Research Articles

Diurnal variation of hue discriminatory capability under artificial constant illumination

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Abstract. Diurnal variation of hue discriminatory capability under artificial constant illumination of 4000 lux was studied with 10 young female adults using the 100-hue test. There were conspicuous diurnal variations in the yellow-blue and red-green systems, with marked reductions of error score in the evening. However, observations of the blue, yellow, green and red systems separately disclosed that there existed clear diurnal rhythms in the blue and green systems, but not in the yellow and red systems. This suggests the existence of diurnal variation in function of the S and M cones responsible for the blue and green hue.

Key words. Diurnal variation; 100-hue test; hue discriminatory capability; color.

Light plays important roles not only in vision, but also as a synchronizer for the entrainment of biological rhythms. As there has been some literature indicating the existence of diurnal rhythm in the visual receptor substances in the cone and the rod, like iodopsin and rhodopsin, and also in the shedding and degradation of rod and cone outer segment membranes in birds and mammals[1-4], we presume that hue-discriminating capability might change diurnally. Our present paper describes a study of the diurnal variation of hue discriminatory capability in humans, as a first step to predicting the role of wavelength in the entrainment mechanisms of human circadian rhythms to light-dark cycles. We should like to investigate the possibility that morning and evening bright light could advance or delay the human circadian rhythm[5,6] to different extents, even if the spectrum distribution of the light is identical between the morning and evening[7]. The present study describes an investigation of changes in the spectral sensitivity of the eye throughout the day.

Materials and methods

Ten females, aged 20–25 yrs, volunteered as subjects. They all had normal color vision. The subjects entered the bioclimatic chamber in pairs at around 20.00 in the evening before the start of the experiments. The chamber had a controlled temperature of 25 °C and a relative humidity of 50%. Lighting was by incandescent lamps (50 lux). The subjects retired at 22.00 and rose at 06.00 the following morning. They carried out the 100-hue test[8] between 07.00 and 19.00 every 1 or 2 hours. The 100-hue test consists of 4 boxes, each of which has 25 different color chips, with colours obtained by dividing the changes of hue from red to yellow, green and blue into 100 steps. Three minutes were allowed for each subject to arrange 25 color chips. The results obtained by the subjects in the hue test were not known to them. The subjects were fully accustomed to the 100-hue test before the beginning of the experiments. During the experimental period the light intensity from the fluorescent lamps was kept constant at 2000 lux at the eye level of the subjects and 4000 lux on the desk top where the test was done. In recording the results of the experiments, errors in the order of color chips were taken as error score. The error score was calculated every test trial as a relative change with the following equation:

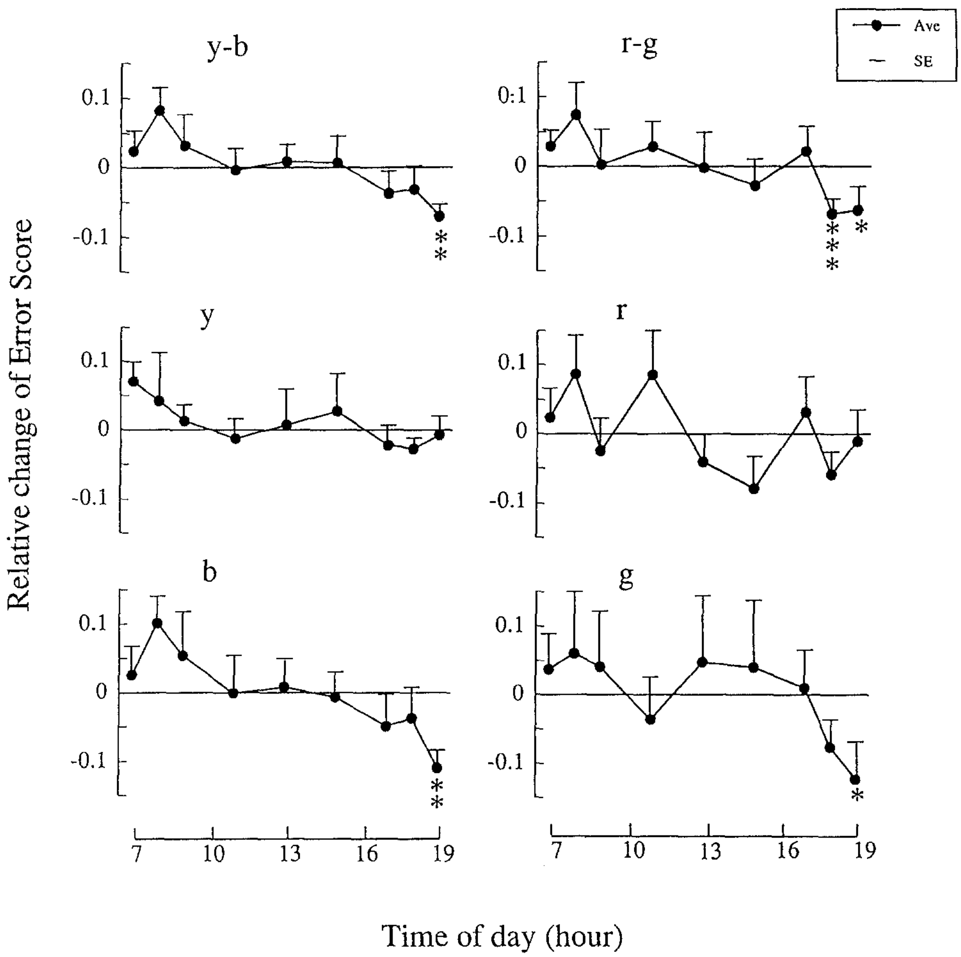
relative change of error score =

$$\left[\sum_{j=1}^{i}\left\{ES_{kj} - \left(\sum_{k=1}^{n} ES_{kj}\right)\middle/ N\right\}\right]\Big/ I$$

where ES = error score, i = subject number, n = time of day. The results obtained were arranged according to the stage theory[9] of color vision processing.

Results

The figure shows diurnal variation in the relative change of error scores in hue discriminatory in the red-green (r-g), red (r), green (g), yellow-blue (y-b), yellow (y) and blue (b) systems. In this figure, r corresponds to chips nos 1–9 and 82–100 in the 100–hue test, and y, g and b correspond to nos 9–28, nos 28–50 and nos 50–82, respectively. It is apparent that there was a gradual reduction of error score with the advance from early morning to evening, i.e., the error scores were significantly smaller at 18.00 and 19.00 than those at 07.00 in the r-g system, at 19.00 in the g system, and at 19.00 in the y-b and b systems ($p < 0.01$–0.05).



Diurnal variation in relative change of error score in hue discriminatory capability under artificial constant illumination. ***$p < 0.01$, **$p < 0.02$, *$p < 0.05$.

We repeated the same test 3 times with one subject, to assess the influence of habituation on the error score. Although the error score reduced gradually with repetition, there was always the tendency for the error score in hue discriminatory capability to be reduced in the evening, suggesting that the factor of habituation could be excluded in the data analysis.

Discussion

The color vision processing in man can be explained by the sensitivity of the L, M and S cones in the retina and their interactions, i.e., the stage theory which combines theories involving three primary colors and opponent colors. We discuss our present findings in terms of the stage theory modified by Ikeda[10].

The hue discriminatory capability for the y-b system was higher in the evening compared with that in the morning ($p < 0.02$). However, the observations of the individual systems, b and y indicated highly significant differences between the morning and evening in the b system only ($p < 0.02$). These results strongly suggest the existence of diurnal variation in the S cones (responsible for the b system), with their hue discriminatory capability being more sensitive in the evening, but not in the combined effects of the L and M cones which constitute the y system.

There were also diurnal changes of hue discriminatory capability in the r-g system. The g system changed diurnally but the r system did not, which indicated the existence of diurnal variation in the M cones (responsible for the g system), but not in the combined effects of the S and L cones which constitute the r system. These results for the y-b and r-g systems could suggest indirectly that the L cones might have reduced hue discriminatory capability in the evening.

In summary: 1) The reduced error score in the b system towards the evening means that the S cones are more sensitive then. 2) The reduced error score in the g system towards the evening means that the M cones are more sensitive then. 3) The absence of diurnality in the y system could be ascribed to the cancellation of the increased sensitivity of the M cones by a decrease in sensitivity of the L cones. 4) The absence of diurnality in the r system could be ascribed to the cancellation of the increased sensitivity of the S cones by the decreased sensitivity of the L cones.

What implications are there in the findings that the S cones and M cones became more sensitive and the L cones less so in the evening, which implies that humans become more sensitive to blue and green colors in the evening? Light from fluorescent lamps includes strong blue components which could stimulate the S cones more strongly around the evening, causing a sensation of irritation. On the other hand, light from incandescent lamps contains strong red components and weak blue components; therefore, this type of light would not stimulate the S cones although these become more sensitive in the evening. Moreover, the decreased sensitivity of the L cones in the evening could give people a relaxed and calm sensation then. These speculations are in agreement with previous reports[11,12], concerned with the quality of light and the psychological sensation it produces.

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