INFANT BEHAVIOR AND DEVELOPMENT **19**, 233-240 (1996)

Suppression of the Optokinetic Reflex in Human Infants: Implications for Stable Fixation and Shifts of Attention

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The ability of 1-, 2-, and 4-month-old infants to attend to a small, stationary visual target while a large background texture moved horizontally was assessed using electrooculography. The background texture, consisting of a randomly arranged field of dots or a set of vertically oriented stripes, was effective at all ages in eliciting the optokinetic reflex (OKR), which stabilizes gaze on a moving display. When the target, consisting of a red bar, was added to the center of the moving background display, it was effective in suppressing the OKR, except in 1-month-olds. Under monocular viewing conditions, background motion in the nasal–temporal direction was ineffective in eliciting robust OKR in 1- and 2-month-olds. These same infants presented with temporal–nasal background motion showed robust OKR equal to their OKR under binocular viewing conditions. However, the 2-month-olds showed OKR suppression only half as often as they did under binocular viewing conditions, and the 1-month-olds did not show OKR suppression. The 4-month-olds showed no nasal–temporal OKR asymmetry under monocular viewing conditions, and, like the 2-month-olds, OKR suppression was present about half as often as under binocular viewing conditions.

infant visual fixation optokinetic reflex visual attention nasal–temporal asymmetry

The visual environment consists of stationary and moving objects that confront the stationary observer with four basic situations: (a) a stationary target in front of a stationary background, (b) a moving target in front of a moving background, (c) a stationary target in front of a moving background, and (d) a moving target in front of a stationary background. In each of these situations, the observer can direct attention either to the target or to one or more of the objects that comprise the background. If the observer is moving, then stationary and moving targets and backgrounds create similar competitive foci for attention. Typically, attention is correlated with the direction of gaze; that is, the observer moves the eyes so that the object of attention is projected onto the fovea of each retina.

These typical viewing situations are a challenge for uninstructed observers, because the target and the background compete for their attention (and gaze). For example, because infants preferentially fixate a moving display over an otherwise identical but stationary display (c.f. Aslin & Shea, 1990; Dannemiller & Freedland, 1989; Volkmann & Dobson, 1976), one might expect infants to attend to, and track with their eyes, a moving target in front of a stationary background, but to have difficulty attending to a stationary target in front of a moving background. This latter situation may be particularly challenging for infants, because the movement of any large-field display serves as an effective stimulus for eliciting the optokinetic reflex (OKR). The OKR triggers both eyes to match the velocity of the large-field motion, thereby stabilizing the moving display on the retina. When the motion is continuous, the smooth tracking of the OKR alternates with rapid (saccadic) return eye movements to create a repetitive oculomotor response called optokinetic nystagmus (OKN).

Additional evidence suggests that infants may have difficulty attending to a stationary target in front of a moving background. Fixation of a small visual target, even in the absence of a background, is quite variable in young infants (Bronson, 1982; Hainline, Harris, & Krinsky, 1990; Haith, 1980). Moreover, although the OKR is present at birth (Hainline, Lemerise, Abramov, & Turkel, 1984; Krem-enitzer, Vaughn, Kurtzberg, & Dowling, 1979), the smooth pursuit system,

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S. Johnson is now at the Department of Psychology, Lancaster University, Lancaster LA1 4YF, England. This research was supported by a NSF research grant to R.N.A. (BNS91-08723) and by a NEI Center grant (EY-01319). We thank Jill Gallipeau for assistance in testing the infants and scoring the data.

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which like the OKR serves to match the velocity of the eye to that of the target, is known to be immature until at least 6 weeks of age (Aslin, 1981; Dayton & Jones, 1964; Kremenitzer et al., 1979; Rou-coux, Culee, & Roucoux, 1983). Not only is smooth pursuit to a single visual target in an otherwise dark background frequently interrupted by saccades, but the maximum smooth pursuit velocity begins to saturate at target velocities as low as 5 to 10 °/s (Shea & Aslin, 1990), considerably lower than to large-field displays which remain effective in driving OKN at higher velocities (Kremenitzer et al., 1979). Anatomical (Yuodelis & Hendrickson, 1986) and psychophysical (Banks & Bennett, 1988; Sireteanu, 1994) evidence also suggests that the fovea is not as specialized, compared to the periphery, in infants as it is in adults. Thus, there is considerable support for the hypothesis that the OKR, elicited by large-field motion, is likely to dominate over the foveal-based fixational and smooth pursuit systems in young infants.

One final aspect of the two viewing situations—a moving target in front of a stationary background and a stationary target in front of a moving background—may lead to further competition between the objects of attention. If the observer attends to, foveates, and pursues the moving object in front of the stationary background, then the image of the target remains stable on the retina, but the image of the background sweeps across the retina. This retinal-image motion of the background is a stimulus for the OKR in a direction *opposite* to the motion of the moving target. Similarly, if the observer attends to, foveates, and maintains fixation of the stationary target in front of the moving background, then there is a retinal-image motion of the background which, via the OKR, could drive the direction of gaze *away from* the target. In these two situations, the observer must suppress the OKR in order to maintain stable fixation on the target.

It is important to point out that, under typical viewing situations, there is a depth difference between the target and the more distant background. Thus, both monocular (motion parallax) and binocular (convergence and stereopsis) information could be used to segregate the target from the background and to assist in the task of OKR suppression. Binocular information has been shown to facilitate OKR suppression in adults, even when the depth difference between the target and the background is simulated in a stereoscopic display (Howard & Gonzalez, 1987). Although rudimentary convergence is present shortly after birth (Aslin, 1977; Slater & Findlay, 1975), mature convergence to near targets (Aslin, 1977; Thorn, Gwiazda, Cruz, Bauer, & Held, 1994) and stereopsis (Birch, Gwiazda, & Held, 1982; Fox, Aslin, Shea, & Dumais, 1980) emerge at approximately 13 weeks of age. Thus, if young infants rely on a detectable depth difference between a target and a background for object segregation and attention, then they may have difficulty suppressing the OKR until these binocular abilities emerge, and older infants may have difficulty suppressing the OKR under monocular viewing conditions where binocular depth cues are absent.

The purpose of this study was to examine the ability of young infants to deploy their attention to a small visual target while texture in a large background was undergoing continuous, horizontal motion. One- and 2-month-olds were chosen as subjects because robust smooth pursuit does not emerge until at least 6 weeks of age, thereby testing the hypothesis that smooth pursuit is required for OKR suppression. Two-dimensional displays were used to eliminate depth information from motion parallax, convergence, and stereopsis. Four-month-olds were also chosen as subjects because robust convergence and stereopsis do not emerge until 13 weeks of age. If these binocular cues, although absent in the two-dimensional displays used in this study, had been employed by 4-month-olds for several weeks prior to testing, their three-dimensional experience with object segregation and attention might have facilitated OKR suppression to two-dimensional displays.

METHOD

Subjects

The subjects consisted of 19 1-month-olds (*M* = 4.8 weeks, *SD* = 0.70; 10 males, 9 females), 14 2-month-olds (*M* = 9.2 weeks, *SD* = 1.77; 7 males, 7 females), and 12 4-month-olds (*M* = 17.2 weeks, *SD* = 2.83; 8 males, 4 females). An additional 27 infants (19 1-month-olds, 5 2-month-olds, and 3 4-month-olds) were tested but did not provide sufficient data to be included in our final sample because of sleepiness/fussiness (*n* = 19), persistent inattention to the display (*n* = 4), or equipment failure (*n* = 4). Only those infants who completed all four binocular display conditions were included in the final sample. All infants were born within 2 weeks of their due date and were from white, middle-class families.

Apparatus

The displays were generated by an Amiga 3000 computer and were rear-projected onto a 2 x 3 m Polacoat screen by a Sharp projection television (model XV-100). The infants' horizontal, conjugate (binocular) eye movements were recorded using electrooculography (EOG) with Beckman miniature biopotential electrodes. The EOG signal was sampled at 100 Hz by a 12-bit A/D converter (GW Instruments MacAdios ADPO), visualized on-line with GW Instrument's SuperScope II software, and stored on the hard disk of a Macintosh IIci computer for later analysis. Each trial was initiated by pressing the mouse button on the computer, which in turn sent a signal to the Amiga to initiate the movement of the stimulus on the large-screen display.

Design

Each infant was presented with four displays at a viewing distance of 1 m. All displays except the fourth were viewed under binocular conditions. The displays were presented in a fixed order to ensure that each infant provided calibration data as well as data in the two binocular viewing conditions before patching the infants in the final monocular viewing conditions. The first display was designed to obtain calibration data for the EOG recording so that the scorer(s) could determine the relevant magnitude of eye movements to the other three displays.[1] The first display consisted of a vertically oriented red bar (4.7 x 13°; 20.3 cd/m^2) on a black background (0.27 cd/m^2; 97% contrast). This calibration target moved horizontally across the screen through a 42.6° excursion at a constant speed of 35.5 °/s. At the horizontal endpoints of this excursion, the target remained stationary for 1 s to allow the infant's gaze to "catch up" to the target. Each calibration trial consisted of nine excursions (4.5 cycles), and two calibration trials were presented to each infant.

The second display, called *background-only*, consisted of either a 50 x 90° field of 15 randomly spaced green dots (5.9° in diameter) or a 50 x 90° field of vertically oriented black-and-white stripes (3.6° stripe width). The luminance of the green dots was 47.9 cd/m^2 and of the white stripes was 70.3 cd/m^2, and the luminance of the background and black stripes was 0.27 cd/m^2, creating a stimulus contrast greater than 98%. On one trial, the display moved to the left at a constant speed of 18.8 °/s, and on the other trial, the display moved identically to the right. Trial duration was variable, with a goal of collecting at least 30 s of noise-free EOG in each condition.

The third display, called *target+background (binocular)*, was identical to the second, except that the same red bar used as the calibration stimulus was superimposed on the moving dots (or bars) and remained stationary in the center of the display. On one trial, the background moved to the right, and on the other trial, it moved to the left. Trial duration was variable as in the previous condition.

The fourth display, called *target+background (monocular)*, was identical to the third except that the left eye and then the right eye of the infant was patched to create monocular viewing conditions. Each infant was presented with four trials using this display: nasalward and temporalward background motion, while the red bar was fixed in the center of the moving background display, with each eye alternately patched. Trial duration was variable as in the previous condition.

Procedure

After obtaining informed consent from each infant's parent(s), electrodes were attached to the outer canthus adjacent to each of the infant's eyes and to the cheek (ground) using small adhesive collars. The infant was seated in the parent's lap at a 1-m distance from the rear-projection screen. With the infant's head directed toward the center of the display, a small rattle was used to attract the infant's gaze to the red bar, which was stationary at this central location. A reset button was pressed to center the EOG signal within the range of the A/D converter, and the first calibration trial was presented. The second calibration trial was presented in the same manner.

The two background-only and the two target+background (binocular) trials were presented (with direction of background motion alternated), followed by patching of each eye separately, to complete the four target+background (monocular) trials. If the EOG signal showed significant drift, the reset button was used to recenter the signal (changes in EOG baseline did not affect EOG gain). If the infant became fussy or sleepy, a short break was taken between trials.

Data Analysis

Two types of analyses were performed on the EOG tracings. The first consisted of a visual inspection of the horizontal eye position tracing for each trial. A primary observer, who knew which of the four displays was presented on each trial, segmented each trial into three categories: (a) OKN, (b) stable fixation, and (c) other. The other category consisted primarily of randomly directed saccades and large eye/head movements, with no consistent pattern of OKN or stable fixation. Because some of the trials contained segments of unacceptable EOG noise or eye position drift that were out of the range of the A/D converter (prior to manual recentering by the experimenter), the three categorical judgments were normalized across subjects by expressing them as a proportion of each trial duration exclusive of unacceptable data. A secondary observer, who was unaware of the design of the study or the displays presented on each trial, scored a subset of the final sample (5 infants at each of the three ages) to provide a measure of interrater reliability. Mean reliabilities were .93, .90, and .80 for the 4-, 2-, and 1-month-olds, respectively, across the eight noncalibration trials. The two calibration trials were used by the scorers to establish the range of eye excursions, assuming fixation of the calibration target, that were then

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[1] Quantitative calibration of EOG in young infants is possible, though difficult, (Finocchio, Preston, & Fuchs, 1990), especially when the head is not immobilized. The trade-off in any experiment is between the accuracy of calibration data and the time remaining before the infant becomes uncooperative. We chose to collect some calibration data, but not in sufficient detail to accurately measure the amplitude or velocity of eye movements in degrees or °/s, respectively.

used to make meaningful judgments of OKN and stable fixation during the experimental trials.

The second analysis consisted of (a) filtering saccades out of the eye position tracings from the OKN segments in the background-only and the target+background (binocular) trials and (b) computing the relative eye velocity of the slow phase of OKN. The saccade filter consisted of a 39-point weighting function that was passed over the samples taken by the A/D converter of the EOG signal. Relative velocity was defined as the ratio of the slow-phase velocity of OKN in the target+background (binocular) display to the slow-phase velocity of OKN in the background-only display.

RESULTS

Figure 1 shows sample OKN tracings from a 4-month-old to the background-only and the target+background (binocular) displays. Notice that OKN was robust when no stationary target was present, but OKN was intermittently suppressed (i.e., the infant showed stable fixation) when a stationary target was present. These trends were evident in the group categorical data as shown in Figure 2. In the 2- and 4-month-olds, OKN predominated in the background-only condition, but it was reduced by approximately 50% in the target+background (binocular) condition, and it alternated equally often with stable fixation, indicating the presence of OKN suppression. In the 1-month-olds, OKN was less frequent in the background-only condition than for the two older groups of infants, prompting the use of stripes rather than dots to maximize the salience of the display. Although OKN was somewhat more frequent in 1-month-olds presented with stripes than with dots, OKN remained less frequent in 1-month-olds than in older infants. Moreover, OKN was just as frequent in the background-only condition as in the target+background (binocular) condition. Thus, the presence of a stationary target did not reduce the incidence of OKN to the background in the 1-month-olds, suggesting that OKN suppression is not operative in these youngest infants.

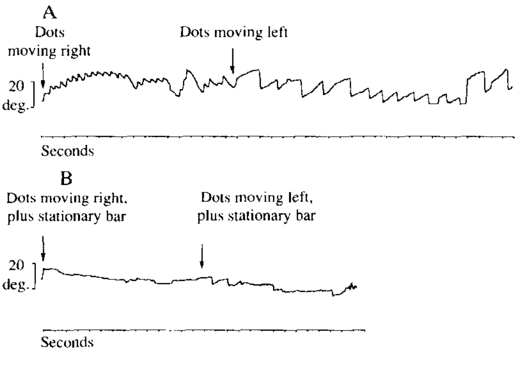

Figure 1. Sample EOG tracings from a 4-month-old under binocular viewing conditions showing (A) rightward and leftward OKN, and (B) OKN suppression to rightward and leftward stimulus motion in the presence of a stationary target.

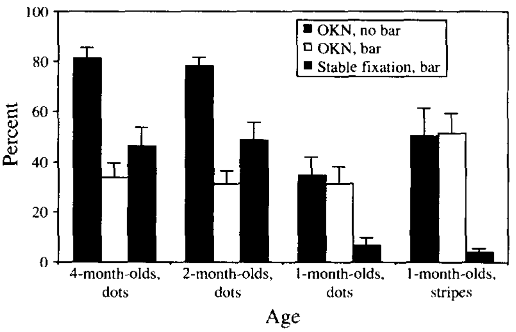

Figure 2. Average percent of trial during which infants in the three age groups showed OKN or stable fixation in the background-only and the target+background displays under binocular viewing conditions.

Support for this conclusion that OKN suppression is not present in 1-month-olds comes from a rescoring of the background-only condition for the presence of periods of stable eye position (using the same criterion for the category of stable fixation in the target+background condition). This baseline level of stable fixation was not significantly greater in the target+background (binocular) condition than in the background-only condition for the 1-month-olds in the dots, $t(14) = 0.61$, *ns*, or the stripes, $t(11) = -1.76$, $p > .10$, displays.[2] Thus, the equivalent frequency of OKN and of stable fixation in the background-only and the target+background (binocular) conditions supports the conclusion

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[2] The presence of brief segments of steady eye position (5.1% for dots; 2.2% for stripes) for the 1-month-olds in the background-only condition sometimes occurred when the direction of background motion switched from leftward to rightward (or vice versa). Because these shifts in direction occurred after up to 60 s of unidirectional background motion (inducing OKN), and because OKN in infants and adults induces an aftereffect called OKAN (which is evident as OKN in the direction *opposite* to stimulus motion when the movement ceases; see Schor, Narayan, & Westall, 1983), the 1-month-olds may have shown "suppression" due to the summation (or cancellation) of OKAN to the initial direction of background motion with OKN to the subsequent direction of background motion.

that OKN suppression is absent in 1-month-olds. In contrast, as described earlier, Figure 2 reveals that the 2- and 4-month-olds not only showed twice as much OKN as the 1-month-olds in the background-only condition, but they also showed approximately half as much OKN in the target+background (binocular) condition as in the background-only condition. Thus, the 2- and 4-month-olds showed clear evidence of OKN suppression.

Figure 3 shows sample OKN tracings from a 2-month-old infant in the four target+background (monocular) conditions. Notice that OKN was present in the nasalward but not the temporalward direction. This finding is consistent with several previous reports (c.f. Lewis, Maurer, Smith, & Haslip, 1992; Naegele & Held, 1982). In the temporalward direction, OKN suppression was present, and the stable fixation in the nasalward direction can be attributed to the absence of OKN in need of being suppressed. This pattern of OKN, OKN suppression, and stable fixation in the absence of OKN is summarized in the group categorical data shown in Figure 4. For the 4-month-olds, OKN was present in both the nasalward and temporalward directions approximately 40% of the time, a frequency that did not differ from the value obtained in the binocular conditions. Moreover, there was no nasal–temporal asymmetry in OKN or OKN suppression. In contrast, both the 1- and 2-month-olds showed more frequent OKN in the nasalward direction than in the temporalward direction, with a correspondingly greater frequency of stable fixation in the temporalward direction than in the nasalward direction.

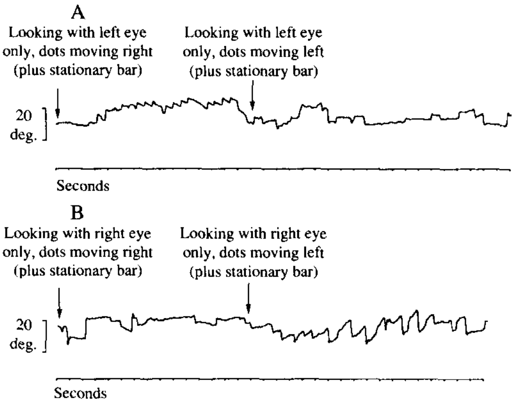

Figure 3. Sample EOG tracings from a 2-month-old under monocular viewing conditions to the target+background displays showing OKN to nasalward stimulus motion, and the absence of OKN (or the presence of OKN suppression) to temporalward motion, when (A) the right eye or (B) the left eye was patched.

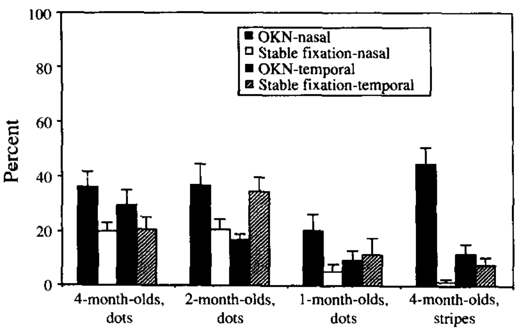

Figure 4. Average percent of trial during which infants in the three age groups showed OKN and stable fixation (or the presence of OKN suppression) to the target+background (monocular) displays moving nasalward or temporalward.

The relative velocities of the slow phase of OKN in the background-only and the target+background (binocular) conditions were computed for each infant and averaged across infants within each of the three age groups. Because the accuracy of the calibration data did not allow for an estimate of slow-phase velocities in °/s, their values in volts/s were expressed as a ratio (OKN slow-phase velocity in the target+background (binocular) condition divided by OKN slow-phase velocity in the background-only condition). Thus, if OKN were unaffected by the presence of a stationary target, the ratio would be 1.00. The mean ratios for the 1-, 2-, and 4-month-olds were 0.84, 0.72, and 0.72, respectively. An ANOVA revealed significant effects of condition (target-absent vs. target-present), $F(1, 39) = 20.62$, $p < .001$, and condition × age, $F(2, 39) = 3.51$, $p < .05$. Thus, when infants showed OKN in the presence of a stationary fixation target, this target decreased the velocity of their tracking eye movements to the moving background, and this effect was stronger in the two older age groups. Note that this effect occurred *during* OKN and was not due to any age difference in OKN suppression. This implies that although 1-month-olds showed little or no OKN suppression, whereas 2- and 4-month-olds showed clear shifts of attention from the moving background to the stationary target when OKN was being suppressed, the slow-phase velocity of OKN in all of the infants was decreased significantly by the presence of a stationary target.[3] An example of this decrease in slow-phase velocity is illustrated in Figure 5.

DISCUSSION

The results of this experiment demonstrate that 4-month-old infants, in addition to showing robust OKN, are able (without instruction) to suppress OKN when a small, stationary target is introduced in the middle of a large moving-texture display. Although a difference in the distance of the target and the background, which was not present in the displays used in this experiment, may have enhanced OKN suppression in the 4-month-olds, it clearly was not necessary because 4-month-olds showed OKN suppression. The performance of the 2-month-olds was virtually identical to the 4-month-olds. Thus, 2-month-olds may have shown enhanced OKN suppression if a binocular- or a motion-defined depth difference had existed between the target and the background, but such a depth difference is clearly not necessary for OKN suppression in 2-month-olds who lack stereopsis and control of near convergence.

In contrast to the 2- and 4-month-olds, the 1-month-olds showed less robust OKN in the background-only condition, and they showed no significant evidence of OKN suppression. There are several possible explanations for the absence of OKN suppression in the 1-month-olds. First, these infants may not be able to direct their attention to a small visual target when it is surrounded by a larger background, especially a background that is moving. Numerous scanning studies (c.f. Haith, 1980; Maurer, 1983) have shown that young infants attend predominantly to the larger of two shapes. Thus, OKN suppression in young infants may be present only when the salience (however defined) is equated between the target and the background. Perhaps a more interesting target would have enhanced the probability of OKN suppression in 1-month-olds.

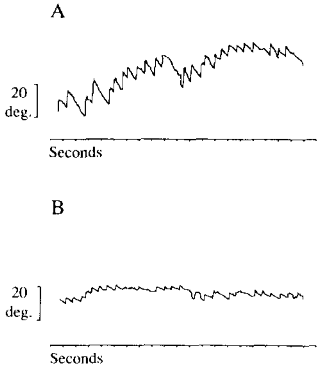

Figure 5. Sample EOG tracings from a 2-month-old under binocular viewing conditions showing higher OKN slow-phase velocity to the (A) background-only display than to the (B) target+background display.

Arguing against the interpretation that young infants are dominated by large displays was the reduced proportion of OKN in 1-month-olds compared to 2- and 4-month-olds in the background-only condition. A second possibility, therefore, is that the 1-month-olds were less able to use *binocular* fixation of the stationary target to facilitate or guide OKN suppression. This hypothesis is supported by previous studies which have shown that prior to 3 months of age, infants show inaccurate binocular fixation to near targets (Aslin, 1977; Slater & Findlay, 1975) and no evidence of sensory fusion (Shimojo, Bauer, O'Connell, & Held, 1986). The data from the 2- and 4-month-olds in this study are also consistent with this hypothesis in that they showed approximately equal amounts of OKN in the target+background (binocular) and in the temporal-to-nasal target+background (monocular) conditions, but only half as much OKN suppression in the monocular condition. Thus, even infants who have the ability to align their eyes binocularly are less likely to show OKN suppression when they are limited to monocular viewing conditions. In contrast, the 1-month-olds showed no

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[3] This summation of inputs from the entire visual display contrasts with the "leakage" of OKN in adults when they are showing OKN suppression. Pola, Wyatt, and Lustgarten (1995) have shown that OKN suppression in adults does not lead to the complete absence of OKN. Rather, a small fraction of slow-phase velocity (with a gain of 0.01 to 0.05) "leaks" through the OKN-suppression system.

greater OKN suppression under binocular than under monocular viewing conditions.[4]

A third explanation for the poor OKN suppression in 1-month-olds is that they have an overall lower level of attention than older infants, both to the background and to the target. Supporting this hypothesis was the lower level of OKN in all conditions among the 1-month-olds. However, as shown in Figure 2, there was a disproportionate deficit in OKN suppression among the 1-month-olds that cannot be attributed to general inattention to the displays. Thus, although the developmental shift from no OKN suppression at 1 month to robust OKN suppression at 2 months may be due, in part, to generalized improvements in attention, the 1-month-olds showed a particular deficit in attending to a small, stationary target surrounded by a large field of moving texture. It remains unclear whether this deficit is fundamentally monocular (resulting from the foveal immaturity which is correlated with poor smooth pursuit) or binocular (resulting from inaccurate eye alignment and its attendant double vision, confusion, or suppression). Regardless of the underlying mechanism, it seems clear that young infants find it difficult to disengage attention from a large-field moving display and direct it to a small, stationary target. In contrast, both 2- and 4-month-olds showed approximately equal frequencies of OKN and OKN suppression, suggesting that attention can more easily be directed to a small, stationary target despite the presence of a large-field moving background.

Finally, regardless of the ability to show OKN suppression, infants at all ages showed a significant decrease in the slow-phase velocity of OKN under binocular conditions when a stationary target was added to the moving background display. This effect suggests that the slow-phase velocity of OKN is determined by the summation of inputs from the entire visual display, unless attention to the stationary target filters out signals from the moving background and leads to OKN suppression. Interestingly, the youngest infants, who showed little or no OKN suppression, were *less* affected by the stationary target in the target+background (binocular) display. This age effect is consistent with foveal immaturity and/or a postretinal representation that is not disproportionately devoted to foveal stimuli.

In summary, we have shown that 2- and 4-month-olds are able to flexibly shift their attention between a large-field moving display and a small, stationary target. In contrast, 1-month-olds are generally inattentive to a small, stationary target when it is surrounded by a large, moving field of dots or stripes. It remains unclear whether 1-month-olds are incapable of attending to a stationary target when a large, moving display is also present. However, these results, as well as those from previous studies of smooth pursuit, suggest that 1-month-olds are rather limited in deploying their attention (and gaze) to a small target.

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[4] The absence of a decline in the proportion of OKN in the target+background conditions when infants at all three ages went from binocular to monocular viewing argues against the hypothesis that the presence of a patch over one eye caused the infants to be generally less attentive to the displays.

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11 November 1994; Revised 15 November 1995 ■