A NEW PROCEDURE DESIGNED TO ASSESS CONTRAST AND COLOR VISION IN YOUNG INFANTS

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BY

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Abstract

An enduring practical problem in studying human visual development is to obtain enough data to evaluate the vision of individual infants. With this problem in mind, we have produced a new test of basic color vision using Munsell Hues and a method patterned after the Teller Acuity Cards (TAC).

In our procedure, we first evaluate an infant's sensitivity to luminance contrast. The baby is shown large gray cards (21.5 x 56 cm) that have a 7.5 x 12 cm gray "standard" patch of the same luminance on the left or the right side, and a gray "test" patch of different luminance on the other side. Like the TAC procedure, a "blind" observer attempts to correctly judge the location of the test patch. The procedure continues until the smallest detectable luminance increment and decrement is determined. Next, we test the infant with chromatic test patches. To eliminate brightness cues, the relative luminance of the chromatic patch and the gray background is varied systematically (Teller & Bornstein, 1987) in equiluminant steps over a wide range (about 1 log unit) centered around an adult brightness match. The step size (thus, the number of cards needed for each chromatic test) is determined by the subject's sensitivity to contrast in the first phase.

We used the Color/Contrast Cards to test 70 2- and 3 month-olds with four broad-band chromatic stimuli, namely a red (dominant wavelength = 660 nm), a (580 nm) yellow, a (520 nm) green, and a (475 nm) blue. In approximately 20 minutes, 83% of 2-month-olds and 87.5% of 3-month-olds completed the contrast phase and at least one of the four chromatic stimuli, and of these, 37% of 2-month-olds and 34% of 3-month-olds completed all four chromatic stimuli. Both groups of infants were significantly better at detecting luminance decrements than increments. 3-month-olds discriminated all four chromatic stimuli from gray. In contrast, 2-month-olds discriminated the red and blue from gray but failed to discriminate the yellow and green from gray at relative luminances close to the adult brightness match. Reasons for 2-month-olds' "failures" are discussed in detail.

In general, the procedure was successful. Over a relatively short period, we could test an infant's sensitivity to luminance contrast, her/his chromatic-achromatic discriminations, and the relative luminances at which the infant "fails" to make these discriminations. In future, the Color/Contrast Cards should prove to be clinically useful for screening younger infants and handicapped children, as well as experimentally useful in providing information about the development of color vision and its underlying mechanisms.

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Introduction

With the advent of a number of new research methods for studying human infants (for a review, see Maurer, 1975), there has been renewed interest in the ontogeny of sensory processes, particularly in the early development of vision. As a result, significant advances have been made in understanding how infants perceive important aspects of their visual environment, such as form, pattern, and contrast. A notable exception, however, has been the study of early color vision in which only the most fundamental questions have been addressed.

However, this paucity of knowledge is not due to a lack of interest. Researchers are interested in examining infants' color vision for a variety of reasons. For example, a physiological psychologist studies early color vision because information about immature neural mechanisms provides insight into the functioning of adult neural mechanisms (e.g., photoreceptors, opponent channels). By studying the mechanisms in their simplest form, researchers are able to trace their development and understand these mechanisms in their mature state (e.g., Gordon and Abramov, 1977). A psychologist interested in perception may examine infants' color vision to better understand adults' perceptual processes (e.g., Hurvich, 1981). Clinicians and others in the medical profession (e.g., Pease and Allen,

1988) are interested in color vision to assist them in detecting early visual abnormalities (e.g., cone deficiences).

Methodological Issues.

Despite numerous practical problems, researchers have managed to utilize three types of responses to assess non-verbal infants' color vision: reflexive, electrophysiological, and behavioral responses. One of the first reflexive measures used to test infants' color vision was the "eye-on-the-neck" reflex (the spontaneous jerking of the head in response to sudden illumination). Peiper (1927), and Trincker and Trincker (1955) used the "eye-on-the-neck reflex" to measure infants' spectral sensitivity. Both studies reported that, at photopic levels, adult and infant spectral sensitivity functions are virtually identical. More recently, researchers have tested infants' sensitivity to chromatic stimuli using ocular reflexes, such as the pupillary response (Young, Clavadetscher, & Teller, 1987), and optokinetic nystagmus (OKN is a reflexive oscillatory movement of the eyes elicited by moving large stripes through the visual field). For example, Anstis, Cavanagh, Maurer, & Lewis (1986) used a complex OKN task and found infants' and adults' spectral sensitivity to be virtually identical.

Other researchers (e.g., Barnet, Lodge, & Armington, 1965; Dobson, 1976; Moskowitz-Cook, 1979) chose to directly measure the nervous system's response to chromatic stimuli by using electrophysiological techniques such as the electroretinogram (ERG) or the visually evoked potential (VEP). For example, Dobson (1976) used VEPs to measure the spectral sensitivity of both 2-month-olds and adults and found that infants were relatively more sensitive than adults in the short-wavelength region of the spectrum.

Behavioral measures have had the longest history in the study of early color vision. Baldwin (1893) assessed his nine-month-old daughter's color preferences by presenting her with colored papers and observing her grasping behavior. He found that she reached most for blues and reds, followed by greens and browns. Grasping was later used, in combination with forced-choice and reinforcement procedures (e.g., Marsden, 1903; Valentine, 1914, respectively) to measure infants' ability to make chromatic discriminations. Although a convenient measure, grasping is not a reliable one because it is a perceptual-motor response which likely relies on more complex neural coordination than is needed to process chromatic information. Therefore, it is difficult to determine whether an infant's failure to grasp for a particular chromatic stimulus is due to her/his inability to grasp or to her/his inability to process chromatic information.

Presently, the most successful and most popular behavioral measures employ infants' visual orienting behaviors, rather than complex motor skills. These include habituation-dishabituation (e.g., Bornstein, 1975; Adams, Maurer, & Davis, 1986), preferential looking (e.g., Fagan, 1974) and forced-choice preferential looking (e.g., Peeples & Teller, 1975; Packer, Hartmann & Teller, 1984). In the habituation-dishabituation paradigm, an infant is presented repeatedly with stimuli that are the same or similar, (e.g., a white light of different luminances) until the infant habituates or "becomes bored" with the stimulus. Once the infant decreases his looking time to a pre-specified criterion, a novel stimulus (e.g., a red light) is displayed and "looking time" is compared to that for the familiar stimulus. If the infant increases his looking time, or dishabituates to the novel stimulus, this is taken as evidence that the infant can discriminate the novel from the familiar stimuli.

In a typical preferential looking (PL) procedure (Fantz, 1958), an infant is presented, over a series of trials, with pairs of stimuli. An adult observer, who is unaware of the position of the stimuli, judges the direction of the infant's first fixation, or the amount of time that the infant spends fixating each stimulus. Currently, the most popular technique is a version of PL called forced-choice preferential looking (or FPL) (Teller, 1979). The subject is presented with a pair of stimuli, one of which matches the background and a second (test) stimulus which differs in some way (e.g., is a different color or pattern). The location of this test stimulus is varied from trial to trial and an observer is unaware of its' position. The observer is forced to choose on which side the test stimulus is located based on the subject's head, eye, and body movements. If the observer's choices are correct for a majority of the trials (e.g., at least 75% of them), it is assumed that the infant can discriminate the test stimulus from the background.

Nonetheless, regardless of these procedural advances, a major methodological problem must be considered in the study of any organism's color vision. This problem is to insure that the subject discriminates among chromatic stimuli on the basis of differences in hue and not on the basis of brightness differences.

<u>The Brightness Problem</u>

Color is defined by three attributes - hue, brightness, and saturation. An adult with normal color vision is capable of using all three of these attributes to discriminate among differently colored objects. However, even without the ability to perceive hue or saturation, a colorblind adult can still use brightness cues to discriminate among most chromatic stimuli. A good example of this is to consider a colorblind person viewing a colored photograph. He/she is easily able to discriminate objects of different "hue" as long as they differ in brightness. Similarly, an infant with immature color vision may be able to discriminate among chromatic stimuli using brightness cues only.

In a first attempt to address the brightness problem, researchers studying infants' color vision have used chromatic stimuli that were matched in brightness by an adult. This is based on the assumption that if an adult could not discriminate chromatic stimuli on the basis of brightness, neither could a baby. However, studies of photopic spectral sensitivity (Dobson, 1976; Moskowitz-Cook, 1979; Peeples & Teller, 1977) imply that infants and adults differ qualitatively in their sensitivity to the luminance of chromatic stimuli. For example, Moskowitz-Cook (1979) used VEPs to obtain spectral sensitivity curves for both infants and adults. She found that although the functions of older infants' (15-22 weeks) were similar to those of adults, the functions of younger infants (3-14 weeks) were slightly elevated (by about 0.5 log units) in the short-wavelength region. These results imply that infants and adults do not respond to the brightness of chromatic stimuli in the same way; therefore, adult brightness matches are inappropriate for studying infants' chromatic vision.

Teller and Bornstein (1987) describe two alternative methods used to minimize brightness cues. These techniques are termed the "unsystematic" and "systematic" variation of luminance. The unsystematic variation of luminance is uses a wide range of luminances centered around an adult brightness match. For example, if one were testing the discrimination of red from white, the luminance of the white would be varied over a broad range, centered around the luminance at which an adult would perceive the red and white as equal. Varying the luminance provides the baby with many different examples of white and therefore, reduces the likelihood that the infant will discriminate the red from the white solely on the basis of any particular brightness difference. Therefore, if an infant can discriminate the two stimuli on the basis of wavelength, one assumes that he will respond differentially to the red and the white(s), despite differences in brightness or not. On the other hand, if the infant fails to respond differentially, we conclude that the infant cannot discriminate the red from the white on the basis of wavelength alone. Bornstein (1975) and Adams, Maurer, and Davis (1986) used the unsystematic variation of luminance in combination with a habituation-dishabituation paradigm to test infants' color vision. Adams et al. presented newborns with a series of white squares which, from trial to trial, varied in luminance. Once the infant had habituated, or became "bored", the infant was shown either a 630 nm red or a 480 nm blue of mid-range luminance and another white square of a novel luminance. The infants recovered (i.e., looked longer) to the red but not to the blue. Because there was not a significant difference in the looking time between the white square and the blue square, Adams et al. reasoned that newborns could not make the discrimination on the basis of wavelength information. However, the authors did note that this procedure also has limitations. Negative results may be due to the fact that infants have to both recognize and remember the stimuli presented on previous trials for successful discrimination. Therefore, habituation not only requires the ability to discriminate the stimuli, but also requires memory which may result in an underestimate of the infant's color vision. Moreover, an habituation paradigm assumes that the organism possesses the neural mechanisms necessary for habituation, an assumption that has been questioned with regard to young infants (Banks and Salapatek, 1983).

The systematic variation of luminance procedure developed by Teller and her colleagues (Peeples and Teller, 1975) is a more refined method than the unsystematic variation of luminance. The systematic version consists of two phases: In the first (luminance contrast) phase, the infant views a large achromatic background that contains an achromatic test patch, the luminance of which varies from trial to trial. The index of an infant's sensitivity to achromatic contrast is the smallest luminance difference between the patch and the background that he/she appears to discriminate. In the second (chromatic) phase, the achromatic test patch is replaced by a chromatic test patch (e.g., a 650 nm red patch) which also varies in luminance. The luminances of the chromatic patch are centered around and include the adult brightness match, and range broadly enough to insure that an infant's brightness match would be included. The spacing between luminances within the range (i.e., the step size) is set by the smallest difference in luminance that the infant can detect in the first phase. Therefore, it is assumed that the infant will be presented with at least one chromatic patch that appears to match the background in brightness. Thus, if an infant's performance falls to chance for even one luminance of the chromatic patch, this implies that the infant is incapable of detecting the wavelength information in that particular chromatic stimulus. On the other hand, if the infant discriminates the chromatic patch at all relative luminances (including, presumably, at least one pair that does not differ in brightness), this implies that the infant can discriminate the chromatic stimulus from white on the basis of wavelength information.

Results From Studies Using Systematic and Unsystematic Variation of Luminance

Investigators have used both systematic and unsystematic variation of luminance to successfully evaluate the early development of human color vision. For example, Hamer, Alexander, and Teller (1982) and Packer, Hartmann, and Teller (1984) have shown that unlike adult protanopes and deuteranopes, 2- and 3-month-olds are able to make Rayleigh discriminations (i.e., discriminations between pairs of wavelengths greater than 545 nm). Also, in a related study, Varner, Cook, Schneck, McDonald, and Teller (1985) found that, unlike adult tritanopes, most 2-month-olds could discriminate a tritan pair, specifically, a 416 nm blue from a 547 nm green. In tests of chromatic-achromatic discriminations, Teller, Peeples, and Sekel (1978) used FPL and found that 2-month-olds were able to discriminate many wavelengths from white. However, 2-month-olds also showed several limitations in their color vision: they failed to discriminate from white, 538 nm green, 561 nm yellow-green, and mid-purple.

The color vision of infants less than 2 months is even more limited. For example, most 1-month-olds fail to make Rayleigh and tritan discriminations (and presumably, like older infants, would fail the white/yellow-green and the white/mid-purple discriminations) (Hamer et al., 1982; Varner et al., 1985). Moreover, Packer et al. (1984) found that even those few 1-month-olds who were able to make successful Rayleigh discriminations required large (8 deg.) stimuli. Newborns show additional limitations; while they successfully discriminate from white, 630, 640 and 650 nm red, 575 and 585 nm yellow, and 540 and 550 nm green, they fail to discriminate from white, 572 nm yellow-green, and 470, 475 and 480 nm blue (Adams and Courage, submitted; Adams, Maurer, & Cashin, 1985; Adams et al., 1986) until approximately 1 month of age (Maurer & Adams, 1987). In addition, Adams (1989) demonstrated that newborns are capable of making a Rayleigh discrimination, but this ability is limited to stimuli that are very large (at least 16 deg.) and of wide spectral separation (e.g., 545 nm green vs 650 nm red). Collectively, these studies indicate that although newborns possess at least some rudimentary color vision, it improves significantly over the first three months.

Further Limitations in Existing Measures of Color Vision and a Proposed Methodological Remedy

Although these procedures appear to be successful in minimizing brightness cues, there are still limitations and problems. For example, the habituation-dishabituation method relies on group estimates of luminance sensitivity and may underestimate an individual infant's sensitivity. Therefore, such an infant may make an apparent chromatic-achromatic discrimination on the basis of brightness cues, rather than on wavelength information. Although the preferential-looking procedure uses estimates of individual infants' luminance sensitivity to test chromatic-achromatic discriminations, it is very time-consuming and requires multiple sessions; thus, many infants become fussy or sleepy, or fail to return for further sessions. Both of these problems, along with the unavailability of simple, standardized equipment, limit the interpretive and clinical value of these techniques. In other words, an assessment of an individual infant's color vision cannot be determined within one short testing session. This is important if a test is to have predictive value and wide-spread use.

Similar problems are faced by researchers attempting to study other important visual functions. In a recent and promising attempt to produce a method to overcome these problems, Teller and her colleagues (McDonald, Dobson, Sebris, Baitch, Varner, & Teller, 1985) designed a set of "Acuity Cards" which allow a quick, yet accurate, assessment of visual acuity in infants even a few hours old. The procedure, which is a modification of FPL, consists of presenting an infant with a series of large gray cards that, on either the right or left side of a central peephole, contain a set of black and white stripes (gratings) that typically vary in spatial frequency from 0.2 to 40 cycles/degree. The space average luminance of the gratings is equal to the luminance of the cards' backgrounds. An observer, who is blind to the location of the grating, watches the baby through the peephole and judges the location of the stripes by observing the infant's head and eye movements. To test her/his assumptions, the observer can quickly rotate each card to position the grating on either side. It is assumed that if the baby is capable of detecting the stripes of a particular spatial frequency, he/she will consistently orient towards them. If he/she does not see them, the entire card will appear gray due to the "fusion" of the stripes into the background. In this case, the infant will either continue to stare at the center of the card or look randomly from side to side.

The procedure begins with large stripes (low spatial frequency) and progresses with increasingly smaller stripes. The point at which the observer cannot judge the location of the stripes is an estimate of the infant's visual acuity. This acuity card procedure can usually be completed within approximately 5 minutes as compared to the traditional FPL procedure which usually requires upwards of 1 hour, often across multiple sessions. In addition, the TAC method yields the same estimates as the traditional FPL method (McDonald et al., 1985).

Because the Teller Acuity Cards have proven successful in efficiently assessing infants' visual acuity, a variation of this procedure may be useful in measuring other visual functions. The present study attempts to develop a new test of infants' color vision by employing Teller's version of the FPL procedure, and stimuli constructed with Munsell Hues - a widely known, standardized color system. Also, to best control brightness cues, the procedure incorporates a two-phase systematic variation of luminance (Teller et al., 1978). In the first phase, the infant's sensitivity to luminance contrast is measured using a set of achromatic contrast cards. In the second phase, the cards are altered in order to assess the infant's ability to discriminate chromatic stimuli, representing various spectral regions, from achromatic backgrounds of greater, lesser, and equal luminance. The number of backgrounds needed to evaluate each infant's ability is determined by his/her sensitivity to luminance contrast in phase 1.

Thus, the general purpose of the present study is to design an efficient technique to assess young infants' contrast and color sensitivity. More specifically, the goals are (1) to design a procedure that allows the rapid and simple, yet accurate assessment of infant color vision, (2) to collect sufficient data from individual infants to determine whether the procedure has diagnostic value, (3) to determine the earliest age at which the Color/Contrast Cards can be used, (4) to compare our results with those obtained with more lengthy procedures (e.g., FPL - Teller et al., 1978), and (5) to make statements about the developmental state of early color vision mechanisms (e.g., photoreceptors, opponent channels).

Method

Subjects.

The subjects were 19 female and 16 male 2-month-old infants (M age = 9.20 weeks; s.d. = 0.61 weeks) and 24 female and 11 male 3-month-old infants (M age = 13.09 weeks; s.d. = 0.70 weeks). All infants were at least 38 weeks gestation and at least 2500 grams at birth. An additional 18 infants (11 two-month-olds and 7 three-month-olds) were tested but not included in the sample: 12 (13.6%) because of incomplete data, and 6 (6.8%) because of a procedural error. An infant was designated as incomplete when he/she failed to complete at least the contrast phase and one chromatic condition. Infant fussiness accounted for all incompletions.

Stimuli.

The cards' backgrounds were constructed by mounting 56 cm long x 21.5 cm wide pieces of gray Munsell matte paper onto 1 cm thick stiff board. On each card, two smaller 12.5 cm long x 7.5 cm wide Munsell patches were mounted on thinner (1/4 cm) board and attached to the backgrounds with Velcro. The nearest edge of each smaller patch was located

7.5 cm to the left and the right of a 1 cm central peephole. To prevent damage, both the backgrounds and the patches were laminated.

The Munsell color notation system identifies color in terms of three attributes - hue (wavelength), value (brightness/luminance), and chroma (saturation). The scale defining each of these attributes consists of numbers which represent, to adults, steps (increments or decrements) of equal spacing. These scales allow precise identification and description of color under standard illumination and viewing conditions.

The hue notation consists of both hue initials (e.g., B for blue) for the ten major hue families, and hue numerals (e.g., 10B for deep blue) for more precise specification of spectral location. The value notation indicates the brightness of a color in relation to a neutral gray scale, which extends from absolute black (symbolized by N 0/) to absolute white (symbolized by N 10/). The chroma notation indicates the amount of saturation of a given hue ranging from /1 (very desaturated) to /16 (extremely saturated).

In the contrast phase of this experiment, we used achromatic (gray) patches which are designated in the Munsell system only by value and not by chroma or hue. The gray patches had values (luminances) ranging from N 2/ (1.09 log cd/m^2) to N 9.5/ (1.86 log cd/m^2) [see Table 1 for other values and luminances], and were mounted on a mid-gray (N 5/) background (1.36 log cd/m2).

Insert Table 1 about here

In the chromatic phase, the achromatic backgrounds had values (luminances) ranging from N 2/ (1.09 log units) to N 9.5/ (1.86 l.u.) and the chromatic patches had values of 4/ (1.33 l.u.), 5/ (1.37 l.u), 6/ (1.49 l.u.), and 8/ (1.67 l.u.), for red, blue, green, and yellow, respectively[1]. All of the chromatic patches were equally saturated (/12). These chromatic stimuli were chosen because they had spectral characteristics similar to those used in the only other study of 2-month-olds' chromatic-achromatic discriminations using a FPL method (Teller et al., 1978).

The luminances of the stimuli were measured _in situ_ with a Minolta Chroma Meter CL-100 and a Macbeth Illuminometer. Stimuli were illuminated under diffuse white light with CIE chromaticity _x_ and _y_ coordinates of 0.31 and 0.31, respectively. This correlates with a color temperature of approximately 7000 deg. K. (CIE Illuminant C) the illuminant for which these Munsell hues were standardized. Under these conditions, the dominant wavelengths of the chromatic patches were determined to be 660 nm for the red, 520 nm for the green, 475 nm for the blue, and 580 nm for the yellow. The chromatic stimuli had chromaticity $\underline{x}$ and $\underline{y}$ coordinates of 0.50, 0.29 for red, 0.20, 0.20 for blue, 0.26, 0.47 for green, and 0.47, 0.46 for yellow. Excitation purity values were calculated from the chromaticity coordinates to be 0.43 for red, 0.57 for blue, 0.30 for green, and 0.81 for yellow.

Procedure.

We used a version of forced-choice preferential looking (FPL) most similar to that used with the Teller Acuity Cards, a modified staircase procedure to determine threshold, and a systematic variation of luminance to control for brightness cues. In our version, the infant sits on the mother's lap and an observer holds the cards approximately 45 cm from the infant's eyes. At 45 cm, the test patches subtend a rectangular field of 9.5 x 16 deg. Because a second experimenter selects and changes the cards, the observer is always "blind" to the characteristics of the stimuli (e.g., location, luminance, and/or hue, of the test patch).

In general, our version of FPL proceeds as follows. The experimenter places two patches on each card - one that matches the background luminance, and a second test patch that differs from the achromatic background, either in luminance (the contrast phase) or in chroma and/or luminance (the chromatic phase). The experimenter then carefully passes the card to the observer so that the observer cannot see the stimuli to be presented. The observer holds the card in front of the infant, and views her/him through a central peephole in the card. The observer rotates the card several times to alternate the position of the test patch and then, either judges the position of the test patch (based on the head and eye movements of the infant), or concludes that the infant cannot discriminate the patch from the background.

During the contrast phase of the experiment, the infant's luminance sensitivity is measured (see Appendix A for a simulation of the entire procedure). First, the observer shows the infant a card with the largest luminance difference (greatest contrast) between the achromatic test patch and the achromatic background - either the largest increment (towards white) or largest decrement (towards black). If the observer correctly judges the side where the test patch is located, the contrast is decreased for the next card. To increase observer uncertainty, the amount of contrast on this second card varies across babies. If the observer again correctly judges that the infant is able to detect this luminance difference, still a smaller difference is tested. However, if the observer judges that the infant cannot make the discrimination, a larger difference is tested (if one exists). The smallest luminance difference that the infant can discriminate is a measure of his/her contrast sensitivity. This staircase procedure is then repeated until we have determined the infant's sensitivity to both luminance increments and decrements.

In the chromatic phase, we use the information from the infant's performance in the contrast phase to test his/her discrimination of chromatic patches from gray backgrounds. For each infant, the smallest luminance difference detected during the contrast phase determines the step size (i.e., the size of the luminance increment or decrement between adjacent cards), and thus, the number of backgrounds that are required to test each wavelength during the chromatic phase. In other words, the better the infants' luminance sensitivity, the greater the number of cards that need to be used during the chromatic phase (see the simulation in Appendix A). The selection of the appropriate step size assures that the infant will be presented with at least one card in which he/she cannot discriminate the chromatic test patch from the gray background on the basis of brightness. Therefore, if the infant can discriminate the chromatic patch from the background for <u>all</u> combinations, including at least one in which the patch and background match in brightness, he/she is probably capable of making that discrimination on the basis of wavelength information. Conversely, if the infant fails to discriminate the chromatic patch from the background for one or more combinations, then we assume that he/she is unable to make the discrimination on the basis of wavelength information.

The order of presentation for the different background luminances used during the testing of each chromatic stimulus was counterbalanced across babies, as is the order of the four chromatic stimuli. The procedure continued until testing with all four chromatic stimuli was completed, or until the infant became uncooperative.

Results

The procedure was successful. 83% of 2-month-olds and 87.5% of 3-month-olds completed the contrast phase and at least one of the chromatic stimuli in an average time of 22.15 minutes (range = 14.11 - 33.45) and 19.18 minutes (range = 12.12 - 28.17), respectively. Of these infants, 37% of 2-month-olds and 34% of 3-month-olds completed all four chromatic stimuli in an average time of 20.92 minutes (range = 13.50 - 31.11) and 20.85 minutes (range = 14.54 - 26.39), respectively.

Discrimination of Luminance Contrast.

Figure 1 displays the cumulative distribution functions for the smallest luminance increments and decrements detected by 2- and 3-month-old infants. A cumulative distribution was chosen because its shape is most

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Insert Figure 1 about here

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comparable to those derived from other psychophysical measures (e.g., FPL, Teller et al., 1979). As Figure 1 shows, both 2- and 3-month-olds appear more sensitive to luminance decrements than to increments. This is indicated by a more steeply rising slope and by a smaller mean for decrements than for increments (means indicated by arrows on Figure 1). On the average, 2-month-olds detected a decrement of 0.20 l.u. (8% Michelson contrast[2]) and a increment of 0.26 l.u. (9% contrast). For 3-month-olds, the mean luminance decrement and increment detected was 0.19 l.u. (7.5% contrast) and 0.30 l.u. (10% contrast), respectively. Wilcoxon tests for matched samples confirm that both 2-month-olds ($\underline{Z}$ = 3.41; $\underline{p} < 0.05$) and 3-month-olds ($\underline{Z}$ = 3.45; $\underline{p} < 0.05$) are significantly better at detecting luminance decrements than increments.

Discrimination of Chromatic Patches From Achromatic Backgrounds.

For an infant to show evidence of discriminating a chromatic patch from gray backgrounds on the basis of wavelength information, the observer had to correctly guess the location of the chromatic patch for all relative luminances (i.e., all the patch/background combinations).

If the observer was not able to make a decision as to the location of a chromatic patch for one or more of the relative luminances, it was concluded that the infant could not discriminate that particular chromatic stimulus from gray, at least not on the basis of wavelength information. Figure 2 shows the percentage of infants who, for each chromatic stimulus, appear to show this pattern of

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Insert Figure 2 about here

"failure". This occured when 12 of 22 (55%) 2-month-olds were tested with yellow, 8 of 23 (35%) were tested with green, 5 of 25 (20%) were tested with red, and 5% (only 1 of 21 subjects) were tested with blue. In contrast, virtually none of the 3-month-olds show this pattern of "failure" with any of the chromatic stimuli. However, in order to state that 2-month-olds, **as a group**, can discriminate a particular chromatic stimulus from gray, significantly more than 50% of the infants had to show evidence of making that discrimination. Chi-square analyses revealed that 2-month-olds showed evidence of discriminating the 660 nm red [$\chi^2(1,\underline{n}=25) = 9.00$, $\underline{p} < .01$] and the 475 nm blue [$\chi^2(1,\underline{n}=21) = 17.19$, $\underline{p} < .001$] patches from gray but not the 520 nm green [$\chi^2(1,\underline{n}=23) = 2.13$, $\underline{p} > .05$] or the 580 nm yellow [$\chi^2(1,\underline{n}=22) = 0.18$, $\underline{p} > .05$] patches from gray. In contrast, chi-square analyses revealed that 3-month-olds showed evidence of discriminating all four chromatic stimuli from gray. There were no sex differences in performance on any of the measures.

With this procedure, it is also possible to determine the relative luminance(s) at which an infant "fails" to discriminate a chromatic patch from an achromatic background, and compare these with the typical adult brightness match. Figure 3 shows the distributions of

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Insert Figure 3 about here

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relative luminances at which 2-month-olds appear to "fail" to discriminate the red, yellow, and green patches from the achromatic backgrounds. For each of the red, yellow, and green patches, these failures appear to cluster around the typical adult brightness match. The differences in luminance between the adult match and the infants' "failures" were all within +/- 0.18 l.u. for the red (M = -0.06 l.u.), +/- 0.20 l.u. for the yellow (M = +0.05 l.u.) and within +/- 0.22 l.u. for the green (M = -0.13 l.u.).

Developmental Changes.

Figure 1 illustrates that 2- and 3-month-olds are very similar in their ability to detect luminance differences. Moreover, Mann-Whitney U tests for independent samples confirmed statistically that there are no significant differences between 2- and 3-month-olds' ability to detect either luminance increments ($\underline{U} = 0.996$; $\underline{p} > .05$) or decrements ($\underline{U} = 0.636$; $\underline{p} > .05$).

To determine whether there are significant changes between 2- and 3-months-olds' ability to discriminate each of the chromatic stimuli from gray, we performed chi-square tests (see Figure 4). The results of these analyses indicate that between 2- and 3-months, there were

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Insert Figure 4 about here

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significant improvements in the infants' ability to discriminate the green [$\chi^2(1,\underline{N}=43) = 8.54$; $\underline{p} < .005$] and the yellow [$\chi^2(1,\underline{N}=43) = 15.89$; $\underline{p} < .001$] from gray. Because 2-month-olds had already shown evidence of discriminating red and blue, as expected, there were no additional improvements between 2 and 3 months for either the red [$\chi^2(1,\underline{N}=47) = 3.84$; $\underline{p} > .05$] or the blue [$\chi^2(1,\underline{N}=45) = 1.15$; $\underline{p} > .05$].

Discussion

The Color/Contrast Cards proved to be an efficient procedure for assessing the contrast and color vision of 2- and 3-month-old infants. In a relatively short session we obtained information about an infant's sensitivity to luminance contrast, his/her ability to discriminate chromatic from achromatic stimuli, and the relative luminances at which the infant "fails" to make a chromatic-achromatic discrimination. We found that 2- and 3-month-olds are sensitive to luminance differences, especially to luminance decrements. Most 2-month-olds are able to discriminate both red and blue from gray at all luminances, but many fail to discriminate yellow and green from gray at relative luminances close to the adult brightness match. In contrast, 3-month-olds discriminate all four chromatic stimuli from gray.

Evaluation of the Color/Contrast Card Procedure.

The main purpose of this experiment was to design a rapid and accurate procedure to assess an infant's color vision. Although the procedure is not as efficient as that used with the Teller Acuity Cards, it still requires much less time and provides more information than alternative color vision procedures such as Teller's version of FPL (e.g., Varner et al., 1985) and habituation-dishabituation (e.g., Adams, 1989). Our Color/Contrast Cards allow one to measure in a single session, not only an infant's sensitivity to luminance contrast, but also his/her ability to discriminate several chromatic stimuli from gray. Although 36% of the infants completed testing with **all** four chromatic stimuli in a single session (and 85% with at least one stimulus), there are a number of ways to improve the procedure. First, if we enhance the salience of the stimuli, they should capture and hold the infant's attention more easily, and thus hasten the procedure. This could be accomplished by increasing stimulus size and saturation, and/or by using patterned stimuli such as gratings or checkerboards composed of chromatic elements. A second improvement to shorten the procedure would be to restrict the range of background luminances used in the chromatic phase. This is justified by the fact that none of the infants "failed" the chromatic-achromatic discriminations at luminance differences greater than plus or minus 0.22 log units. Thus, the *entire* range of background luminances could be reduced from 0.8 l.u. (+ or - 0.4 l.u.) to 0.5 l.u. (+ or - 0.25 l.u.). A third improvement would be to include "catch" trials both within the contrast and the chromatic phases. In this case, the observer would present the infant with a card containing two achromatic patches that have the same luminance as the background. The observer would also be unaware at which point these "catch" trials would occur. This modification should improve the objectivity of the procedure in two ways. First, it will better insure that the observer is certain of the location of a test patch before making a decision. Secondly, the inclusion of "blank" trials will provide the observer with ongoing examples of the infant's behavior when presented with an "indiscriminable" pair of stimuli.

Discrimination of Luminance Contrast.

The finding that infants are better at detecting decrements than increments in luminance is consistent with previous studies of infants' sensitivity to contrast (Peeples and Teller, 1975; Teller, Peeples, and Sekel, 1978). For example, Teller et al. presented 2-month-olds with an achromatic bar embedded in a gray screen and found that infants were better at detecting smaller differences in luminance when the bar was dimmer than when it was brighter than the screen. In addition, the 2-month-olds in Teller et al.'s study showed nearly identical mean performance for luminance increments (10%) and decrements (8%) as did the 2-month-olds in the present study (9% for increments, 8% for decrements). Thus, although infants can discriminate relatively small luminance differences, they are much less sensitive than adults who, under ideal conditions, are able to detect luminance differences smaller than 0.3% (Campbell

& Robson, 1968). However, like infants, adults are better at detecting luminance decrements than increments (R.D. Hamer, personal communication, May 4, 1989). It is not known why humans display this pattern of asymmetry. However, the fact that both infants and adults show this asymmetry, implies that the mechanisms mediating contrast detection (e.g., B/W opponent channels, lateral inhibition) may be similar in infants and adults, but that the infants' mechanisms are much weaker. In other words, the mechanisms mediating infants' detection of contrast may be quantitatively, rather than qualitatively, different from those of adults'. Finally, the present finding that 2- and 3-month-olds do not differ in their sensitivity to luminance contrast complements previous findings. These results show that, for stimuli of very low spatial frequency (like those used in the present study), contrast sensitivity does not improve between 2 and 3 months (see Atkinson, Braddick, and Moar, 1977; Banks and Salapatek, 1978).

Discrimination of Chromatic Patches From Achromatic Backgrounds.

Although 3-month-olds showed evidence of discriminating all four chromatic stimuli from the achromatic backgrounds, 2-month-olds showed a different pattern of results. First, we found that 2-month-olds, like 3-month-olds, appear to discriminate 660 nm red and 475 nm blue from gray. This result complements earlier reports that 2-month-olds can discriminate a 633 nm red and a 486 nm blue from gray (e.g., Peeples, Teller, & Sekel, 1978). Studies of even younger infants (Adams et al., 1986, experiment 2; Maurer & Adams, 1987a, experiment 2; Adams, 1989) have found that newborns are able to discriminate 630, 640, and 650 nm red from gray and, after 1 month, can discriminate 475 nm blue from gray.

Because 2-month-olds are able to discriminate some chromatic stimuli from achromatic stimuli on the basis of wavelength, they must possess at least dichromatic color vision (i.e., possess two functioning receptor types with different spectral sensitivities). Assuming these receptors are similar to the adult receptors [i.e., rods, or one of the three cone types - short-wavelength-sensitive (SWS), mid-wavelength-sensitive (MWS), or long-wavelength-sensitive (LWS) cones], it is likely that 2-month-olds possess either a rod/cone receptor combination or a cone/cone combination. The latter combination is more likely because both human psychophysical evidence and infrahuman physiological evidence (see Hurvich, 1981) have yet to show that rods and cones combine their input at post-receptoral levels (i.e., within an opponent channel) .

The finding that many 2-month-olds fail to discriminate a 580 nm yellow and a 520 nm green patch from an achromatic background is also consistent with Teller et al.'s (1978) results that 2-month-olds may have a neutral zone (a band of wavelengths indiscriminable from white) in the green and yellow spectral regions. In addition, Teller et al.'s subjects, like our's, failed to discriminate green and yellow from an achromatic background at relative luminances near the adult brightness match (all differences < 0.25 l.u.). Younger infants also appear to reveal a neutral zone in the yellow-green region. Adams (submitted) used the habituation procedure to test newborns' ability to discriminate 16 deg. 565 and 572 nm yellow-green squares from white and found that newborns did not show evidence of making either discrimination.

There are three possible types of explanation to account for the failure of 2-month-old infants to discriminate broadband 520 nm green and 580 nm yellow from gray; those which are based on 1) receptoral immaturities, 2) post-receptoral/neural immaturities, or 3) motivational factors. The most obvious receptoral explanation is that young infants lack one of the three cone types, and thus have dichromatic color vision. Most classical adult dichromats possess at least one neutral zone in the spectrum. For protanopes (those presumed to be lacking the LWS cones), this zone is a small band of wavelengths centered at about 496 nm; for deuteranopes (those lacking the MWS cones), at about 496 nm; and for tritanopes (those lacking the SWS cones), at about 575 nm (Hurvich, 1981). In the present study, 2-month-olds fail to discriminate a chromatic stimulus (580 nm yellow) that is very close to the predicted tritanopic neutral point and a second (520 nm green) at a spectral location not predicted by any of the classical dichromacies. Thus, from the "missing cone" perspective, the best explanation for these results and those of Teller et al. (1978) is that 2-month-olds may be tritanope-like dichromats, possibly with a broader neutral zone. Moreover, in a previous attempt to isolate SWS cones in infants, Pulos, Teller, and Buck (1980) used chromatic adaptation, a technique commonly used to isolate SWS cones in adults. This procedure revealed that 3-month-olds, but not 2-month-olds, appear to possess functional SWS cones. However, in a more recent study, Varner et al., (1985) found that 2-month-olds are capable of making tritan discriminations, a result suggesting that 2-month-olds possess functional SWS cones.[3] In addition, Volbrecht and Werner (1986) report electrophysiological evidence suggesting the presence of SWS cones in 1-month-old infants. However, due to great methodological differences between the studies of Varner et al., Pulos et al., Volbrecht and Werner, and the present study, whether or not 2-month-olds possess functional SWS mechanisms and whether this is an explanation as to why 2-month-olds fail to discriminate broadband green and yellow from white is still uncertain.

Another possible explanation based on receptoral factors is that 2-month-olds possess all three types of cone but that at least one of these receptors is sparse or poorly developed. The rationale for this explanation stems from anatomical and behavioral studies of other subject populations. For example, the density of peripheral cones in adults decreases with increasing eccentricity (Curcio, Sloan, Packer, Hendrickson, and Kalina, 1987). As a result, adults using their peripheral vision require large targets to successfully discriminate chromatic from achromatic stimuli, especially when those targets are located at greater eccentricities (Gordon and Abramov, 1977). Similarly, cats have a relatively low retinal cone density (Steinberg, Reid, and Lacy, 1973) and also require large stimuli to make chromatic discriminations (Loop, Bruce, and Petuchowski, 1979). Recent evidence shows that the density of human retinal cones is not adultlike until at least 6 months after birth (Abramov, Gordon, Hendrickson, Hainline, Dobson and LaBossiere, 1982; Yuodelis and Hendrickson, 1986). Therefore, one would expect that 2-month-olds, like newborns (Adams, Maurer, and Cashin, submitted), may also require large stimuli to make successful chromatic-achromatic discriminations, at least for chromatic stimuli in some spectral regions (e.g., the yellow and green regions). Future studies designed to examine 2-month-olds' discriminations of achromatic from chromatic stimuli of varying size (e.g., with yellow and green patches larger than those used in the present study) may help to evaluate the explanation that 2-month-olds' color vision limitations are based on sparce or immature cones.

Additional support for the weak cone explanation is provided by examining results from studies of adult saturation discrimination (for a review, see Hsia and Graham, 1966). For adults, the yellow-green region appears the least saturated (i.e., most like white) (Boynton, 1979). If 2-month-olds have weak or poorly developed cones, the entire spectrum will appear desaturated (Adams and Courage, submitted), especially the yellow-green region. Therefore, the yellow and green patches used in the present study may have appeared very desaturated to the infants, making the patches less discriminable from the gray background. To further evaluate this explanation, future studies are needed which examine 2-month-olds' ability to discriminate chromatic patches of varying saturation from an achromatic background.

An alternative explanation to account for infants' apparent discrimination failures is one based on a post-receptoral (or neural) limitation. It is now well established that, following initial processing by the photoreceptors, chromatic and luminance information is processed within the opponent channels (Hurvich, 1981). Hurvich argues that adults possess three opponent channels: a luminance (or B/W) channel composed of the weighted sum of LWS and MWS outputs, a R/G channel composed of the weighted difference of LWS and MWS cone outputs, and a B/Y channel composed of the weighted difference between SWS cones and the sum of the LWS and MWS cone outputs. Infants may have functional cones but their apparently weak color vision may be caused by either a dysfuntional or absent opponent channel, most likely the B/Y channel. However, even this explanation is unlikely: the neutral zones predicted for an adult with a dysfunctional B/Y channel would fall around 475 nm and 575 nm (Porkorny, Smith, Verriest, & Pinckers, 1979). This prediction is made because, at these wavelengths, the R/G channel shows little, or no, activity (see Figure 5).

Insert Figure 5 about here

In the present study, 2-month-olds display only one of these neutral zones (575 nm). Thus, an explanation based on a dysfunctional B/Y channel is insufficient to fully account for their failure to discriminate 520 nm green and 580 nm yellow from gray.

Another post-receptoral explanation is one based on immature receptive fields. Hamer et al. (1982) suggest that infant color vision is analagous to adult **peripheral** color vision. Adults may require increasingly large targets with greater eccentricities to successfully discriminate chromatic from achromatic stimuli, not only because of a receptoral limitation due a paucity of cones, but also because of a neural convergence problem due to large receptive fields. Similarly, young infants may fail to discriminate certain chromatic stimuli (e.g., green and yellow) from achromatic stimuli because of large receptive fields at higher levels of the infants' visual system. Large summation areas would cause small stimuli to be fused with their surrounds, resulting in a degradation of the wavelength information received from the receptors. However, further studies are needed to determine whether the large stimulus requirement is due to limitations at either (or both) the receptoral and/or neural level(s).

A final neurally based explanation is that 2-month-olds' color vision resembles that of an adult who has an acquired color deficiency. For example, one possibility may be a Type III B-Y deficiency (Pokorny et al., 1979). These patients possess a broad neutral zone that includes the yellow-green region. This deficiency is most prevalent amongst elderly people, usually because of degeneration of an important visual structure, such as the optic nerve, and/or the visual cortex. With infants, however, the color deficiency may be due to an immature structure (see Banks and Salapatek, 1983) rather than a degenerated or damaged structure. For example, anatomical studies have shown that the development of the human visual cortex is not complete until about 6 months of age (Conel, 1939-1963). Recent evidence shows that, at least in higher primates, several layers of the primary visual cortex (e.g., layers 4C-beta, 2, and 3) are essential in the processing of chromatic information (Livingston and Hubel, 1988).

Finally, a third type of explanation is one of general "motivational" factors. Young infants may be able to discriminate yellow and green from gray, but these chromatic stimuli may be no more interesting or more preferred than the achromatic background. For example, Bornstein (1975) tested both 4-month-old infants' and adults' color preferences and found that wavelengths in the green to green-yellow region were relatively non-preferred for both infants and adults (cf. Adams, 1987b). If this is true for 2-month-old infants, their motivation to look at the green or yellow patch may be no greater than that for the gray background.

Unfortunately, the present study does not allow us to determine definitively which explantion(s) is(are) the most accurate in explaining why 2-month-old infants succeed in discriminating 660 nm red and 475 nm blue from gray but fail to discriminate 580 nm yellow and 520 nm green from gray. However, on balance, the evidence does **not** point to the absence of a specific color vision mechanism. This is because 2-month-olds show at least a rudimentary ability to perform successful luminance, Rayleigh, and tritan discriminations and do not show neutral points in all the spectral locations predicted for subjects who lack an opponent channel. This implies that 2-month-olds possess three functional cone types and three neural pathways capable of preserving receptoral information[3] (see Varner et al., 1985). Rather, it is more likely that these mechanisms are present but are very weak and/or immature. Theoretically, an adult with weak color vision mechanisms would, like young infants, be able to detect wavelength information only with relatively large stimulus sizes (Packer et al., 1984), be able to make only very broad chromatic discriminations (Clavadestcher, Brown, Ankrum, and Teller, 1988), and show a selective loss of chromatic-achromatic discrimination in the mid-spectral region (present study).

In summary, the Color/Contrast Cards appear to hold much promise as a procedure for testing an individual infant's ability to discriminate among stimuli differing in contrast and/or chromatic characteristics. The cards have already proven to be an improvement over other experimental procedures because of their quickness, portability, and potential for individual assessment. Further modifications of the cards to assess chromatic-achromatic discriminations, as well as saturation and chromatic discriminations (e.g., Rayleigh and tritan discriminations) should improve both the clinical and experimental usefulness of the Color/Contrast Cards. For example, the procedure may prove to be a valuable method for screening infants and non-verbal handicapped children for congenital color vision defects, cone deficits, or central nervous system problems. Moreover, any additional modifications of the procedure should help us in the continuing effort to pinpoint the nature of the mechanisms underlying the early development of human color vision.

Table 1

Munsell values and calculated luminances for both achromatic and chromatic Munsell papers.

Paper type	Munsell value	Luminance (log cd/m^2)
Achromatic	2	1.09
	3	1.16
	4	1.28
	4.5	1.33
	5	1.36
	5.5	1.38
	6	1.43
	7	1.60
	8	1.68
	9	1.85
	9.5	1.86
Chromatic	R 4	1.33
	B 5	1.37
	G 6	1.49
	Y 8	1.67

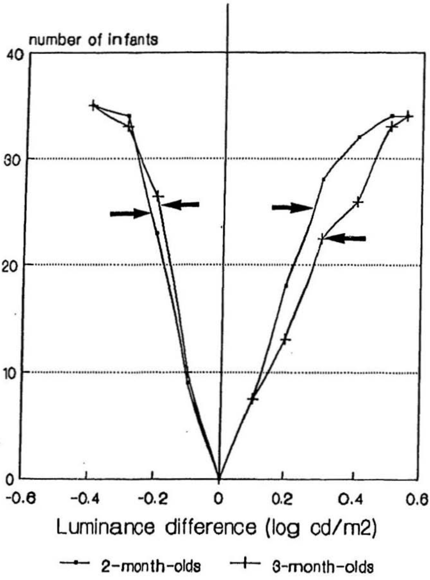

Figure 1. Cumulative Frequency Distribution of 2- and 3-month-olds' Detection of Luminance Differences.

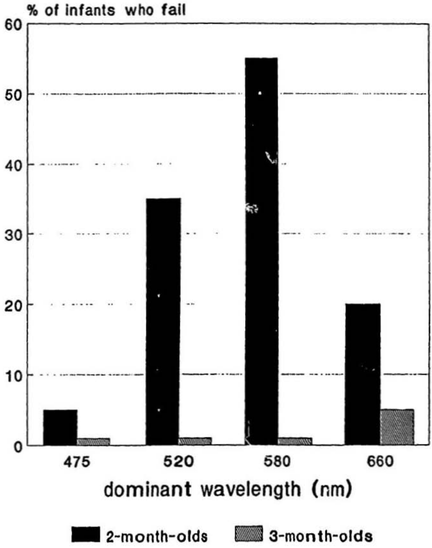

Figure 2. Percentage of infants who fail to discriminate the chromatic patches from a gray background.

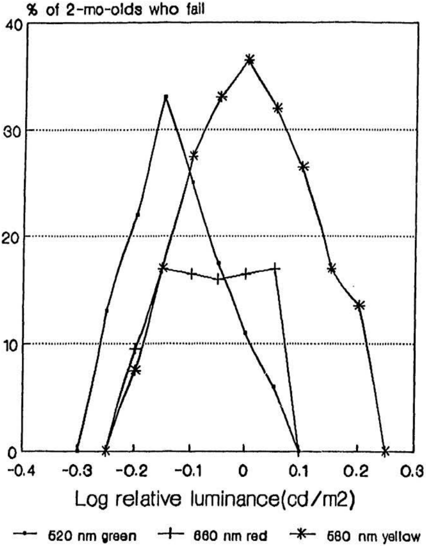

Figure 3. Distribution of relative luminances at which 2-month-olds fail to discriminate chromatic patches from a gray background.

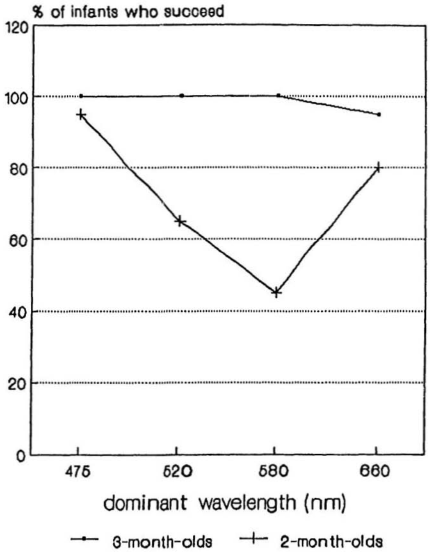

Figure 4. Percentage of 2- and 3-month-olds who discriminate the chromatic patches from a gray background.

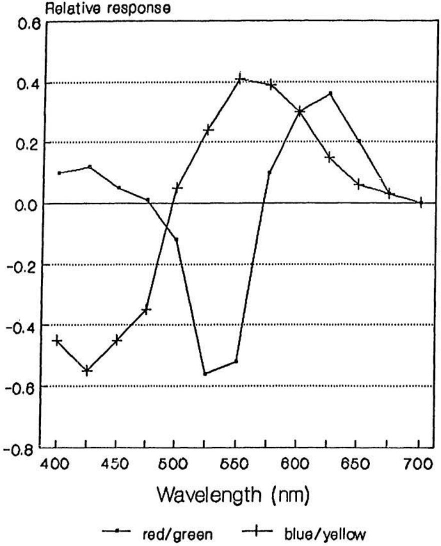

Figure 5. Yellow/Blue and Red/Green response functions across the visible spectrum.

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Footnotes

1) Ideally, all of the chromatic patches would have had Munsell values at, or very near, the centre of the luminance range of the gray backgrounds (i.e., Munsell Value N 5/). Instead, the Values ranged from N 4/ (red) to N 8/ (yellow). This was because at Munsell Values of N 5/, many of the Munsell hues appeared very desaturated or they did not represent the appropriate dominant wavelength. Therefore, in order to use spectrally representative stimuli as well as those with high and equal Munsell Chroma designation (in this case a Chroma of /12), the only option was to select chromatic stimuli with Values from different parts of the Munsell Brightness (luminance) range.

A sceptic might argue that the 2-month-olds failed to discriminate the yellow and the green from the gray backgrounds because the luminances of these chromatic stimuli were higher than those of the blue and the red. Therefore, if the luminance of a chromatic stimulus influences 2-month-olds' ability to discriminate it from the achromatic backgrounds, this may account for the present results. Although I think that this alternative explanation is very unlikely because of the relatively small luminance differences between the different chromatic stimuli, its possibility cannot be dismissed without additional information.

2) Contrast is defined as the difference in luminance between components of a stimulus, expressed as a percentage, and calculated by the formula $[(L1 - L2)/(L1 + L2)] \times 100$ where L refers to the luminance of each component.

2) However, not all researchers in color vision agree that successful wavelength discriminations imply the presence of 3 receptor types and opponent pathways. For example, Hurvich and Jameson (1957) have theorized that there is input from the SWS cones to the R/G channel. If this is so, then successful tritan discriminations may be mediated by this channel rather than by the B/Y channels, and therefore, does not implicate the presence of a B/Y channel.

Appendix A

Simulation of the Color/Contrast Card Procedure: The following 3 pages describe how the procedure might progress with a typical 2-month-old infant. The 3rd page shows the child's actual data sheet and the first two pages explain in detail her performance during each of the phases. The heading "Step" refers to the order of events during the testing (follow numbers on accompanying data sheet). The headings "Background Value" and "Test Patch Value" refer to the Munsell values (luminances) of the backgrounds and patches, respectively. The heading "Discriminates" refers to the performance of the infant in discriminating the test patch from the background

Procedure During the Contrast Phase. During this phase, we measure the infant's sensitivity to luminance contrast. On each trial, the test patch luminance is changed while the background luminance remains constant. From the first four steps, we calculate her sensitivity to luminance increments and from the next four steps, her sensitivity to luminance decrements.

Step	Background value	Test patch value	Discriminates
1	N 5/	N 9.5/	Yes
2	"	7/	No
3	"	8/	Yes

4 Calculate Increment Sensitivity (IS): IS = Smallest Test Patch Value Detected - Background Value. i.e., 8.0 - 5.0 = 3.0

5	N 5/	2/	Yes
6	"	3/	Yes
7	"	4/	No

8 Calculate Decrement Sensitivity (DS): DS = Background Value - Highest Test Patch Value Detected. i.e., 5.0 - 3.0 = 2.0

9 Determine Brightness Threshold (BT): BT = Smallest Difference Failed (Increment or Decrement) i.e., 1.0 (from Step 7).

<u>Procedure During the Chromatic Phase</u>. During this phase, we determine the infant's ability to discriminate four chromatic patches from achromatic backgrounds. The number of backgrounds needed for each infant is determined by the brightness threshold (BT) (from step 9). In this case, her BT was 1.0. requiring that we use the third row of stimuli (5 background/chromatic patches). Note that any potential brightness match between the chromatic patch and the background is never more than 1.0 unit (the BT) away from any of the stimuli used. Thus, for this infant, at least one of the stimuli must not differ in brightness.

Step	Background value	Test patch hue and value	Discriminates
10	N 4/	G 6/	Yes
11	N 8/	"	No
12	N 9.5/	"	Yes
13	N 2/	"	Yes
14	N 6/	"	Yes

15 - 29 Continue with blue, red, and yellow test patches.

30 Infant completed testing with all four chromatic patches.

31 Infant discriminated red and blue from gray.

32 Infant failed to discriminate green and yellow from gray at a Munsell value of N 8/.