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The Perception of Chromatic Figure/Ground Relationships in 5-Month-Olds

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This study tested the hypothesis that 5-month-old infants are able to encode and retrieve the spatial relationships between chromatically different regions in a simple visual pattern. Twenty-four 5-month-old infants were familiarized with a bichromatic figure/ground pattern. Across familiarization trials, the ratio of figure luminance to ground luminance changed over a large range, whereas the chromatic relationship between the figure and the ground remained constant. Infants responded with increased attention to changes in the color either of the figure or of the ground alone, or to a *reversal* of the chromatic relationship between the figure and the ground. The results show that 5-month-olds are capable of encoding and retrieving the relationship between the chromatic and spatial characteristics of a simple bichromatic pattern.

color vision figure/ground spatial vision novelty recognition

Visual patterns can be perceived on the basis of luminance and/or chromatic differences. The adult human visual system contains channels selectively sensitive to both luminance differences and chromatic differences (Boynton, 1979). Human infants over the age of approximately 3 months probably possess trichromatic color vision (Teller & Bornstein, 1987). Recent work by Brown, Liman, and Teller (1986) also suggests that 3-month-olds possess at least one of the chromatically opponent channels that probably contributes to hue encoding in the adult visual system. However, little empirical work exists on the question of whether or not human infants can use the information in chromatic channels to encode the spatial characteristics of patterns.

Representing the relationship between the chromatic and spatial regions of a surface is an important aspect of image processing. For example, a predominantly yellow banana with a few, spatially sparse green regions does not convey the same information as a predominantly green banana with a few, spatially

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sparse yellow regions. Recent work by Treisman and Schmidt (1982) on illusory conjunctions of form and color suggests that some attentional effort is necessary even for adults to perceive and briefly remember which colors occurred in which locations in simple displays. It is, of course, entirely plausible to imagine a visual system that used chromatic differences to aid in the initial segregation of figure from ground in an image, yet lost the information about which colors went with figure and which colors went with ground at some later stage in processing. For such a visual system, there would be a tendency to confuse a bichromatic pattern with a version of that pattern in which the chromatic regions were exchanged.

The purpose of the present study was to examine this question of the fidelity of chromatic and spatial encoding in 5-month-old infants. We chose 5-month-olds to avoid complicating interpretations that might arise from testing very young infants with immature color vision (Teller & Bornstein, 1987). There are several reasons why 5-month-olds might not show evidence of discriminating between a bichromatic pattern and its chromatically reversed counterpart. First, information relating the spatial and chromatic characteristics of a pattern might be lost at some early stage in processing after figure/ground segregation has taken place. In other words, abrupt chromatic and/or luminance differences might be used to define the boundaries of a figure; however, the color of each region might not be preserved in subsequent representations. This could occur if the pattern were encoded only in terms of its chromatic and/or luminance zero-crossings without also preserving the *directions* of those zero-crossings (Marr, 1982). Second, because the paradigm used to test for discrimination necessarily requires some minimal memory, it could also be the case that the difference between a pair of chromatically reversed figure/ground patterns is perceptually evident to the 5-month-old, but the arbitrary nature of the chromatic–spatial relationship might make it particularly difficult for the 5-month-old to remember which pattern he/she had seen.

Finally, a bichromatic pattern may be discriminable from its chromatically reversed counterpart, and the 5-month-old may be capable of remembering which pattern he/she has seen. However, the reversed pattern may simply not be different enough to elicit an increase in attention. Null results would be uninformative regarding the locus of the loss of the information relating the chromatic and spatial aspects of the pattern. In contrast, positive evidence of discrimination with proper controls would demonstrate that the 5-month-old's visual system is capable of encoding the relationship between the chromatic and spatial aspects of an image with enough fidelity to allow recognition and discrimination to occur.

Previous research on the perception of color-form compounds in young infants would at first appear to have answered the question elaborated above. For example, a recent study by Bushnell and Roder (1985) indicated that 4-month-olds paid more attention to novel combinations of familiar colors and forms than they did to familiar color-form compounds. This contrasts with earlier work by Cohen (1973) that indicated that 4-month-olds did not respond to novel combinations of familiar colors and forms. However, in both of these studies, the familiar color was always presented at a fixed luminance across trials.[1] In the absence of any empirical estimate of the relative brightness of the familiar and novel colors for infants, it is entirely possible that infants were using the information in achromatic brightness channels to encode the patterns. For example, pink and blue patterns were used in the Bushnell and Roder (1985) study. If the pink color were perceived as brighter (or dimmer) than the blue, then information exists for encoding brightness-form compounds as well as color-form compounds. There is no a priori reason to suppose that 4-month-olds relied on the information in chromatic channels rather than the information in achromatic channels. The only way to address the question of whether or not young infants make use of purely chromatic information to encode the spatial characteristics of patterns is to render the information in luminance channels irrelevant for this purpose.

Relationships between chromatic and spatial information in a pattern are most easily discussed in terms of the concept of spatial phase. The relative locations of features in a pattern depend on the relative phases of spatial frequency components within the pattern. For example, consider a luminance edge that becomes abruptly brighter immediately to the right of the center of a visual pattern. Next, consider the mirror image of this pattern. Now the edge is brighter to the left of the center position. This pair of features differs simply in that all of the luminance spatial frequency components in one member of the pair have been shifted by 180° relative to the same components in the other member of the pair. Similarly, a bright cricle on a grey background and a dark circle on the same grey background differ by 180°-phase shifts of all spatial frequency components. It is relatively easy to extend this formalism to the case of chromatic spatial phase. Thus, one may speak of a chromatic edge that is red to the right of center and green to the left or red features within green surrounds as differing by 180° in chromatic phase from their chromatically reversed counterparts.

Research on sensitivity to spatial phase during infancy has focused exclusively on luminance variations. Young infants under 3 months of age appear to be deficient in encoding relative spatial phase (Braddick, Atkinson, & Wattam-Bell, 1986). Dannemiller and Stephens (1988) showed that 12-week-olds but not 6-week-olds preferred the normal-phase version of a schematic face rather than the contrast-reversed, negative version of the face. Kleiner and Banks (1987) have shown that 12-week-olds but not younger infants exhibit phase sensitivity in their visual preferences. All of these studies, however, have addressed the question of phase sensitivity to luminance differences rather than to chromatic differences. The present study extended this earlier work to the question of chromatic spatial phase.

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[1] Neither study reported the luminance levels of the stimuli. We assumed, therefore, that luminance was fixed during familiarization trials, and furthermore, that the different colors were not equated for luminance.

METHODS

Subjects

Twenty-four infants approximately 5 months of age (*M* age = 19.3 weeks; range = 15.2–21.4 weeks) participated in the study. All infants were full-term and healthy, with no reported birth complications and no diagnosed visual defects. One additional infant failed to complete testing due to state problems.

Apparatus and Stimuli

Stimulus patterns were displayed on an RGB monitor under the control of a microcomputer. A custom-built video processor allowed independent control of the red, green, and blue phosphors on the RGB monitor. The monitor was centered in a matte black wall with two small observation holes on either side.

The stimulus pattern is shown in Figure 1. The figure and the ground each occupied 50% of the total display area. The figure and the ground could take

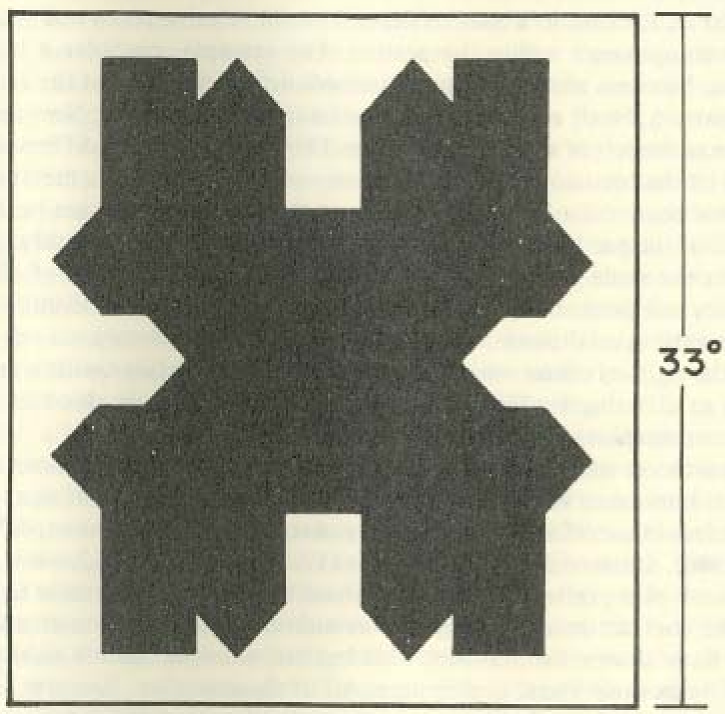

Figure 1. The figure used on all trials. The rectangular border was not actually present on the display. Instead, the display outside the rectangle was dark. The figure and ground both occupy 50% of the total area. Dimensions are in degrees of visual angle. The largest vertical extent of the figure was 29°; its largest horizontal extent was 26°. The figure is drawn to scale.

on any one of three colors—red, blue, or green. This yields six chromatic figure/ground combinations. For example, one such combination would be a red figure embedded within a green background. The average luminance of the display remained constant to within 10% across all chromatic conditions and all familiarization and test trials.

During familiarization there were 20 trials. There were two blocks of 10 trials on which the luminance contrast between the figure and the ground differed. The actual luminance contrasts of the trials and the mean luminance for each contrast are shown in Table 1. Five trials of each block resulted in ratios with the figure luminance greater than ground luminance, and five trials resulted in patterns with ground luminance greater than figure luminance. The second block of habituation trials was identical to the first block. Also shown in Table 1 are the contrasts and mean luminances of the three types of test trials. The mean luminance and contrasts are equivalent on all three types of test trials. The *no-change trial* preserved the chromatic, figure/ground relationship presented during familiarization, but presented this relationship at a novel luminance contrast. The *reversal trial* simply reversed the chromatic relationship between the figure and the ground from that shown during familiarization. The *new-color trial* introduced a novel color into either the figure or the ground. Increased attention on this type of trial probably indicates true chromatic discrimination rather than brightness discrimination because the relative luminances of the figure and the ground were varied over a large range during

TABLE 1
Luminance Contrasts for Familiarization and Test Trials[a]

	Luminance Contrast[b]	Log Contrast[c]	*M* Luminance[d]
Familiarization	.84	.23	3.65
	.76	.18	3.71
	.64	.11	3.68
	.40	−.09	3.75
	.27	−.27	3.75
	−.10	−.70	3.65
	−.24	−.32	3.61
	−.49	.01	3.55
	−.62	.09	3.55
	−.72	.16	3.55
Test Trials			
No Change	.02	−1.40	3.41
Reversal	.02	−1.40	3.48
New Color	.02	−1.40	3.44

[a] The nominal chromaticity coordinates of the phosphors on the monitor were red (.62, .36), green (.28, .58), and blue (.16, .04).

[b] Contrast = (Figure Lum. − Ground Lum.)/(Figure Lum. + Ground Lum.). Negative contrasts indicate Figure Lum. < Ground Lum.

[c] Defined as Log (|Figure Lum. − Ground Lum./Mean Lum.).

[d] Units are cd/m².

familiarization, rendering brightness contrast irrelevant as a discrimination cue (see Teller & Bornstein, 1987, for a discussion of the logic of this technique). This new-color trial was included as a control to demonstrate that infants were at least capable of remembering two colors in the familiarization pattern even if they weren't capable of remembering their proper spatial relationship.

The luminance levels of the stimuli were calibrated using a United Detector Technology #248 Uniprobe with a photopic filter yielding luminance in photopic ft-Lamberts. The design of the experiment called for 10 different luminance contrasts to be used during familiarization trials. All of the test trials, however, involved chromatic stimuli with very little (2%) luminance contrast. The contrasts of these test stimuli were also determined using the Photometer described above. The test stimuli differ from the familiarization stimuli in the sense that they contain chromatic contrast but very little luminance contrast. This could have presented a potential problem because truly equiluminant patterns with only chromatic contrast appear to adults to have very indistinct edges or contours because purely chromatic acuity is quite poor relative to luminance acuity (Hilz & Cavonius, 1970; Kelly, 1983; Noorlander, Heuts, & Koenderink, 1981). Thus, on all of the familiarization trials, luminance contrast and perceptually sharp edges could have been present, whereas on all of the test trials, patterns with less distinct borders or edges could have been present.

This potential, systematic difference between familiarization and test trials probably was not a problem with infants for several reasons. First, infant luminance acuity at 20 weeks is generally poorer than adult acuity (Dobson & Teller, 1978). Therefore, both familiarization and test trials may have been perceived as having blurred or indistinct borders by the infants. Second, achieving true equiluminance requires in situ heterochromatic flicker photometry or the use of some other technique such as the method of "minimally distinct borders." We used neither of these techniques because it was not our intention to produce truly equiluminant chromatic patterns. Even if we had used these techniques with adults to create equiluminant patterns, it is doubtful that such settings would be appropriate for infants because preretinal absorption differs between infants and adults (Werner, 1982; Werner, Donnelly, & Kliegl, 1987). Finally, the results detailed below suggest that infants did not respond on the basis of blurred versus distinct edges on the test trials.

Conditions

The three primary colors—red, blue, and green—allowed six bichromatic, figure/ground conditions. Infants were randomly assigned to one of these six color-combination conditions with the constraint that an equal number of infants serve in all conditions. Additionally, infants were assigned randomly to either a *figure-change group* ($n = 12$) or a *ground-change group* ($n = 12$). This assignment determined what part of the pattern was changed chromatically on one of the test trials. For example, infants in the red/green figure-change group were presented with a red figure embedded within a green background during familiarization. At test, these infants were presented with (a) the same red figure and green background with a novel luminance ratio not experienced during familarization, (b) a reversal of the figure and ground colors with the same luminance ratio used on the no-change trial, and (c) a blue figure and a green background with the same luminance ratio used on the no-change trial.

Procedure

The infant was seated on the parent's lap approximately 40 cm from the display. The parent's view of the screen was obscured by a curtain. The observer recorded the duration of the infant's fixations on the pattern on each trial. Durations were relayed to the computer using a hand-held response box. The computer timed the trials and printed summary values of fixation behavior at the end of the experiment.

A trial was started when the infant was judged to fixate a flashing bar at the edge of the screen. The flashing bar was presented against a white uniform field with a luminance of 4.77 cd/m^2. This uniform field remained illuminated between trials to keep the infant light-adapted to the mean luminance of chromatic displays. The pattern appeared at the center of the screen. Presenting the flashing bar at the edge of the screen proved helpful to the observer in judging the onset of the infant's first fixation on the pattern at the center of the screen. Interobserver reliabilities were always greater than .90 (Pearson r) for the duration of fixation measure.

The infant was presented with 23 trials. Trial durations were 15 s. The first 20 trials served as familiarization trials. The figure/ground pattern was presented using the 10 figure/ground luminance ratios shown in Table 1. Two blocks of these 10 luminance ratios were presented to the infant. The order of the 10 luminance ratios within the first block was randomized for an infant, and this same order was used in the second block. The order of the three types of test trials shown in Table 1 was randomized across infants.

RESULTS

Fixation times during familiarization were analyzed using an ANOVA with one between-subjects factor (Figure-change groups vs. ground-change group) and one repeated measure (Block 1 = average fixation on trials 1 to 10, and Block 2 = average fixation on trials 11 to 20). The repeated measure showed a significant decrease in average fixation between Block 1 and Block 2, $F(1, 22) = 42.24$, $p < .001$. This decrease is shown in Figure 2. There was no main effect of the between-subjects factor, $F(1, 22) = 0.09$, $p > .10$, nor did this factor interact with the repeated measure, $F(1, 22) = 0.05$, $p > .10$. Of course, this lack of a difference between the two groups is to be expected because both groups were treated identically during the 20 familiarization trials. The average decrease from Block 1 to Block 2, collapsed across both groups, was 2.37 s. The lack of a large decrease across these two blocks is perhaps attributable to the substantial

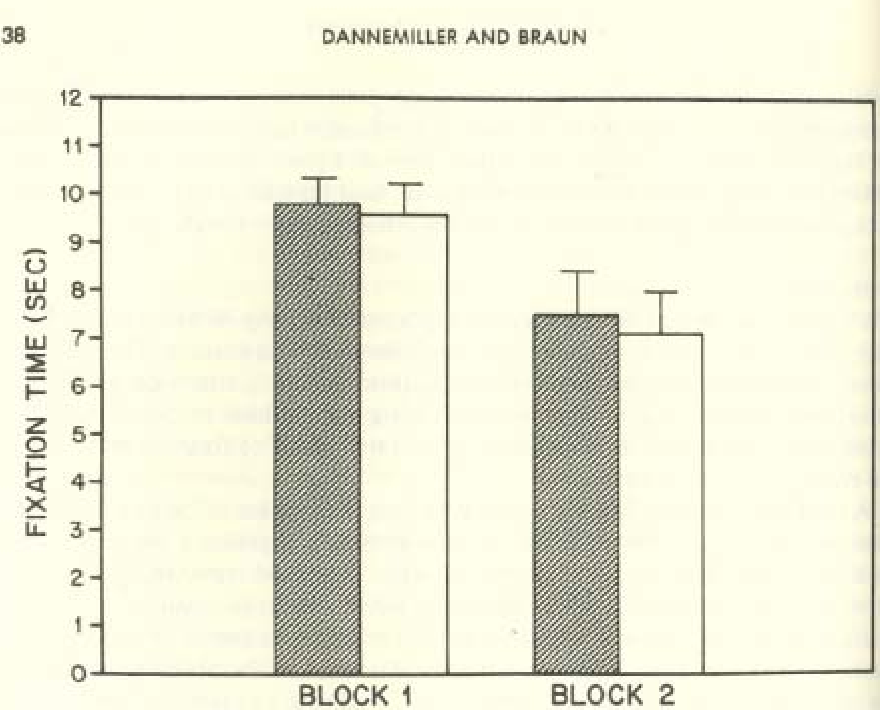

Figure 2. Average fixation times during familiarization on trials 1 to 10 (Block 1) and trials 11 to 20 (Block 2) in the figure-change (hatched) and ground-change (open) groups. Error bars are +1 s.e.m. The decrease across blocks is significant, $p < .001$.

variations in the luminance ratios across these trials. Bornstein, Kessen, and Weiskopf (1976) and Cornell (1974) have observed that response decrements to varied stimuli are less than response decrements to repeated stimuli.

The test data were analyzed using two between-subjects variables (Color-Combination Group and Figure-Change Group vs. Ground-Change Group) and one within-subjects variable (Type of Change; i.e., No Change, Reversal, and Change in Figure *or* Ground Color). The only significant effect was that of Type of Change, $F(2, 24) = 7.04$, $p = .004$. None of the other main effects or interactions was significant. The lack of a difference between the Figure-Change and Ground-Change Groups indicates that, under the present conditions, changes in the color of either the figure or the ground produce approximately the same result. Neither seems to be more salient in terms of eliciting an increase in attention.

Figure 3 shows the test-trial data collapsed across the Group variable (Figure Change vs. Ground Change) and across the Color-Combination variable. Also shown in Figure 3 is the average fixation time on the last familiarization trial (T20). It is clear from Figure 3 that infants respond with significantly greater fixation when either a new color is introduced into the figure or the ground (NEW) *or* when the chromatic relationship between the figure and ground is reversed (REV). Posttests revealed that average fixation time on these two

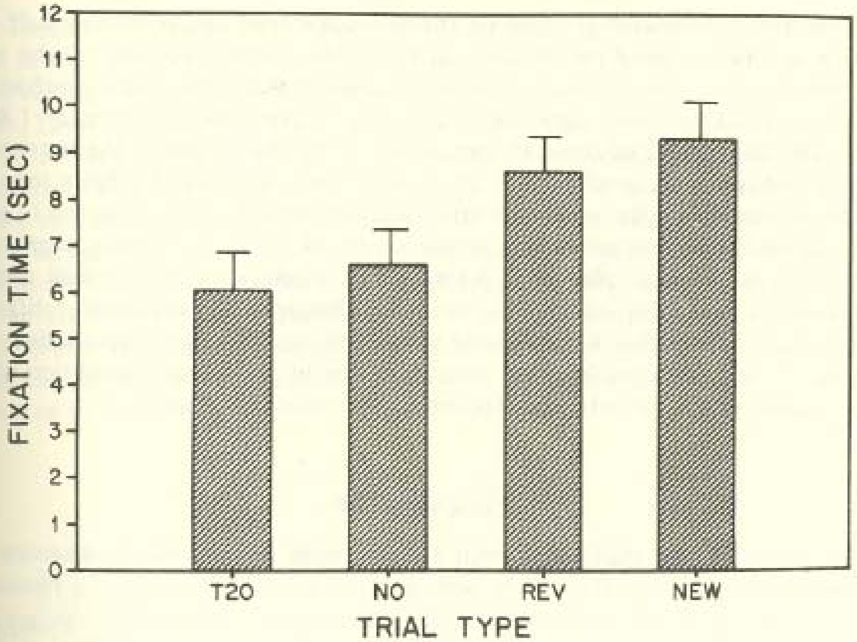

Figure 3. Average fixation times on the three types of test trials (NO, REV, NEW) and on the last familiarization trial (T20). Error bars are +1 s.e.m. The REV and NEW averages both differ significantly from the NO average, $p < .01$. The difference between REV and NEW is not significant. (NO = no change in the chromatic relationship between figure and ground; REV = reversal of the chromatic relationship between figure and ground; NEW = introduction of a new color into either the figure or the ground.)

types of test trials differed significantly, $p < .01$, from fixation time on the trial that preserved the chromatic relationship between the figure and the ground. Average fixation on these two types of trials (NEW and REV), however, did not differ significantly.

An alternative explanation that has nothing to do with chromatic phase could be offered for the discrimination on the reversal trials. Suppose that an infant consistently fixated the same region (e.g., lower left ground corner) of the display across familiarization trials. Although previous research on scanning patterns makes this implausible, we may entertain it as a possibility. On the reversal test trial, the infant would always see a new color in this location. This could account for discrimination on this type of trial. However, this hypothesis also predicts that whereas all infants would experience a change on the reversal trial only half would experience a change on the new color trial because for half the infants, the new color would have been introduced in the part of the display to which they were not attending. As noted above, the *magnitude* of dishabituation did not differ on these two types of trials. More to the point, however, the restricted fixation hypothesis predicts that infants should respond with increased fixation on the new-color trial approximately half as often as they respond on the reversal trial. The number of infants who responded with increased fixation on the reversal trial relative to the no-change trial was 17. This differs significantly from the 12 expected by chance ($z = 1.84$, $p < .05$). Because 12 of these 17 were expected by chance alone, the restricted fixation hypothesis predicts that one-half of the additional 5 infants should have responded on the new-color trial. Adding these 2.5 infants to the 12 expected by chance, we arrive at a prediction of 14.5 infants showing increased attention on the new-color trial. A total of 19 infants showed increased attention on the new-color trial relative to the no-change trial. This number differs significantly from the 14.5 predicted by the restricted fixation hypothesis ($z = 1.88$, $p = .03$). We conclude that discrimination in the reversal condition was not mediated by the restricted fixation behavior of the infants.

DISCUSSION

The results of this study show that 5-month-olds are capable of detecting a change in the spatial relationship between the chromatic regions of a familiar bichromatic pattern. Furthermore, they do so despite substantial changes in the relative luminances of the two colors in such a pattern. In other words, they encode the invariant chromatic characteristics of a display independently of the relative luminance levels of the regions in the display. This shows that 5-month-olds are capable of using the information in chromatic channels to encode the spatial characteristics of a pattern. Finally, they respond with increased attention when a new color is introduced either into the figure or the ground, or when the spatial relationship between the two previously seen colors is reversed. These results demonstrate conclusively that the 5-month-old's representation of a simple bichromatic pattern has information that tags each spatial region with its chromatic characteristics.

Such a result is perhaps not surprising from the perspective of adult capacities. Adults know that the chromatic characteristics of a region probably carry some information about the material properties of that region. For example, abrupt spatial changes in the chromatic characteristics of an image probably signal changes in the material composition of the surface(s) in that part of the image (Gershon, Jepson, & Tsotsos, 1986). There is a good reason to represent explicitly not just chromatic changes or *differences* (boundaries) in the image but also the spectral characteristics of the regions themselves. However, the fact that adults process visual patterns in this way is no guarantee that the same chromatic information is made explicit in the 5-month-old's representation of an image. In Gibson's (1969) terminology, it is logically possible that experience with surfaces and objects may be necessary before the 5-month-old begins to use chromatic spatial phase as a distinctive feature for differentiating patterns in the environment. The present results show that at least by 5 months of age, this information is used to represent bichromatic patterns.

These results extend the results of Dannemiller and Stephens (1988) into the chromatic domain. An achromatic pattern and its contrast-reversed, negative counterpart are clearly discriminable to 12-week-olds. When the image is a face, 12-week-olds treat these two images differently. They prefer the normal-contrast version of the face that preserves the *direction* of contrast differences that they have experienced with faces in the environment. The current results show that by 5 months of age, chromatically, reversed image pairs are also discriminable. This representation of the chromatic characteristics of regions within an image could provide visual support for learning that a material change in surface characteristics (distal property) is often accompanied by a change in the chromatic characteristics at that point in the image (proximal property), or that the particular chromatic characteristics of a region carry information regarding its identity.

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