Preferential-Looking Assessment of Fusion and Stereopsis in Infants Aged 1–6 Months

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The ability of infants to discriminate zero-disparity stimuli from both reverse contrast (rivalrous) and disparate (stereoscopic) stimuli was investigated in a two-alternative, forced-choice, preferential-looking paradigm. Few infants under 4 months of age demonstrated discrimination for any stimulus pairing. Of the infants tested at 4 months of age, approximately 70% preferred zero-disparity stimuli to reverse contrast stimuli, and 82% preferred stereoscopic stimuli to zero-disparity stimuli. Nearly 100% of 5- and 6-month-old infants exhibited these preferences. These findings suggest that sensory fusion is not present at birth but develops rapidly over the first 6 months of life. The time course for the development of sensory fusion was similar to the time course for the development of stereopsis in nine infants tested longitudinally. Invest Ophthalmol Vis Sci 26:366–370, 1985

Previous studies using classical and random-dot stereograms have shown that the onset of a visual preference for stereoscopic stimuli is abrupt in a given infant and occurs on the average at 4 months of age. Infants over 4 months of age show consistent preference for line stereograms containing binocular disparities over zero disparity, with percent preference rising from chance to approximately 100% over a range of disparities from 0 to 60 min. For even larger disparities, perceived as rivalrous or lustrous by adults, percent preference decreases to chance or reverses to a preference for the zero-disparity stimulus. A similar pattern of responses was noted in a study employing random-dot stereograms of 45- and 313-min or 447-min disparity.6 One interpretation of this reversal is that the disparate elements of the stereogram are perceived as rivalrous and that infants over 4 months of age prefer a fusion stimulus over one that has rivalrous elements. However, the 75-min disparity grating must be considered a weak stimulus for eliciting a preferential response since less than half of the infants had a preference. This may be due to the fact that only alternate bars were binocularly disparate.

The purpose of the present study was to determine at what ages fusion stimuli are preferred over rivalrous stimuli. In addition, the onset age of preference for fusion and the onset age for preference for stereoscopic depth were compared. For these purposes, two separate but similar stimulus configurations were developed independently by two investigators and presented to separate populations of infants. The stimulus configurations were designed to enhance the dichotomy between rivalry and fusion, based on the findings in adults that (1) reverse-contrast classical stereo half-images are fused poorly and (2) in the case of random-dot stereograms, they cannot be fused at all. Because of the similarities in results and conclusions, we report the two studies together, despite differences in stimuli and procedures.

Materials and Methods

General

Healthy infants aged 1–6 post-term months were solicited through letters to parents listed in birth records. All infants were examined by a pediatric optometrist, and only those who were orthophoric and within the normal range of refractive error were recruited for participation. Infants were assigned to one of six 1-month age groups. The number of infants participating in each age group and experimental paradigm is shown in Table 1. Informed consent was obtained from all parents after the procedure had been explained fully. Six adults aged 20–50 years also were tested.
Table 1. Age distribution of participating infants

<table>
<thead>
<tr>
<th>Post-term age (months)</th>
<th>Stereo pair and checkerboard</th>
<th>Random dot</th>
<th>Stereo</th>
<th>Check</th>
<th>Stereo</th>
<th>Check</th>
<th>Random dot</th>
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Paired stimuli were rear-projected (Hawk MK.V or Hawk MK.VI Stereoprojector) onto two 38 deg × 30 deg Polacoat Lenscreens, which were located to the left and right of a 4-deg-wide opaque panel containing two small light-emitting diodes. The two channels of the stereoprojector were polarized orthogonally, and infants wore goggles containing polarizing filters while viewing the images. The extinction ratio for the filters was $10^{-4}$. Since all stimuli were comprised of two polarized half-fields whether or not binocular disparity was present, head rotation could not provide a differential intensity cue by which the disparate stimulus could be discriminated from the nondisparate stimulus. The three stimulus pairs employed in the study are shown schematically in Figure 1. Each stimulus pair consisted of a zero-disparity pattern (identical half-fields for each eye) and a binocularly disparate pattern or reverse contrast pattern. Each infant was held by its parent at 50 cm from the screens. The parent was instructed to maintain the infant's head in an upright position and an observer, watching through a peephole from behind the screens, monitored head position throughout the experiment. The room was dark so that the only light came through the projection screens. Thus, the only stimulus cues present for accommodation and convergence were located at the plane of the screens. On each trial, an observer centered the infant's gaze by flashing the light-emitting diodes. The stimulus pair then was presented, and the observer, without knowledge of the positions of the stimuli, made a forced-choice judgment of the side at which the infant preferred to look. The stimulus positions were randomized over trials differently for each subject. The disparate stimulus appeared on the same side no more than three times in a row. No feedback was
given to the observer about stimulus location, since the judgment was one of preference and not of stimulus location.

Paradigm 1

This study employed bar stereogram and checkerboard stimulus patterns. The bar stereogram was identical to the ones that were previously employed to assess the development of stereopsis. Briefly, these stereograms were composed of seven 2.0-deg-wide vertical black bars spaced 2.0 deg apart (0.92 contrast). To create 45-min crossed binocular horizontal disparity, alternate bars on one half-field were shifted laterally. When normal adults viewed this stimulus through polarizing filters, all seven bars on one side appeared to lie in the plane of the screen while the second, fourth, and sixth bars on the other side appeared to stand out in front of the screen. The checkerboard stimulus pair (check size = 2.0 deg; 0.92 contrast) consisted of checks that were of the same contrast for the two eyes on one screen, paired with checks that were reversed in contrast for the two eyes on the second screen. When viewing through polarizing goggles, normal adults reported black and white checks on one screen and checks that appeared alternately black and white on the second screen (rivalry).

The classical stereogram pair contained two monocular cues that possibly could have mediated discrimination and served as the basis for any preference shown. The first monocular cue (due to incomplete polarization) was the presence of faint gray stripes, which appeared on either side of the black bars only in the disparate pattern. This difference could be enhanced by tilting the goggles and/or head. To determine whether this monocular cue alone was sufficient for the infants to show a preference, the polarizing filters in the projector were oriented parallel to one another. This had the effect of occluding one eye while the other eye viewed both half-fields presented on both screens. A second monocular cue on which discrimination may have been based was the difference in spacing of the bars in the two patterns. In the disparate pattern, alternate bars were shifted laterally while, in the zero-disparity pattern, the bars were spaced regularly. In order to examine whether the irregular spacing itself was attractive to the infant in the absence of binocular horizontal disparity, both polarizers in the goggles were oriented in parallel, while the filters in the projector remained orthogonal. In this case, both eyes viewed only one-half of the stereo pair present on each screen. Two control conditions for the checkerboard stimuli were generated in the same way.

In this experimental paradigm, each of 55 infants participated in a single test session of 20 trials with the stimulus pair designed to assess stereopsis (45-min vs 0-min crossed disparity) and 20 trials with the checkerboard stimulus pair. Twenty-six infants viewed bar stereograms first, and 29 viewed checkerboards first, with the order of the stimulus pairs unknown to the observer. In addition, 45 of these infants aged 3–6 months received 10 trials in each of one or more of the control conditions during the same test session. The order of experimental and control conditions was counterbalanced. Four other infants failed to complete 40 trials, and their data have been excluded from analyses. Nine additional infants were tested bi-weekly beginning at age 1–11 post-term weeks (mean age at first test session = 7.9 weeks, SD = 3.0 weeks). These infants were tested until they reached criterion on both stimulus pairs.

Criterion performance was 75% preference in the experimental conditions. Since the hypothesis tested predicted which one of the stimulus pair would be preferred (one-tailed test), the binomial probability associated with criterion performance was 0.021. Criterion performance in the control conditions was 80% preference (one-tailed binomial probability = 0.055).

Paradigm 2

The second study employed a stimulus pair consisting of random-dot patterns (dot size = 30 min; density = 50%; contrast = 0.92). The patterns presented to each eye were identical on one screen. On the other screen, random-dot patterns were opposite in contrast for each eye. When viewed through polarizing filters by normal adults, one screen appeared as a fused black-and-white pattern, while the other side appeared rivalrous or lustrous. Twenty-six infants participated in a single session in which they received 10 trials with the random-dot stimulus pair. Nineteen of these infants aged 3–6 months also were tested monocularly on 10 trials during the same test session. This control condition was used to determine whether contrast differences between the two stimuli might mediate preference. The order of experimental and control conditions was counterbalanced.

Criterion performance for both the experimental and control conditions was 80% preference. Since the hypothesis predicted which one of the stimulus pair would be preferred (one-tailed test), the binomial probability associated with criterion performance was 0.055.

Results

The proportion of infants attaining a criterion preference for binocularly identical patterns (Fig. 2A)
and for binocular disparate patterns (Fig. 2B) varied as a function of age. With both the checkerboard and random-dot patterns, over 60% of the 4-month-old infants preferred zero disparity. All 10 of the 6-month-old infants preferred the fusional stimulus. None of the infants tested preferred reverse contrast stimuli at any age. In general, infants who reached criterion with the checkerboard stimulus pair also reached criterion with the line stereogram pair, while infants who failed to reach criterion with the checkerboard stimulus pair also tended to fail to reach criterion with the line stereogram pair (contingency coefficient C = 0.41, P < 0.01; see reference 14). For the line stereogram stimulus pair, none of the infants preferred the zero-disparity stimulus at any age. The proportion of infants preferring 45-min crossed disparity was larger in the older age groups. Over 80% of the infants aged 4–6 months preferred the binocularly disparate stimulus. All six adults were capable of making discriminations for each of the three stimulus pairs on 100% of 10 trials.

Data from the nine infants who were tested biweekly with both the line stereogram pair and the checkerboard pair are summarized in Table 2. The age at which each infant first reached criterion with each stimulus pair was defined as the onset age for stereopsis (line stereograms) and fusion (checkerboards). Six of the nine infants first reached criterion for fusion and stereopsis during the same test session. Two infants reached criterion with the checkerboard stimulus pair first, and one reached criterion with the line stereogram first. The mean ages of onset for stereopsis (12.3 weeks) and for fusion (11.7 weeks) were not significantly different (t-test for paired comparisons, t = 0.7, P > 0.05).

The performance of 3–6-month-old infants in each of the control conditions is compared with their performance on the same day in the experimental conditions in Figure 3. Over 70% of 3–6-month-old infants reached criterion in each of the three experimental conditions (stereogram, checkerboard, and random-dot patterns). In contrast, less than 11% of the infants reached criterion in each of the three control conditions.

### Discussion

The results with line stereograms in this study are consistent with previous behavioral and electrophysiologic studies, which have shown that most infants aged 4–6 post-term months can discriminate binocularly disparate stereoscopic stimuli from zero-disparity stimuli.
parity stimuli. A few infants aged 1–3 months also reached criterion in the stereopsis paradigm. This result is in accord with previous reports that 10–30% of infants aged 2 months are capable of this discrimination.1,5,7,15

The novel finding in the present study is that infants over 4 months of age tested with checkerboard and random-dot patterns discriminate between binocularly identical and reverse contrast stimuli. However, in this case, the preference is reversed. Infants prefer a binocularly disparate stereoscopic stimulus to a zero-disparity stimulus but prefer the zero-disparity stimuli to reverse-contrast stimuli. The longitudinal data presented here show an agreement between the average ages at which discrimination of these two distinct classes of binocular stimuli first occurs (within 2 weeks). The qualitatively different responses that infants produce for stimuli which adults perceive in depth (preferred) and for stimuli which adults perceive as rivalrous (nonpreferred), suggest that the 4–6-month-old infant has approximately the same upper limit in fusional range as adults.

The time course for the development of sensory fusion described in the present study is similar to the time course for the development of stereopsis previously reported in both behavioral and electrophysiologic studies.1–7 That the fourth month of life represents an important age for the development of binocular vision and hyperacuity also is supported by studies of convergent eye movements,16 binocular summation,13 evoked-potential responses to binocular correlation,7,18 amblyopia,19 and vernier acuity.20

Key words: fusion, stereopsis, preferential looking, infants, development

References