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Visual Half-field Development in Children: Detection of Colour-contrast-defined Forms

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Recently we have shown that children's ability to perceive motion-defined forms shows an asymmetry in the left and right visual half-fields which disappears in adulthood. The present study is focused on the visual half-field development of colour contrast vision in the same group of subjects. It was found that colour contrast thresholds for the detection of colour-contrast-defined forms decrease with age to reach adult values around puberty. This improvement of colour contrast vision with age is attributed to the maturation of cortical mechanisms. However, in contrast to a visual half-field asymmetry for motion detection during childhood, no visual half-field differences were observed for colour contrast detection in children. © 1998 Elsevier Science Ltd. All rights reserved.

Maturation Colour contrast Threshold Visual half-field asymmetry

INTRODUCTION

The ability of children to detect borders defined by relative motion is not matured before late childhood. Hollants-Gilhuijs, Ruijter, & Spekreijse (submitted) found that the thresholds for the detection of motion-defined forms are higher in children (age 6–16 years) than in adults, and that the ability of children to detect motion-defined forms matures asymmetrically in the left and right visual half-fields. Since left and right visual half-fields are projected to the right and left hemisphere, respectively, it was concluded that left-hemispheric and right-hemispheric cortices involved in the processing of relative motion have different maturational time tables. Maturation of the cerebral hemispheres may continue until late in adolescence, as was shown in visual evoked potential studies (Ossenblok, Reits, & Spekreijse, 1992; Ossenblok, De Munck, Wieringa, Reits, & Spekreijse, 1994), brain imaging studies (Chiron *et al.*, 1992; Hassink, Hiltbrunner, Müller, & Lütschg, 1992), and neuroanatomical studies (Conel, 1939–1963; Yakovlev & Lecours, 1967).

It is generally believed that processing of visual motion information and colour are mediated by specific combinations of visual cortical regions in humans. Zeki, Watson, Lueck, Friston, Kennard, & Frackowiak (1991), for example, measured patterns of regional cerebral blood flow in subjects watching either a coloured or a moving stimulus, and found that the two conditions activated spatially segregated areas of the extrastriate cortex. This result was reinforced by Gulyás, Heywood, Popplewell, Roland, and Cowey (1994). In addition, a selective inability to perceive colours while the perception of motion is spared has been reported in patients suffering from brain damage to a region of the extrastriate cortex (Heywood, Cowey, & Newcombe, 1991; Rizzo, Nawrot, Blake, & Damasio, 1992; Kennard, Lawden, Morland, & Ruddock, 1995).

The present study aims to investigate the hemispheric development of colour-contrast vision. Using a two-alternative forced-choice procedure we tested children (age 6–16 years) and adults (age 21–31 years) on their ability to detect colour-contrast-defined forms in the left and right visual half-fields.

METHODS

Human subjects

Eighteen children of 6–16 years of age, and 14 adults of 21–31 years of age, participated in the experiment. All subjects were healthy volunteers with no history of neurologic disorders and with normal or corrected-to-normal vision. All subjects showed normal colour discrimination with Ishihara colour plates. The subjects watched the stimulus with the eye of choice.

We restricted our group of adults to those younger than 31 years since the density of lens pigmentation increases sharply with age after the third decade of life (Coren & Girgus, 1972; Wyszecki & Stiles, 1982) which results in increasing detection thresholds in the short-wavelength

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range (Werner & Steele, 1988; Johnson, Adams, Twelker, & Quigg, 1988; Schefrin, Werner, Plach, & Utlaut, 1992).

Apparatus

Stimuli were presented on a colour monitor (Barco, Belgium) driven by a digital stimulus generator (Venus 1020, Neuroscientific) with a resolution of 256 × 256 pixels and a frame rate of 119.73 Hz. The screen with a mean luminance of 30 cd/m^2 was 30 × 30 cm and viewed from a distance of 233 cm; thus corresponding to a visual angle of 7.3 deg. Manufacturer's specifications of the chromaticity coordinates of the phosphors of the colour monitor were verified with a Tektronics J17 Lumacolor photometer and a J1820 chromaticity probe (Tektronix, U.S.A.).

Stimulus

Colour-contrast-defined Landolt "C"s were revealed from a difference in colour between the figure (i.e. the "C") and the white isoluminant background. Figure and background were matched in luminance using Judd modified CIE 1931 standard observer functions (Wyszecki & Stiles, 1982). Conversion formulas from Vos (1978) were used to convert from CIE 1931 chromaticity coordinates to Judd modified chromaticity coordinates.

Three types of "C"s were used: "blue" (short-wavelength), "green" (middle wavelength), and "red" (long-wavelength) with colours centred around an equal-energy white, CIE chromaticity coordinates $x = 0.333$, $y = 0.327$, and luminance 30 cd/m^2.

The diameter of the "C" was 1.8 deg, and the width of the gap in the "C" was 22 min arc. The gap was presented either "up" or "down" at an eccentricity of 1 deg in the left or right visual half-field. Macular presentation was used because (1) chromatic mechanisms are in adults better developed in the central visual field than in the peripheral visual field; and (2) colour sensitivity in the central visual field does not show nasal/temporal asymmetry (Noorlander, Koenderink, Den Ouden, & Edens, 1983; Mullen, 1991).

Procedure and threshold determination

Colour contrast thresholds were determined for blue, green, or red "C"s in separate sessions. Subjects sat in the dark and were adapted to the white background. At the centre of the screen, four markers were glued forming a square of 30 min arc by 30 min arc. The subject was instructed to fixate at the centre of this square in which the fixation point appeared, and to maintain fixation during the whole experiment. The fixation spot appeared 100 msec before the "C". Both the fixation spot and the "C" disappeared simultaneously.

In the initial trial of each session an easily detectable "C" was presented to the subject. The "C" was flashed for 84 msec, randomly appearing to the left or right of the fixation spot. During the 1.6 sec intervals between the presentations of the "C", the subject had to indicate verbally whether the gap in the "C" had been seen "up" or "down" (two-alternative forced-choice). The subject was instructed to guess in case of uncertainty about the correct answer. For further details see Hollants-Gilhuijs *et al.* (submitted).

A staircase technique was applied to reach threshold. The chromaticity coordinates (x; y) of the phosphors in the first trial were for the blue, green, and red "C"s, and for the white background: (0.306; 0.228), (0.317; 0.320), (0.387; 0.290) and (0.353; 0.308), respectively. In

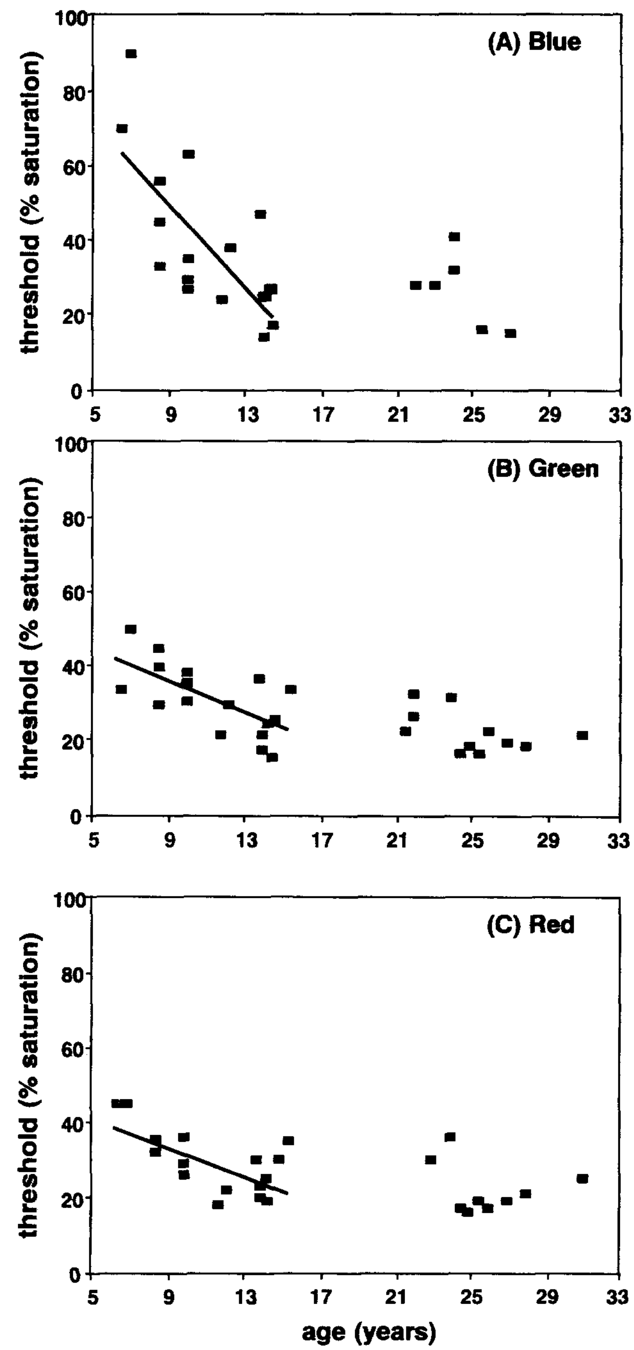

FIGURE 1. Colour contrast thresholds as a function of age for detection of (A) blue colour-contrast-defined "C"s; (B) green colour-contrast-defined "C"s; and (C) red colour-contrast-defined "C"s. Percent saturation (i.e., purity) is defined with respect to the spectrum locus. A purity of 100% refers to colour contrast of the "C" in the initial trial. A purity of 0% indicates no difference in colour contrast between figure and background. The solid lines in the child group, in each part of the figure, are regression functions.

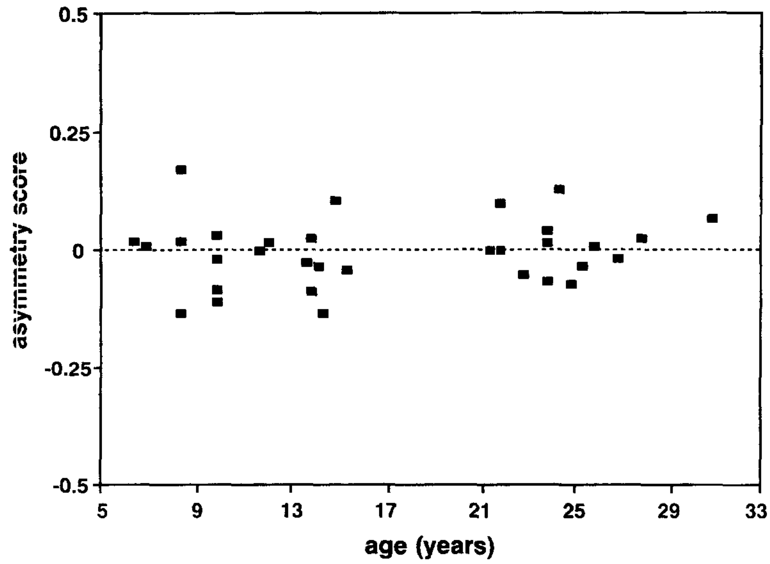

FIGURE 2. Asymmetry scores as a function of age. The asymmetry scores were pooled for blue, green, and red stimuli. Asymmetry scores were obtained by subtracting the right half-field error proportion from the left half-field error proportion.

successive trials colour contrast (i.e. purity) of the "C" was decreased or increased in accordance with a correct or false response by shifting the chromaticity coordinates of the "C" towards or away from, respectively, the chromaticity coordinates of the background until threshold performance had been reached (i.e., a correct "C" identification between 65 and 80% in either visual half-field). Note that while the amount of white light added to the "C" was changed from trial to trial, screen luminance was held constant at 30 cd/m^2. Prior to the experiment, subjects were trained with 24 practice trials to ensure that the instructions given were comprehended and that the subjects could correctly identify the stimulus. Each subject was tested with at least two colours.

After threshold determination, the subject could relax for up to 10 min before 120 trials at threshold, 60 trials in each visual half-field, were presented to the subject. The performance of the subject in this series of 120 trials was used to examine the extent of the visual half-field asymmetry, for each colour.

Determination of visual half-field asymmetry

An asymmetry score was used as a measure of visual half-field asymmetry. This asymmetry score was defined as the difference between error proportions [i.e., the number of errors divided by the number of presentations) in the left and right visual half-fields (AS = p(l) − p(r), where AS is the asymmetry score, and p(l) and p(r) are the left and right half-field error proportions, respectively]. A positive asymmetry score indicates that the subject had more difficulty in perceiving the "C" presented in the left half-field than in the right half-field (i.e., a left half-field deficit). A negative asymmetry score indicates a right half-field deficit, and an asymmetry score of 0 indicates similar detection scores in both visual half-fields. This score was calculated for each subject and for each colour.

Analysis and statistics

Regression analysis was used to test age dependency of thresholds (see Fig. 1) and age dependency of asymmetry scores (see Fig. 2) in the group of children and that of adults.

Asymmetry scores were pooled for left and right eyes and for colours, and are presented as one value per subject in Fig. 2. The data may be presented in this way since repeated measure analysis of variance of left and right half-field error proportions showed no significant differences between eyes and between colours.

RESULTS

Thresholds

Figure 1(A) shows the detection thresholds for blue "C"s. The figure shows that children have much more difficulty with the detection of the blue "C"s than adults, as the colour of the "C" becomes less saturated. Moreover, as the regression line indicates, thresholds decreased significantly ($P < 0.005$) with age in the child group. In contrast, there was no significant relation between age and thresholds in adults.

Figure 1(B, C) shows the detection thresholds for the green and red "C"s. As for the blue stimulus, children up to about the age of 10 years have thresholds which are higher than those in older children or adults. The regression line in the child group is significant both for the green ($P < 0.005$) and red stimulus ($P < 0.005$), without a significant relation between age and thresholds in the adult group. Furthermore, the decrease in threshold with age is less pronounced for the green and red stimuli than for the blue one. The slope of the regression line for blue differs significantly ($P < 0.05$) from the green and red ones; the latter two are not significantly different.

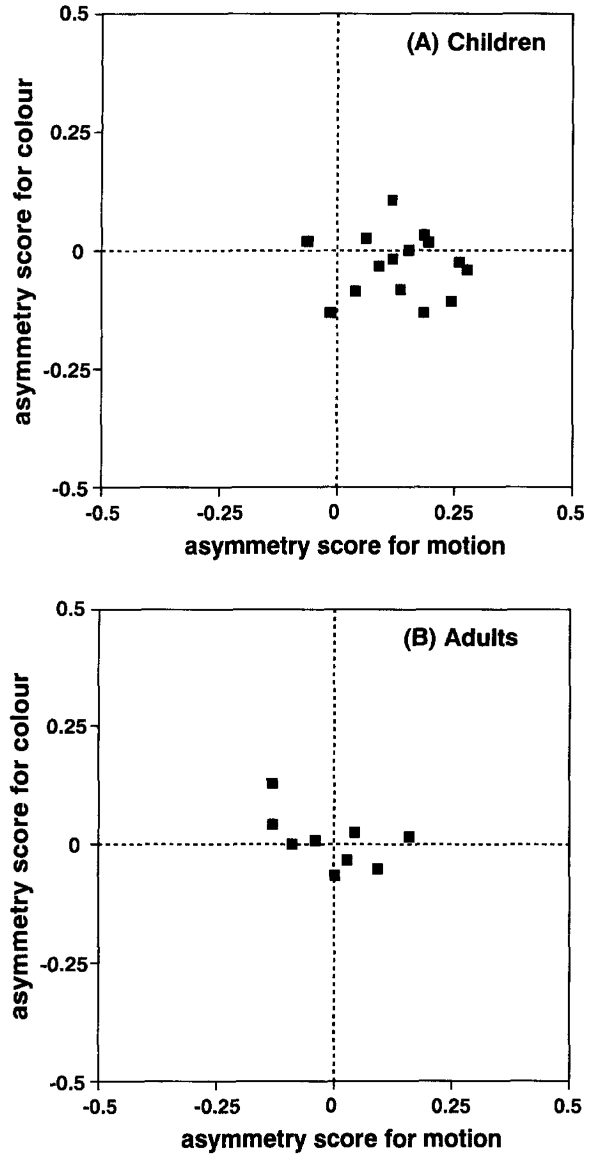

FIGURE 3. Scatter plots of asymmetry scores for colour vs those for motion in (A) children, and (B) adults. The asymmetry scores for colour correspond with the data points presented in Fig. 2. The asymmetry scores for motion are copied from Hollants-Gilhuijs *et al.* (submitted).

Visual half-field asymmetries

Asymmetry scores obtained in a particular subject were not significantly different for the colour of the "C". Figure 2 therefore shows the pooled asymmetry scores for the various colours for which a subject was tested. The figure shows that there is no effect of age on asymmetry scores in children, and that the ability to detect colour-contrast-defined "C"s is in both children and adults similar in the left and right visual half-fields.

DISCUSSION

Thresholds

Our results of higher colour contrast thresholds in children compared with adults is in accordance with the results of Abramov *et al.* (1984) showing that 6–8-year-old children have higher two-colour increment thresholds than adults. In addition, Knoblauch, Barbur, and Vital-Durand (1995) report that between 3 months and 15 years of age chromatic sensitivity increases gradually.

This improvement of colour contrast thresholds with age is unlikely to be caused by non-visual factors such as attention or motivation biases, since then the improvement of performance with age should have been the same irrespective of the colour of the stimulus, which was not the case. Therefore, maturation of the visual system should be involved. Pre-retinal factors seem unlikely since only minor changes occur in the amount of lens pigmentation (Coren & Girgus, 1972), the density of the ocular media (Tan, 1971; Werner, 1982), and the density of the macular pigment (Werner, Donnelly, & Kliegl, 1987; Bone, Landrum, Fernandez, & Tarsis, 1988) from age 5 to 30 years. Furthermore, morphological studies report that major maturational changes in the photoreceptors of the retina take place before the fourth year of life, except for the outer segment length of cones and their packing density (Abramov, Gordon, Hendrickson, Hainline, Dobson, & LaBossiere, 1982; Hendrickson & Yuodelis, 1984; Yuodelis & Hendrickson, 1986; Hendrickson, 1994). However, these studies provide no information that the morphological development of the blue cones is delayed with respect to that of the green and red ones. It is furthermore known that the physiology of the retina, as assessed by means of the electroretinogram (Kriss, Jeffrey, & Taylor, 1992) resembles that of adults before the fourth year of life.

In contrast, maturation of the visual cortex is not completed before late in adolescence (De Vries-Khoe & Spekreijse, 1982; Ossenblok *et al.*, 1994; Conel, 1939–1963; Yakovlev & Lecours, 1967). Therefore, we propose that the immaturity of the visual cortex is the primary constraint for the difficulty children have with the detection of forms composed of poorly saturated colours.

Visual half-field asymmetries

Our finding of symmetry in the detection of colour-contrast-defined forms in the two visual half-fields in children (see Fig. 2) is consistent with the findings by Bernasek and Haude (1993) of equal accuracy to match colours in the left and right visual half-fields in children of 4–6 years of age.

Fifteen children and nine adults from the present study had also participated in a previous study on visual half-field development of motion perception (Hollants-Gilhuijs *et al.*, submitted). A comparison of the visual half-field performance of the two age groups in the two studies (see Fig. 3) may provide evidence that the processing of colour and visual motion are mediated by different cortical streams, as suggested by Carney, Shadlen, and Switkes (1987), Livingstone and Hubel (1987), Zeki and Shipp (1988), Schiller and Logothetis (1990) and Zeki *et al.* (1991). Figure 3 shows that the asymmetry scores on colour and motion do not correlate

(Pearson parametric test) in either children or adults. Since the study on colour took place only 3 months after the study on motion, it is not likely that changes in the maturational state of the brain can account for the difference in asymmetry scores between colour and motion.

Figure 3 shows that the visual mechanisms involved in the detection of *motion-defined forms* mature asymmetrically in the left and right visual half-fields (i.e. left half-field deficit in the children group and a symmetric performance in the adult group) which is in contrast with the symmetry in visual half-field development for the detection of *colour-contrast-defined forms.*

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