

ON THE ROLE AND NATURE OF ADAPTATION IN CHROMATIC INDUCTION

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Abstract

We investigated the role of adaptation in chromatic induction by comparing the magnitude of induction under various viewing conditions. We conclude that adaptation can contribute significantly to chromatic induction. Moreover, our results indicate that adaptation is a local process.

Key words: color vision; chromatic induction; color constancy; adaptation

Introduction

A surface's color is influenced by the colors of its surrounding. This is demonstrated by a grey square appearing reddish when on a green background; a phenomenon referred to as chromatic induction or simultaneous color contrast. It has been suggested that adaptation contributes to chromatic induction (e.g. Jameson and Hurvich, 1964). The aim of the present paper is to shed light on the role of adaptation in chromatic induction.

Using a paradigm in which subjects matched temporally modulating colors, De Valois et al. (1986) found a modest increase in chromatic induction when the saturation of the inducing color was increased. The temporal modulation prevented adaptation. Using a haploscopic matching technique, Valberg (1974) found a much stronger increase in chromatic induction. The long presentation time (210 sec) in his experiment did not prevent adaptation. Moreover, as each eye viewed a different scene, the eyes were able to adapt independently.

The difference in the magnitude of induction found in the two above-mentioned studies could have been due to whether or not the experimental conditions prevented adaptation. However, several other differences do not allow a direct comparison of their data.

Whereas De Valois et al. used equiluminant stimuli, Valberg did not. A difference in luminance between center and surround is known to influence chromatic induction (Kinney 1962). Moreover, fusing the test and reference surrounds (as done in Valberg's paradigm) causes dichoptic chromatic induction (De Weert & Levelt, 1976; Humanski & Shevell, 1985). Finally, different center and surround sizes were used. Several studies have shown that chromatic induction depends on these variables (e.g. Walraven, 1973; Tiplitz, Blackwell & Buchsbaum, 1986; Brenner et al., 1989). In the current experiments we compare chromatic induction for identical fields under conditions that either enhance or prevent adaptation.

Methods and Materials

We presented our stimuli on a RGB-monitor (Sony KX-14CP1) using a computer that allowed us to specify colors with a resolution of 8 bits per gun; the test and reference field (see Fig. 1) each consisted of a $2.5^\circ \times 3.5^\circ$ center surrounded by a 2.5° border. The test field was presented at 5° to the left of the center of the screen, the reference field at 5° to the right. The test and reference fields were displaced vertically by approximately 4° to prevent fusion of the images in the septum condition (see Experiment I). The center of the test field and the border surrounding the reference field were the same neutral grey. The border surrounding the test field was filled with an inducing color of the same luminance. Equiluminance values were determined for each subject by means of flicker-photometry. Average luminance of the stimuli was 17 cd/m^2 . The subject was required to match the color of the center of the reference field to that of the center of the

test field. He had to indicate that a satisfactory match had been made. The first setting made after one minute of presentation was taken as the subject's score (a pilot experiment [Brenner et al., 1988] suggested that one minute was enough to demonstrate differences). The experiments were performed in a room that was dark except for the illumination provided by the screen. The screen was viewed from a distance of 50 cm with the subject's chin in a chin-rest. The subjects were the two authors. We have normal corrected vision and normal color vision when tested with the Munsell-100-hue test, the Ishihara-plates and the Tokyo Medical College test.

Experiment I: Influence of the experimental condition

In the first condition, the subject was able to see the screen with both eyes, and could shift his gaze freely over the screen. It is referred to as the "normal viewing condition" (Fig. 1). Our second experimental condition enhances adaptation. A septum, placed between the observer and the screen, divided the screen into two parts. As one eye was exposed to the test field and the other to the reference field, this allowed the eyes to adapt independently. This condition is referred to as the "septum condition"¹. The center of the reference field was set to match the appearance of the center of the test field. We determined the relationship between the saturation of the color of the surrounding of the test field and that of the center of the reference field. The saturation of the inducing color was varied along three lines in CIE color space by changing the relative contributions of the monitor's phosphors (CIE-coordinates: red: $x=.6489$, $y=.3429$; green: $x=.2814$, $y=.6214$; blue: $x=.1463$, $y=.0621$). We refer to the six resulting colors as red, turquoise, green, purple, blue and yellow. Saturation was increased in steps of 0.04 (distance in CIE-color space), until the maximal saturation that could be attained at the required luminance was reached.

Comparing the results for these two conditions (Fig. 2) shows that chromatic induction does not only depend on the color of the surround. Chromatic induction is much stronger in the septum condition. For the normal viewing condition, the results are similar to those of De Valois et al. Results for the septum condition are

¹ We originally used the term "barrier condition" to refer to this condition (Cornelissen and Brenner, 1989). Dr. J.D. Mollon suggested to us that we use the term "septum condition" instead.

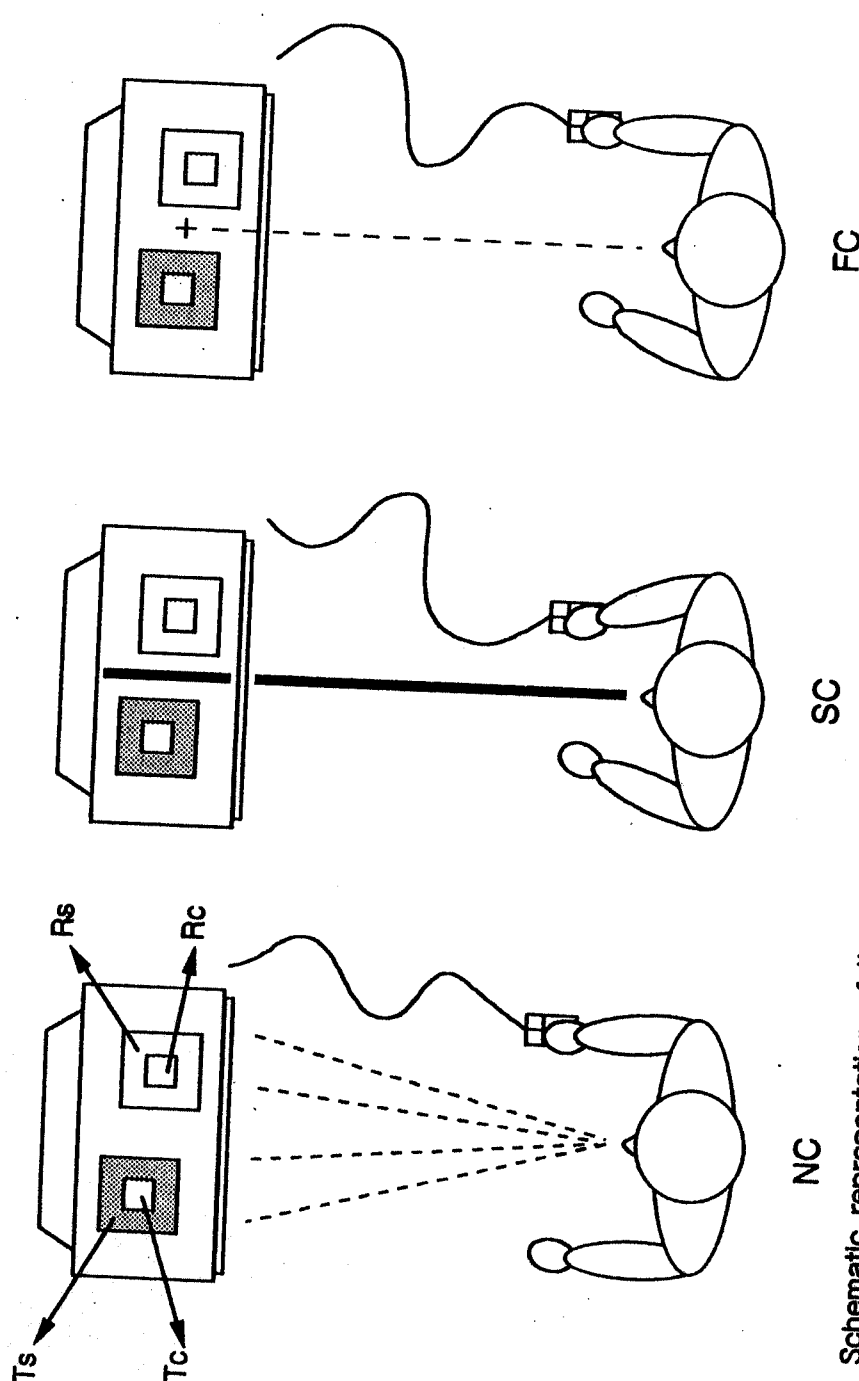


Fig. 1: Schematic representation of the experimental conditions. NC: Normal Viewing Condition; SC: Septum Condition; FC: Fixation Condition; T_c : Center of the test field (always neutral grey); T_s : Surround of the test field (filled with an inducing color of the same luminance as the neutral grey); R_c : Center of the reference field (the color of which could be adjusted by the subject); R_s : Surround of the reference field (filled with the same grey as the center of the test field).

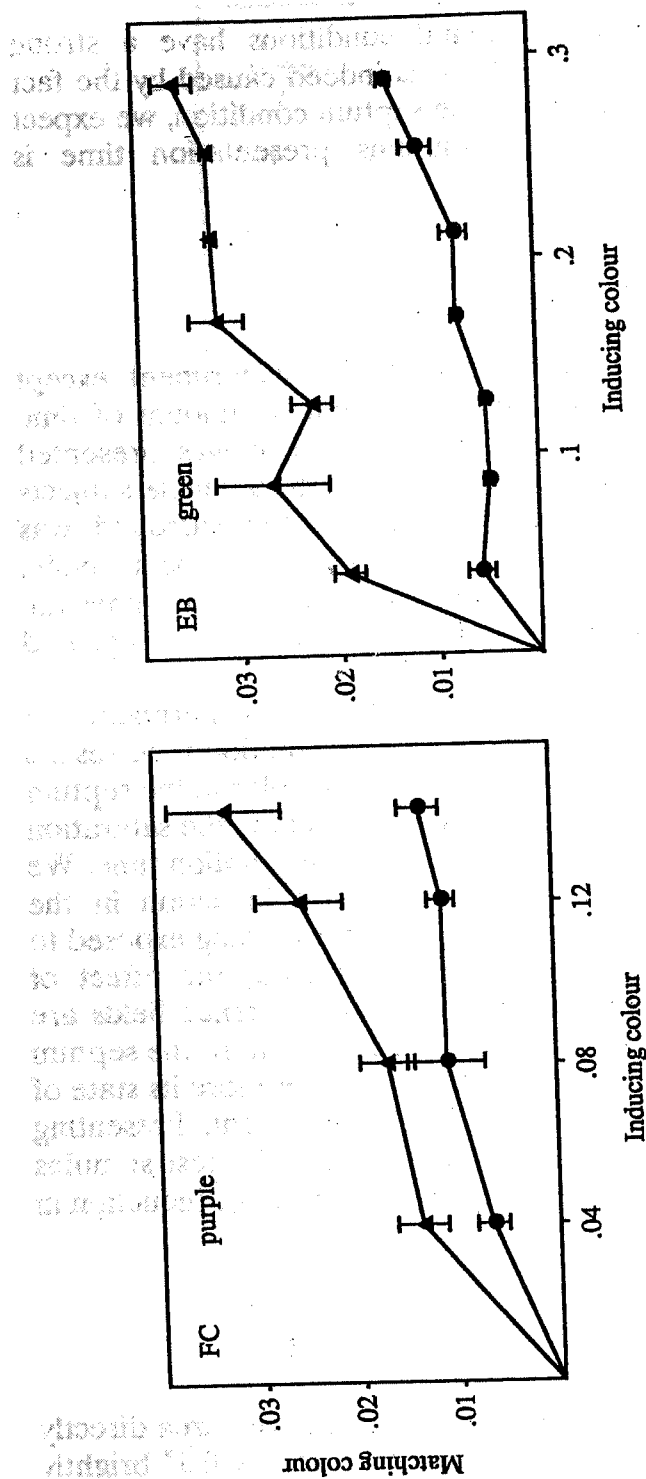


Fig. 2: Comparison of normal viewing (circles) and septum (triangles) conditions. Horizontal axis: saturation of the inducing color; vertical axis: saturation of the color set to match the appearance of the induced color. Values on the axis are the distance from the grey color of the center of the test field in the CIE-1931 diagram. The values of the scales may differ per color. Bars represent ± 1 standard deviation. Mean results for subject FC for a purple inducing surround ($n=4$ for NC and 3 for SC) and for EB for a green inducing surround ($n=2$ for both conditions). We find a large difference in induction between the normal and septum viewing conditions.

comparable to those obtained by Valberg. Fig. 3 shows similar results for two other colors.

We conclude that the experimental conditions have a strong influence on chromatic induction. If this is indeed caused by the fact that the eyes adapt independently in the septum condition, we expect induction to decrease when the stimulus presentation time is shortened.

Experiment II: Temporal aspects

The stimuli were identical to those in the first experiment, except that the inducing color was presented for a limited amount of time (100, 200, 500 or 1000 msec). The reference field was presented continuously. As one presentation was not enough to enable subjects to adjust the reference field, presentation of the surround was repeated until the subject indicated that a match had been made. Between these presentations a grey field was shown (for 10 times the stimulus duration) to prevent adaptation due to repeated presentation.

Examples representative of our results for this experiment are shown in Fig. 4. We find that increasing the presentation time results in a clear increase in the saturation of the induced color in the septum condition. In contrast, for the normal viewing condition, the saturation of the induced color is hardly influenced by the presentation time. We conclude that adaptation causes the increase in induction in the septum condition; it is the result of only the left eye being exposed to the test stimulus. In the normal viewing condition, the effect of adaptation is unimportant because the test and reference fields are seen with the eyes in the same condition of adaptation. In the septum condition, each eye has its own environment, and therefore its state of adaptation depends on the colors in that environment. Presenting colors (of an average neutral chromaticity) around the test stimulus should therefore result in a marked decrease in chromatic induction in the septum condition.

Experiment III: The influence of the surround

We repeated Experiment I with a 10° by 20° colored area directly surrounding the test field. This area consisted of 0.5° by 0.5° brightly colored blocks (and therefore resembled Dutch painter Piet

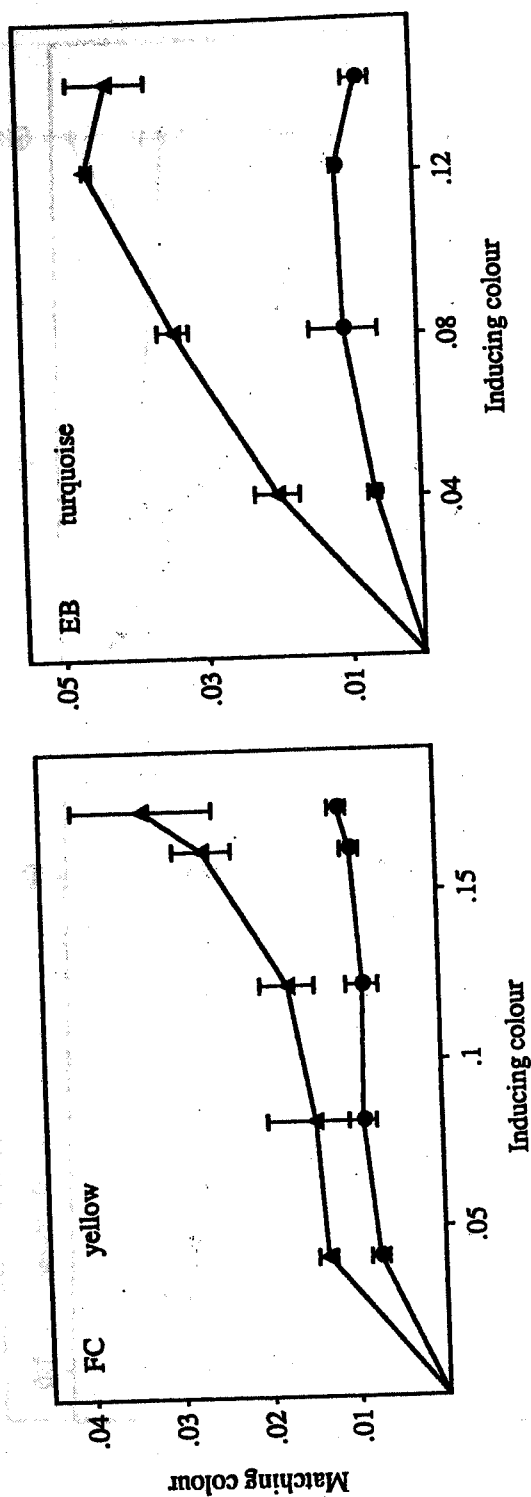
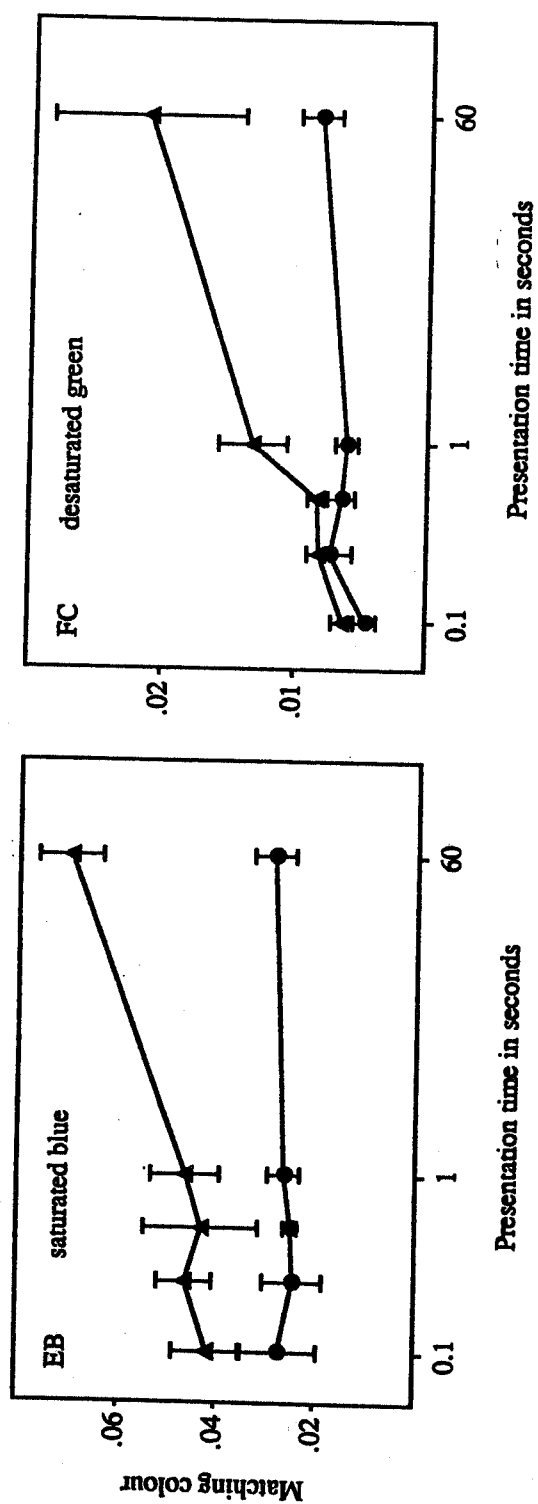


Fig. 3: Similar results to those shown in Fig. 2 but for two other colors. Results for subject FC for a yellow ($n=4$ for NC and 3 for SC) and for EB for a turquoise ($n=2$ for both conditions) inducing surround. Although we find individual differences in the magnitude of induction, the pattern of the results is the same for both subjects and all colors; induction is much stronger in the septum condition.

Fig. 4



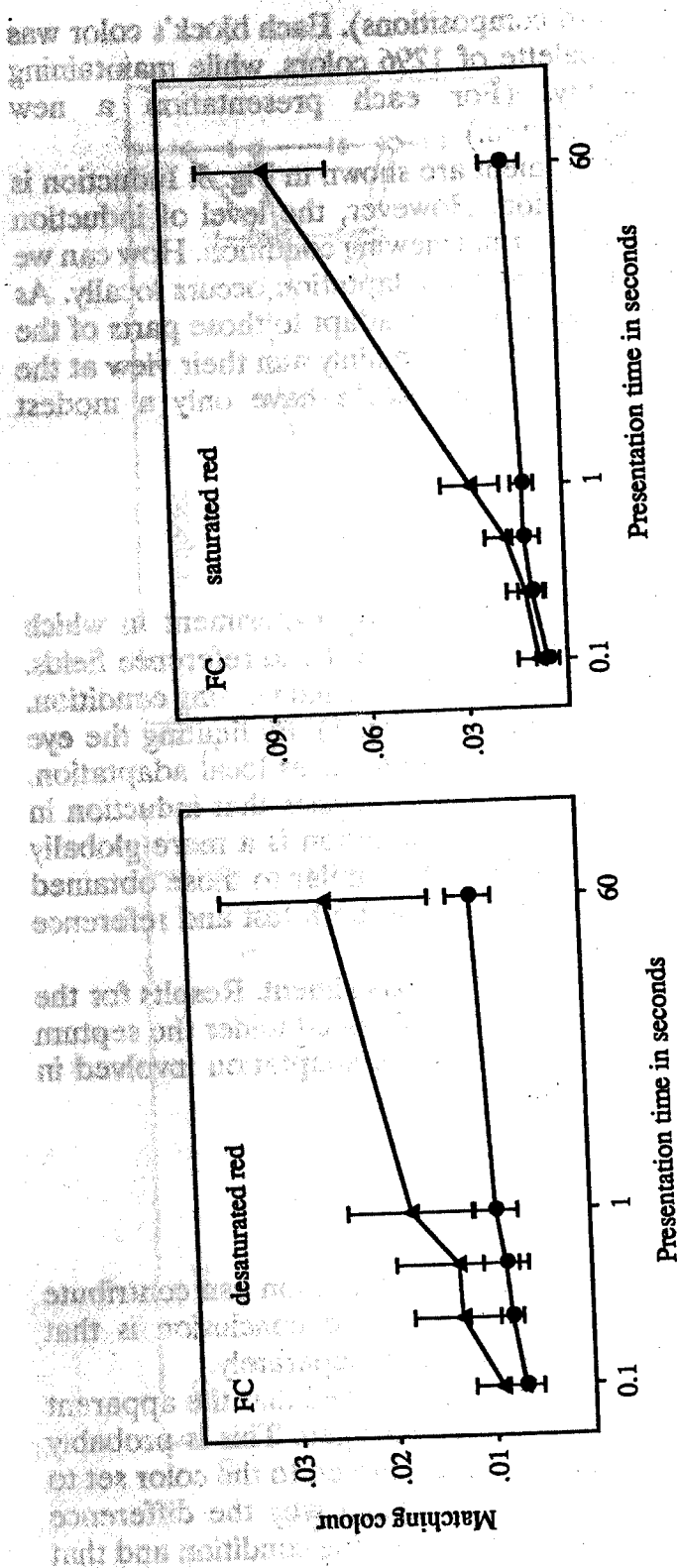


Fig. 4: Influence of presentation time. Horizontal axis: presentation time of the surround of the test field (plotted logarithmically). Other details as in Fig. 2. Results for subject EB for a saturated blue inducing surround (n=2 for both conditions) and for subject FC for a desaturated green (n=4 for NC and 3 for SC), a desaturated red and a saturated red (n=9 for NC and 8 for SC for both saturations) inducing surround. In the normal viewing condition, induction is not influenced by the duration of the presentation. In the septum condition we find a continuous increase when increasing the presentation time.

Mondrian's 1919 checkerboard compositions). Each block's color was chosen at random out of a palette of 1296 colors, while maintaining neutral average chromaticity. (For each presentation a new surrounding "Mondrian" was created.)

Sample results for this experiment are shown in Fig. 5. Induction is decreased in the septum condition. However, the level of induction remains well above that for the normal viewing condition. How can we explain this? Our hypothesis is that the adaptation occurs locally. As we do not scan a scene at random, we only adapt to those parts of the scene that we have looked at. As subjects mainly aim their view at the test and reference fields, the colored blocks have only a modest influence.

Experiment IV: Fixation

In order to test this hypothesis, we did an experiment in which subjects were required to fixate between the test and reference fields. Stimulus conditions were the same as in the normal viewing condition. We refer to it as the "fixation condition" (Fig. 1). By limiting the eye movements that a subject makes, fixation enhances local adaptation. Therefore, the local adaptation hypothesis suggests that induction in the fixation condition will be strong. If adaptation is a more globally organized process, one expects results to be similar to those obtained under the normal viewing condition, because both test and reference fields are seen through each eye.

Fig. 6 shows some of the results of this experiment. Results for the fixation condition are very similar to those obtained under the septum condition, confirming our hypothesis that the adaptation involved in chromatic induction is locally confined.

Discussion

The first conclusion of this study is that adaptation can contribute significantly to chromatic induction. The second conclusion is that (each eye and) each retinotopic location adapts separately.

In the septum condition, we occasionally noticed that the apparent color of the reference's surround had also changed. This is probably because the eye viewing the reference field adapted to the color set to match the induced color. This may also explain why the difference between chromatic induction in the normal viewing condition and that

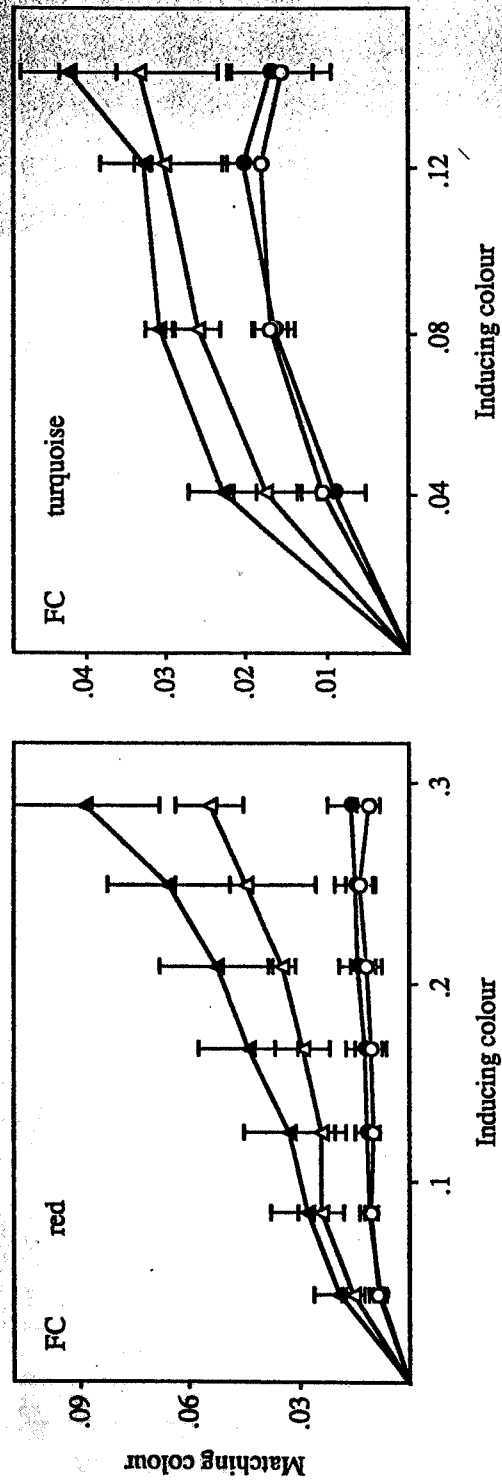


Fig. 5: Influence of adding bright colors. Data for normal viewing (circles) and septum condition (triangles). Open symbols: results with bright colors surrounding the test field; filled symbols: results without additional colors. Results for subject FC for red ($n=9$ for NC and 8 for SC without bright colors; $n=7$ for both NC and SC with bright colors) and turquoise ($n=4$ for NC and 3 for SC without bright colors; $n=2$ for both NC and SC with bright colors) inducing surrounds. Note the decrease in induction when bright colors are added in the septum condition. In the normal viewing condition, results are not influenced by adding such colors. We obtained comparable results for EB and for other colors.

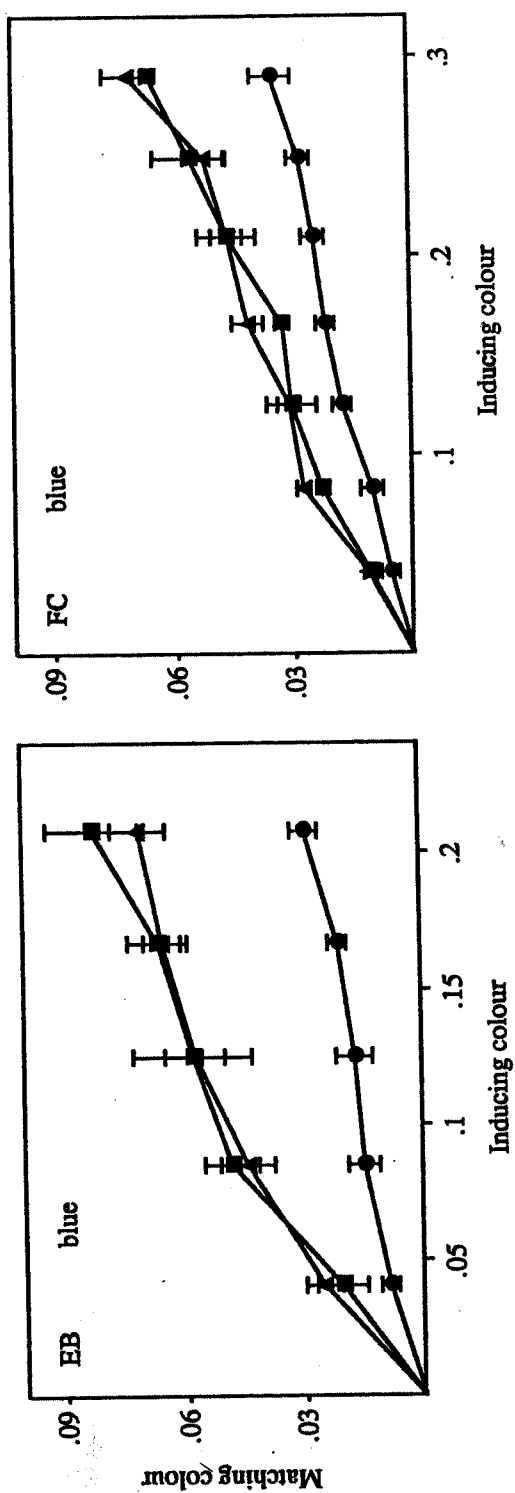


Fig. 6: Influence of fixation (squares) and septum (triangles) conditions on matching colour for subjects FC (n=9) and EB (n=4). Results for all three conditions are shown for comparison. Induction in the fixation condition is strong; note the similarity in the results between the septum and fixation condition. We obtained similar results for other colors.

in the septum condition does not completely disappear at short presentation times.

In the fixation condition, the stimuli were viewed with perifoveal parts of the retina. Equiluminance may not have been completely adequate as it had been determined for the fovea. However, as subjects fixated precisely in between the two fields, any difference in sensitivity as compared to the fovea was the same for both fields.

Purely local adaptation implies that the role of adaptation in chromatic induction is mediated by successively directing the line of sight at different surfaces. How, then, can we attribute any effect to adaptation in the fixation condition? Had fixation caused (near) stabilization of the image on the retina, the image would soon have disappeared. As it did not, observers must have been making small eye movements. These eye movements are probably not very different from those made in the septum condition. In this condition the observer was free to scan the whole screen, but presumably spent most of the time looking at the target field. Making similar eye movements results in a comparable state of adaptation, which explains the similarity in induction for these conditions. A quantitative comparison of the two conditions would require measurement of eye movements.

If one assumes more-or-less global processing of color information (e.g. Land, 1986), one does not expect a large difference in induction between normal viewing and fixation. We find substantial differences. De Valois et al. (1986) argued that, as their paradigm prevented adaptation, chromatic induction must have been the result of a spatial process in their experiment. In our normal viewing condition (test and reference fields seen with eyes in the same state of adaptation), chromatic induction is probably predominantly the result of this spatial process. If so, this spatial process is also well localized; brightly colored blocks surrounding the test field did not reduce chromatic induction in the normal condition. Therefore, chromatic induction is probably only mediated by mechanisms with a local character. Other studies have investigated the spatial aspects of chromatic induction more thoroughly (Walraven, 1973; Tiplitz Blackwell & Buchsbaum, 1986; Brenner et al., 1989). From those studies it appears that the extent of the local mechanisms may be restricted to about 1° . We suggest that the long range effects that have been found are mediated by local adaptation in conjunction with eye movements. This could explain why the long range effects were independent of all spatial parameters that were examined (Brenner et al., 1989).

A phenomenon that is undoubtedly related to chromatic induction

is color constancy. In both, object colors are changed due to their surrounding. Spatial and temporal characteristics of color constancy (Barbur et al., 1989 and personal communication) appear to be similar to those found for chromatic induction (Brenner et al., 1989; this study). Moreover, Brenner et al. (1989) showed that the number of spatial transitions does not affect chromatic induction, whereas Valberg and Lange-Malecki (1990) showed that a homogeneous grey equiluminant surround can account for the same color constancy as a complex colored pattern. The mechanisms mediating color induction are therefore probably also responsible for color constancy. If so, color constancy is also mediated by locally acting mechanisms and deviations from color constancy due to an excessive influence of the nearby surrounding are to be expected (as found, e.g., by Valberg and Lange-Malecki, 1990).

We conclude that chromatic induction is caused by a combination of a local spatial process and a local process of adaptation, their relative influence depending on the specific viewing conditions. We propose that any influence of more distant areas is mediated by adaptation in conjunction with eye movements. This suggests a very important role for eye movements in color vision. The latter is the subject of current investigation.

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