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A pseudoisochromatic test of color vision for human infants

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ABSTRACT

Despite the development of experimental methods capable of measuring early human color vision, we still lack a procedure comparable to those used to diagnose the well-identified congenital and acquired color vision anomalies in older children, adults, and clinical patients. In this study, we modified a pseudoisochromatic test to make it more suitable for young infants. Using a forced choice preferential looking procedure, 216 3-to-23-mo-old babies were tested with pseudoisochromatic targets that fell on either a red/green or a blue/yellow dichromatic confusion axis. For comparison, 220 color-normal adults and 22 color-deficient adults were also tested. Results showed that all babies and adults passed the blue/yellow target but many of the younger infants failed the red/green target, likely due to the interaction of the lingering immaturities within the visual system and the small CIE vector distance within the red/green plate. However, older (17–23 mo) infants, color- normal adults and color-defective adults all performed according to expectation. Interestingly, performance on the red/green plate was better among female infants, well exceeding the expected rate of genetic dimorphism between genders. Overall, with some further modification, the test serves as a promising tool for the detection of early color vision anomalies in early human life.

1. Introduction

Both behavioral and electrophysiological experiments show that human color vision appears very immature at birth (Adams, 1998), but develops quite rapidly over the first few months of life (Crognale et al., 1998; Morrone, Fiorentini, & Burr, 1996; Teller, Civan, & Bronson-Castain, 2004; Teller, Pereverzeva, & Zemach, 2006). For instance, by 3 months of age, infants can make a variety of chromatic discriminations, perhaps most importantly, even those that color-deficient adult protanopes, deuteranopes, and tritanopes remain incapable of making. This suggests that infants possess both the functional short-, mid-, and long-wavelength-sensitive cone systems in the retina and the requisite neural opponent channels within the developing central nervous system.

Despite the development of experimental methods capable of evaluating early color vision (Crognale et al., 1998; Teller, Pereverzeva, & Zemach, 2006), these procedures remain either very time consuming or expensive and thus, are not currently a practical option for the clinical assessment of color vision in individual infants and young children. Moreover, even if they were feasible, the existing procedures do not share a common format with any of the standardized diagnostic tests of color vision used currently for older children, thus limiting any direct comparability and clinical interpretability. The lack of an available screening test to detect early color vision anomalies is a shortcoming for several important reasons. First, within the spectrum of visual disorders, the incidence of color vision deficits is relatively high, especially among Caucasian males who show a prevalence rate of about 8% for all forms of color deficiency (Neitz & Neitz, 2001; Sharpe et al., 1999; Ver Hoeve, France, & Bousch, 1996). Given the importance of color in an infant's visual environment, parents, early childhood educators, and pediatricians are very interested in the early detection of color vision anomalies. Second, the occurrence of color deficits can serve as a marker of more serious visual system pathologies such as cone dystrophy, macular degeneration, retinal detachment, glaucoma, CNS tumors and optic nerve lesions, as well as systemic diseases such as diabetes and acute circulatory conditions (Ver Hoeve, France, & Bousch, 1996). Third, color vision deficits can be markers of acute nervous system damage as a result of head trauma, drug overdose, metabolic or pharmacologic imbalances, and exposure to environmental toxic agents (Till et al., 2005).

The current gold standard test for measuring adult red/green color vision is the Nagel anomaloscope which requires the subject

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to simultaneously adjust a red (670 nm) and green (535 nm) mixture against the luminance of a second 589 nm yellow field, in order to achieve a precise color and brightness match between the two stimuli. Although very accurate in its determination of color anomalies, this meticulous process is difficult even for older children (Birch, 1993). Moreover, the required equipment is somewhat cumbersome and is very expensive. A second class of more portable and cheaper alternatives include the reliable and valid Farnsworth 100 hue test and its shortened version, the D15 panel. However, the cognitive demand of arranging even the D15 color chips in a predefined spectral order is a daunting task for preschool children.

Although there have been some valid attempts to develop a diagnostically oriented electrophysiological test (e.g., the spatio-temporal VEP; Crognale et al., 1998), the only form of conventional color vision test to succeed with a wide variety of young children, are those based on the pseudoisochromatic principal. In these tests, a target stimulus (e.g., a number) configured with discs of one hue is embedded within a background array of discs representing a second hue. The critical aspect of any pseudoisochromatic test is that the target and background hues each represent relative chromaticities that fall precisely on one of the isochromatic confusion axes defined by the three forms of adult dichromacy, namely protanopia, deuteranopia, or tritanopia. Thus, dichromats find the targets impossible to discriminate, as do many of those with moderate to severe forms of anomalous trichromacy (Birch, 1993). To help disguise the target and prevent those with true color anomalies from detecting it based on extraneous cues (notably, brightness differences), the discs composing both the target and background hues vary slightly in their respective brightness and saturation. To complete the test, the patient needs only to name, point at, or simply trace the target, responses that even most preschoolers should be capable of performing.

The Ishihara plates are certainly the best known among pseudoisochromatic tests, boasting both the longest clinical history and high sensitivity and specificity (Birch, 1993, 1997). Several studies (Birch & Platts, 1993; Choi & Hwang, 2009) have reported that about 90% of 3-year-olds can successfully trace Ishihara patterns, although other studies report much less success at this age particularly among children who have just entered the third year (Mäntyjärvi, 1991). Other pediatric-oriented variants of the Ishihara plates have emerged, notably the Hardy Rand Rittler, Kojima-Matsubara, Dvorine, Guy's, and Velhagen plates (Birch, 1993; Birch & Platts, 1993; Lee, Cotter, & French, 1997), and these tests have had some success with preschoolers. The most recent of these tests, the Color Vision Testing Made Easy (CVTMET), employs simple child-oriented pseudoisochromatic targets such as a boat, star, or a dog. Results show excellent success with young children (Cotter, Lee, & French, 1999). Moreover, empirical studies with adults tested with both an anomaloscope and the CVTMET show that it achieves 100% specificity and 91% sensitivity, results identical to those for the more cognitively demanding Ishihara plates. Although the CVTMET can be simplified to a forced-choice format, no study has ever demonstrated its success with younger preschoolers or with infants. Interestingly, when modified and utilized with an operant reinforcement paradigm, the CVTMET has been used to successfully evaluate color vision in horses (Hanggi, Ingersoll, & Waggoner, 2007). Therefore, it is possible that this test procedure may be applicable for very young pre-verbal children, although the time required to test an individual patient would likely be prohibitive within a clinical setting.

The only reported pseudoisochromatic color vision test designed specifically for infants is the hand-held Pease and Allen (1988) pseudoisochromatic plates. The target within each plate is a simple 5 cm × 5 cm square array of discs embedded within the left or right side of a larger 30 × 10 cm background. Detection of the target is determined by an observer-based two alternative forced choice preferential looking procedure (Teller, 1979), much like that employed for the highly successful Teller acuity cards, now the clinical standard for assessing visual acuity in infants (McDonald et al., 1985). The Pease and Allen test consists of four plates: (1) a chromatic target/background combination with respective hues that fall on a red/green dichromatic confusion axis, (2) a chromatic plate representing hues that fall on a tritanopic blue/yellow axis, (3) a demonstration plate to present infants with an easily discriminable achromatic target/background, and (4) a plate with no discernible target. This latter "control" card is used to gauge an infant's response when presented with a presumably indiscriminable stimulus. Interestingly, although ultimately designed for non-verbal patients, the Pease and Allen plates were tested previously only with adults and 3- to-6-year-olds, with both groups showing excellent validation statistics against respective diagnostic gold standards. To date, there is still no reported testing of children under the age of 2, the primary intended patient population. In the present investigation, we test across a broad infantile age range, the utility of a modified, more infant-friendly version of the Pease and Allen test, namely plates with larger elements and overall size. For verification purposes, we also evaluated the Pease and Allen plates with color-normal adults as well as those with identified color deficiencies. If successful, such results would be an important step in the development of a tool required for the much needed goal of assessing and diagnosing the presence of early congenital, environmental, and disease-based color vision deficiencies.

2. Methods and materials

2.1. Participants

The participants were 216 healthy 3-to-23-month-old human infants ($\mathbf{M}_{age}$ = 13.6 months; 106 females, 110 males). Almost all of the infants were Caucasian. At birth, infants weighed a minimum of 2500 g, were at least 38 weeks gestation, and have since had no reported neurological abnormalities. In addition, 220 color-normal adults (age = 18–45 yr; 112 female, 108 male) and 22 adults (19 male, 3 female; **M** age = 29 yr) with verified color deficiencies were also tested. All subjects were volunteers and were recruited by direct hospital contact, word of mouth, phone, email, or by campus posters and announcements. The study protocol was approved by the appropriate university committee for ethics in human research, and informed consent was obtained from all participants.

2.2. Stimuli and apparatus

To better adapt it for infants, a modified version of the Pease and Allen (1988) pseudoisochromatic plates was constructed. Importantly, our version used the same Munsell hues as the original test but there were several physical differences. First, in order to save time which is critical in work with infants, the number of plates was reduced from four to three. Pilot work had indicated that the blank or control plate was unnecessary, as infant behavior which indicated non-discrimination of a target (i.e., a non-response) was very clear to experienced observers. In most cases, a non-response (no preference) was represented by several consecutive trials of an infant quickly looking at the card and then looking away, thus failing to reliably fixate on one side of the card at any point during the observation. Second, to enhance the salience of the plates, and to make them more comparable to the stimuli used in other hand-held preferential looking tests [e.g., the Teller acuity cards (McDonald et al., 1985), or the contrast sensitivity cards