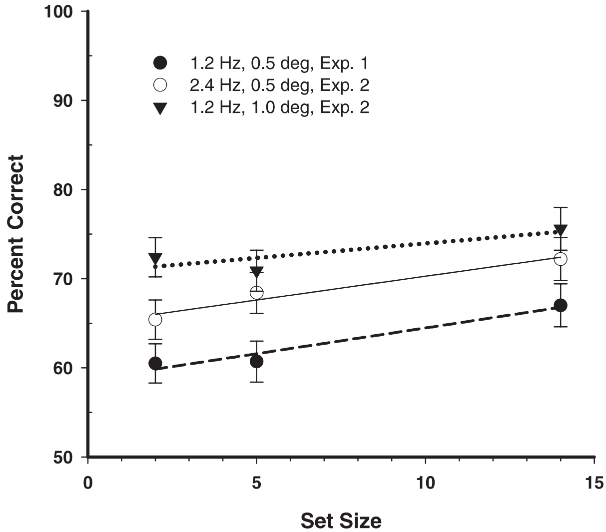

FIGURE 3 Percentages of correct judgments for 4.5-month-olds in Experiment 2 as function of set size. The oscillating target was 1.2 Hz with an amplitude of 1.0° (open circles), or 2.4 Hz with an amplitude of 0.5° (closed circles). For comparison, the results with the 4.5-month-old infants from Experiment 1 are also shown as the closed squares. For this latter group the oscillating target had a temporal frequency of 1.2 Hz and an amplitude of 0.5°. Error bars are ±1 *SEM*. The straight lines are the best fitting lines through the means based on the statistical analysis that showed only significant linear (and not quadratic) trends with set size.

Experiment 1 for comparison. Again, it appears that increasing the set size, and hence the density in the neighborhood of the moving target, produced more consistent orienting to this target, thus replicating the facilitative effect of increasing density in this age range observed in Experiment 1.

A 2 × 3 mixed ANOVA with spatiotemporal combination as the between-subject variable (2.4 Hz/0.5° vs. 1.2 Hz/1.0°) and set size (1, 5, and 14) as the within-subjects variable was used to analyze the data. The percentage of correct judgments out of 24 trials at each set size was used as the dependent variable. There was a significant effect of set size, $F(2, 84) = 3.31$, $p = .042$, $\eta_p^2 = .073$, with this effect confined to a linear trend, $F(1, 42) = 5.36$, $p = .026$, $\eta_p^2 = .113$. Set size did not interact with spatiotemporal combination, but the effect of spatiotemporal combination approached significance, $F(1, 42) = 3.32$, $p = .075$, $\eta_p^2 = .073$. As is evident in Figure 3, overall performance was nominally higher at all three set sizes with the larger amplitude stimulus (1.2 Hz and 1.0°).

It is also evident in Figure 3 by comparing the bottom and top curves that a simple increase in amplitude with temporal frequency held constant produced a large and nearly uniform increase at all three set sizes in the percentages of trials with orienting toward the moving target, whereas a simple increase in temporal frequency with amplitude held constant (middle curve in Figure 3) produced less of an increase in orienting toward the moving target. Statistical analysis with the combined data from Experiments 2 and 1 (older infants only) showed a strong linear effect of set size, $F(1, 63) = 9.11$, $p = .004$, $\eta_p^2 = .126$, and a significant effect of spatiotemporal combination, $F(2, 63) = 10.26$, $p < .001$, $\eta_p^2 = .246$. Duncan's post hoc test showed that the infants from Experiment 1 tested with 1.2 Hz and an amplitude of 0.5° oriented significantly less often toward the moving target than infants in both of the groups from Experiment 2, and that the difference between the two groups in Experiment 2 approached significance ($p = .06$). Thus, when the peak and mean speeds of the oscillating target increased between Experiments 1 and 2, orienting to the moving target increased, and increasing the peak and mean speed either by increasing the temporal frequency of oscillation or by increasing the amplitude of oscillation produced approximately equivalent increases in orienting toward the moving target at all set sizes with some indication that amplitude changes were slightly more effective than temporal frequency changes in influencing orienting. Although the data were not statistically definitive on the question, it appears that the facilitative effect of increasing density most likely arises at this age from the oscillating bar appearing more distinct in the presence of nearby static bars.

GENERAL DISCUSSION

The major results of these two experiments can be summarized succinctly. The density of static bars in the spatial neighborhood of an oscillating bar influenced selective orienting to that moving bar differently at 2 and 4.5 months. Increasing the spatial density of these static bars with 2-month-olds produced less selective orienting toward the moving target. In contrast, these same increases in density facilitated orienting toward the moving target at 4.5 months. The facilitative effect of density at 4.5 months was linear, and it held across three different manipulations of the characteristics of the oscillating target. The facilitative effect of increasing density at 4.5 months and the interfering effect of increasing density at 2 months are reminiscent of the nonmonotonic effects of density on visual popout observed in some studies with adults (Meinecke & Donk, 2002; Nothdurft, 2000; Sagi & Julesz, 1987; Schubo et al., 2004). This idea is discussed further later.

These results with motion popout are similar to those reported by Atkinson and Braddick (1992) with local orientation contrast and texture segmentation. In that study 14- to 18-week-olds segregated a region of small elements that differed in orientation from the surrounding elements. In contrast, 8- to 12-week-olds did not show this segmentation ability based on local orientation contrast. Both of these studies suggest that local feature differences on the dimensions of orientation and motion become increasingly salient between 2 and 4 months of age. The results reported here with element density offer converging evidence that perceptual grouping and segregation processes change over the period from 2 to 4.5 months.

The slope of the percentage correct versus set size relation reversed sign across these ages from negative at 2 months to positive at 4.5 months. There are several potential explanations for this age effect that should be considered. The maximum response signal detection model (Dannemiller, 1998) can be ruled out as a viable explanation of the results certainly at the older ages. The maximum response model predicts that increases in set size should lead to substantial decreases in accuracy over the set size range used in this study. This prediction follows from the fact that as set size increases, the probability that one of the static bars on the display will produce the maximum internal response also increases, resulting in less selective orienting to the singleton moving bar. The data from the younger infants in this study were compatible qualitatively with that model although quantitatively the decrease in accuracy was not substantial enough to think that this model provides a good explanation of those results. This replicates and extends the conclusion in Dannemiller (2005) that the maximum response model does not provide a complete explanation of the impact of orienting toward a salient element in the presence of multiple, alternative targets of attention.

What factors might be responsible for the Age × Set Size interaction observed in this study? One possibility is that the moving target was closer to threshold for the younger infants, thus noise in the motion pathways could have a larger effect at the younger age. This explanation can be ruled out because overall performance at the two ages in Experiment 1 was statistically equivalent. Another possibility is that as the set size was increased, more bars appeared closer to the center of the display. Perhaps the younger infants have a greater tendency to look at the closest contour and have difficulty making a saccade to a distant target over spatially intervening targets. There is clearly evidence for this type of effect (Bronson, 1994; Milewski, 1976). Very young infants have a greater tendency to fixate external contours and have difficulty breaking this fixation to look at contours that are interior to a bounding contour. It is interesting to note that this so-called externality effect can be defeated to some extent by setting the interior contour in motion (Bushnell, 1979).

Could this increase in contours near the center of the display explain the age differences observed in these experiments? It is possible that the results at the younger age might be explained by this effect, but the facilitation of selective orienting at the older ages at higher densities could not be explained by this effect. In other words, there may be a bias to look next at the contour nearest to the point of fixation, but this would not explain why older infants looked even more selectively at a distant moving bar as more bars were added to the display. A diminution of this bias with age to look next at the nearer contours could only produce a null set size effect; it could never by itself produce a positive slope on the percentage correct versus set size function.

At this point, it is possible to propose that two competing processes might be responsible for the age differences observed. One of these processes increases the salience of the moving target as density (set size in a fixed display area) increases. The second process biases the infant to look next at contours that are nearer to the current point of fixation. These two processes are in opposition when set size increases in the current paradigm. The observed value of the set size slope would then be the result of the relative rates of facilitation from the first process and interference from the second process. It might be possible that density has similar effects on the salience of the moving bar at both ages, and that the near-center interference effect diminishes with age. In this case, at the younger age, the interfering effect of adding more bars near the center of the display could be stronger than the increase in salience as density increases. This would yield a negative slope on the observed percentage correct versus set size function. At the older age, a greater ability to saccade across intervening contours could then reveal the density-related increase in the salience of the moving target with a consequent positive slope on the percentage correct versus set size function. There is evidence that the bias to fixate nearby contours diminishes across this age range (Bronson, 1994).

This dual-process explanation of the results is reminiscent of the nonmonotonic effects of increasing set size/density in several popout studies with adults (Meinecke & Donk, 2002; Nothdurft, 2000; Sagi & Julesz, 1987; Schubo et al., 2004). In these studies, detection of a discrepant element at first worsens as set size is increased from a small value, but then detection improves significantly as set size is increased further. It is significant that Schubo et al. (2004) argued based on their data for two different processing modes for large and small set sizes. Similarly, Meinecke and Donk (2002) argued for at least two distinct processing modes for small and large set sizes. The deleterious effect of increasing set size at small base set sizes was attributed to lateral masking and to the limitations of acuity. The facilitative effect of increasing set size at higher base set sizes was attributed to the operation of spatial integration and perceptual grouping that should benefit from smaller interelement distances.

The age differences in this study could be explained by proposing that the spatial integration process that groups elements into a background texture only emerges between 2 and 4.5 months postnatally. This grouping of elements into a texture makes the single moving bar more perceptually distinct. Prior to the efficient operation of such grouping processes, the interfering or lateral masking effects of increasing element density dominate processing as shown in the results with the 2-month-olds. The processes responsible for grouping similar elements over large spatial ranges probably involve intracortical connections (Nothdurft, 2000). The results of this work would suggest that such connections become more efficient over the period from 2 to 4.5 months.

ACKNOWLEDGMENTS

James L. Dannemiller is now at the Department of Psychology, Rice University. The research was supported by National Institute of Child Health and Human Development Grant R01 HD32927. I thank Jacqueline Roessler for observing the infants, Manya Qadir for scheduling the infants, and Daniel Replogle for all of the computer programming. Pat Klitzke helped with the preparation of the manuscript.

REFERENCES

Adler, S. A., & Orprecio, J. (2005). *The eyes have it: Visual pop-out in infants and adults.* Manuscript under review.

Atkinson, J., & Braddick, O. (1992). Visual segmentation of oriented textures by infants. *Behavioural Brain Research, 49,* 123–131.

Banton, T., Bertenthal, B. I., & Seaks, J. (1999). Infants' sensitivity to statistical distributions of motion direction and speed. *Vision Research, 39,* 3417–3430.

Bertenthal, B. I., & Bradbury, A. (1992). Infants' detection of shearing motion in random-dot displays. *Developmental Psychology, 28,* 1056–1066.

Bertin, E., & Bhatt, R. S. (2001a). Dissociations between featural versus conjunction-based texture processing in infancy: Analyses of three potential contributing factors. *Journal of Experimental Child Psychology, 78,* 291–311.

Bertin, E., & Bhatt, R. S. (2001b). Figural goodness, stimulus heterogeneity, similarity and object segregation in infancy. *Developmental Science, 4,* 423–432.

Bhatt, R. S., Bertin, E., & Gilbert, J. (1999). Discrepancy detection and developmental changes in attentional engagement in infancy. *Infant Behavior and Development, 22,* 197–219.

Bronson, G. (1994). Infants' transitions toward adult-like scanning. *Child Development, 65,* 1243–1261.

Bushnell, I. W. R. (1979). Modification of the externality effect in young infants. *Journal of Experimental Child Psychology, 28,* 211–229.

Chapman, L. J., & Chapman, J. P. (1978). The measurement of differential deficit. *Journal of Psychiatric Research, 14,* 303–311.

Chapman, L. J., Chapman, J. P., Curran, T. E., & Miller, M. B. (1994). Do children and the elderly show heightened semantic priming? How to answer the question. *Developmental Review, 14,* 159–185.

Colombo, J., Ryther, J. S., Frick, J. E., & Gifford, J. J. (1995). Visual pop-out in infants: Evidence for preattentive search in 3- and 4-month-olds. *Psychonomic Bulletin & Review, 2,* 266–268.

Dannemiller, J. L. (1998). A competition model of exogenous orienting in 3.5-month-old infants. *Journal of Experimental Child Psychology, 68,* 169–201.

Dannemiller, J. L. (2005). *Evidence against a maximum response model of exogenous visual orienting during early infancy and support for a dimensional switching model.* Manuscript under review.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96,* 433–458.

Duncan, J., & Humphreys, G. (1992). Beyond the search surface—Visual search and attentional engagement. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 578–588.

Hansen, R. M., Hamer, R. D., & Fulton, A. B. (1992). The effect of light adaptation on scotopic spatial summation in 10-week-old infants. *Vision Research, 32,* 387–392.

Kovacs, I. (2000). Human development of perceptual organization. *Vision Research, 40,* 1301–1310.

Manny, R. E., & Fern, K. D. (1990). Motion coherence in infants. *Vision Research, 30,* 1319–1329.

Meinecke, C., & Donk, M. (2002). Detection performance in pop-out tasks: Nonmonotonic changes with display size and eccentricity. *Perception, 31,* 591–602.

Milewski, A. E. (1976). Infants' discrimination of internal and external pattern elements. *Journal of Experimental Child Psychology, 22,* 229–246.

Nothdurft, H. C. (1993). The role of features in preattentive vision: Comparison of orientation, motion and color cues. *Vision Research, 33,* 1937–1958.

Nothdurft, H. C. (2000). Salience from feature contrast: Variations with texture density. *Vision Research, 40,* 3181–3200.

Nothdurft, H. C. (2002). Attention shifts to salient targets. *Vision Research, 42,* 1287–1306.

Quinn, P. C., & Bhatt, R. S. (1998). Visual pop-out in young infants: Convergent evidence and an extension. *Infant Behavior and Development, 21,* 273–288.

Rieth, C., & Sireteanu, R. (1994a). Texture segmentation and "pop-out" in infants and children: The effect of test field size. *Spatial Vision, 8,* 173–191.

Rieth, C., & Sireteanu, R. (1994b). Texture segmentation and visual search based on orientation contrast: An infant study with the familiarization-novelty preference method. *Infant Behavior and Development, 17,* 359–369.

Roessler, J., & Dannemiller, J. (1997). Changes in infants' sensitivity to slow displacements over the first 6 months. *Vision Research, 37,* 417–423.

Sagi, D., & Julesz, B. (1987). Short-range limitation on detection of feature differences. *Spatial Vision, 2,* 39–49.

Schubo, A., Schrogerb, E., & Meinecke, C. (2004). Texture segmentation and visual search for pop-out targets: An ERP study. *Cognitive Brain Research, 21,* 317–334.

Singer, W. (1982). The role of attention in developmental plasticity. *Human Neurobiology, 1,* 41–43.

Sireteanu, R., & Rieth, C. (1992). Texture segregation in infants and children. *Behavioural Brain Research, 49,* 133–139.

Teller, D. Y. (1979). The forced-choice preferential looking procedure: A psychophysical technique for use with human infants. *Infant Behavior and Development, 2,* 135–153.

Wattam-Bell, J. (1992). The development of maximum displacement limits for discrimination of motion direction in infancy. *Vision Research, 32,* 621–630.