CHAPTER 4.5

Temporal Characteristics of Colour Discrimination

Hirohisa Yaguchi, Yasuaki Mohri, Masaki Ishiwata and Satoshi Shioiri

4.5.1 INTRODUCTION

There are a number of studies (e.g. King-Smith and Carden, 1976; Thornton and Pugh, 1983; Sperling and Harwerth, 1971) showing that the mechanism of visual detection may be described in terms of parallel luminance and opponent-colour channels. Recently, Cole *et al.* (1993) obtained detection thresholds for a 2° Gaussian-blurred spot flash of 200 ms on a white adapting field, and found that the threshold detection data were well described by the probability summation of three sets of mechanisms: L + M, L – M, and S – (L + M), each having linear cone contrast inputs. Chaparro *et al.* (1994) measured detection thresholds for foveal small flashes of 200 ms duration on a bright yellow field. They found that the most sensitive mechanism was not a luminance mechanism, but rather a red-green mechanism that responds to the linear difference of equally weighted L and M cone contrasts. Metha *et al.* (1994) measured the detection and direction discrimination thresholds using moving stimuli, and found that the luminance mechanism is directionally sensitive at detection threshold. On the other hand, there are also many studies (e.g. Kelly, 1974; Kelly and van Norren, 1977; Noorlander and Koenderink, 1983) showing that the temporal contrast sensitivity function for chromatic modulation differs from that for luminance modulation in showing no low temporal frequency attenuation and in having a lower high temporal frequency cut. These findings suggest that the colour-discrimination thresholds vary with the temporal configurations of stimulus presentation. There are, however, few studies concerned with the temporal characteristics of colour discrimination.

In the present study, we have measured colour-discrimination thresholds for various temporal conditions. The discrimination threshold data are represented in a red-, green-, and blue-primary luminance contrast space, an L-, M-, and S-cone contrast space, and the CIE 1976 $L^*a^*b^*$ (CIELAB) space.

4.5.2 METHOD

The experiments were done using a computer-controlled colour monitor. The colour of pattern components was controlled by a colour map that has 12 bits of resolution of each primary, that is, there are 4096 discrete colours between the minimum and the maximum output of each primary colour. Determination of the discrimination threshold employed here was originally developed by Cowan *et al.* (1984). In the experiment, the observer saw a brief flash of the test stimulus with a colour slightly different from a steady background colour. The background field was a square of 6° × 6°. The test stimulus and the background were separated with a black gap of 6 min arc width. The idea behind employing this gap is that the observer cannot use a criterion of detecting edges between the test colour and the background colour as a cue of colour discrimination. The test stimulus was presented in any one of four panes, each of them 1° × 1°, aligned as a 2 × 2 matrix with a fixation point in its centre. The observer's task was to report which of the four panes contained the test stimulus. The test patterns were presented in four different temporal conditions: a 50 ms rectangular pulse, a 200 ms rectangular pulse, a Gaussian profile with 200 ms in half width, and a 200 ms rectangular pulse preceded and succeeded by 200 ms dark rectangular blanks that we call temporal gaps. Among these temporal conditions, a 50 ms condition consists of a high temporal frequency component, a 200 ms Gaussian condition has a relatively low temporal frequency component, and a 200 ms condition is an intermediate condition. In the temporal gap condition, the observer cannot see any transient change of the background colour to the test colour.

We employed five background colours: white, red, green, yellow and blue, which the CIE has recommended for the colour difference evaluation. The CIE 1931 (x, y) chromaticity co-ordinates and the luminance of background colours are shown in Table 4.5.1.

Test stimuli are expressed in terms of the luminance contrast, that is, the increment or decrement luminance of the primary-component of test stimulus $(\Delta R, \Delta G, \Delta B)$ is divided by the luminance of the primary-component of background colour (R, G, B). Thresholds for the test stimuli along 26 different directions away from each background colour were determined. When measuring the threshold for a given direction in a colour space, the red/green/blue ratio of the test stimulus was kept constant. Thresholds were determined by the interleaved staircase method, in which the test stimuli along four different directions were presented in a random order in a single session.

4.5.3 RESULTS AND DISCUSSIONS

We plotted the discrimination threshold data in the luminance contrast space. Figure 4.5.1. shows discrimination thresholds plotted on a $\Delta R/R$–$\Delta G/G$ plane (upper graphs) and a $\Delta R/R$–$\Delta B/B$ plane (lower graphs) in the luminance contrast space. Graphs from left to right indicate the results obtained by the observer YM for five background colours, white, red, green, yellow and blue, respectively. The origin of each graph corresponds to each background colour. The straight line shows the isoluminance line for each background

Table 4.5.1. The CIE 1931 (x, y) chromaticity co-ordinates and luminance of the background colour.

Background colour	x	y	L (cd m^{-2})
white	0.314	0.331	30.0
red	0.484	0.342	14.1
green	0.248	0.362	24.0
yellow	0.388	0.428	30.0
blue	0.219	0.216	8.8

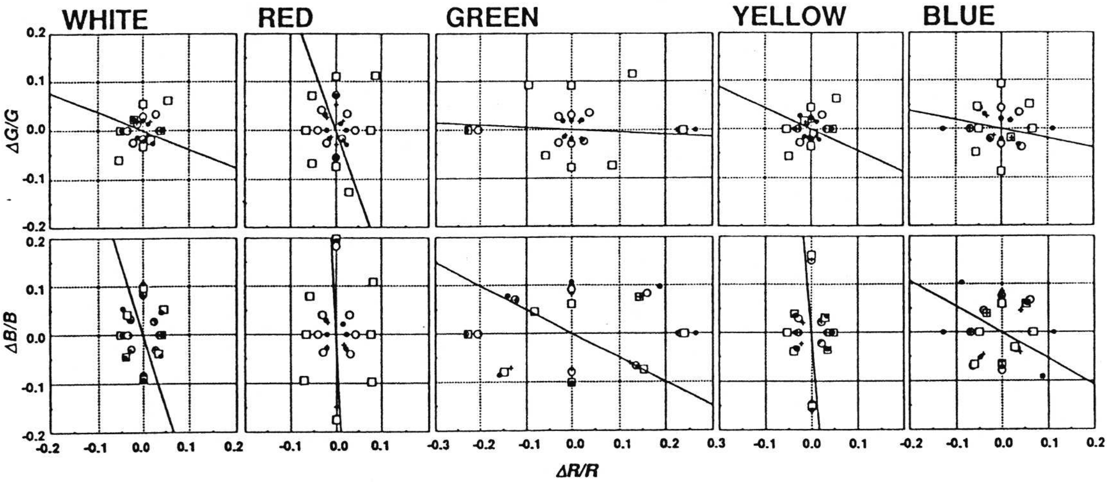

Figure 4.5.1. Discrimination thresholds plotted in the luminance-contrast space.

condition. Different symbols indicate different temporal conditions of the stimulus presentation. The experimental results show that the discrimination thresholds for a Gaussian condition (open circles) and those for a temporal gap condition (open squares) increased toward the direction of change of luminance. On the other hand, a 50 ms pulse condition (dots) shows the threshold elevation along the isoluminance plane where only colour changes. Crosses indicate the 200 ms pulse condition.

We also analysed the obtained data in the cone-contrast space ($\Delta L/L$, $\Delta M/M$, $\Delta S/S$), where ΔL, ΔM and ΔS, are the change in cone excitation in the L-, M- and S-cones due to the increment or decrement of test stimulus, and L, M and S are the cone excitation due to the background colour. The excitations of L-, M-, and S-cone for each test stimulus are calculated by the following equations,

$$L = \int E(\lambda)l(\lambda)d\lambda \quad (1)$$
$$M = \int E(\lambda)m(\lambda)d\lambda \quad (2)$$
$$S = \int E(\lambda)s(\lambda)d\lambda \quad (3)$$

where $E(\lambda)$ is the spectral radiance of the stimulus, and $l(\lambda)$, $m(\lambda)$, and $s(\lambda)$ are the spectral sensitivity functions for L-, M-, and S-cone, respectively, derived by Smith and Pokorny (1975). Figure 4.5.2 shows discrimination thresholds projected on the $\Delta L/L$–$\Delta M/M$ plane (upper graphs) and on the $\Delta L/L$–$\Delta S/S$ plane (lower graphs) for a 50 ms rectangular (left), a 200 ms Gaussian (centre) and a temporal gap condition (right). Thresholds for all background colours are plotted altogether. Different symbols indicate the different background colour; white (open circles), red (closed circles), green (open squares), yellow (crosses), and blue (open triangles). The discrimination threshold contours in the cone-excitation contrast space, particularly on the $\Delta L/L$-$\Delta M/M$ plane, vary little with the background colour but much with the temporal profile of test stimulus presentation. Discrimination thresholds for a temporal gap condition elongate toward a slope of 45°, which corresponds to pure luminance change without colour change. It is clearly shown that the discriminability along the direction of the excitation of S-cone is poorer than those of M- and L-cone.

Finally, we plotted the discrimination threshold data obtained here in the CIELAB space. Upper graphs of Figure 4.5.3. show the discrimination thresholds for a 50 ms condition (open circles) and those for a temporal gap condition (dots) projected on the Δa^*-Δb^* plane for five background colours, and lower graphs are the projections on the Δa^*-ΔL^* plane.

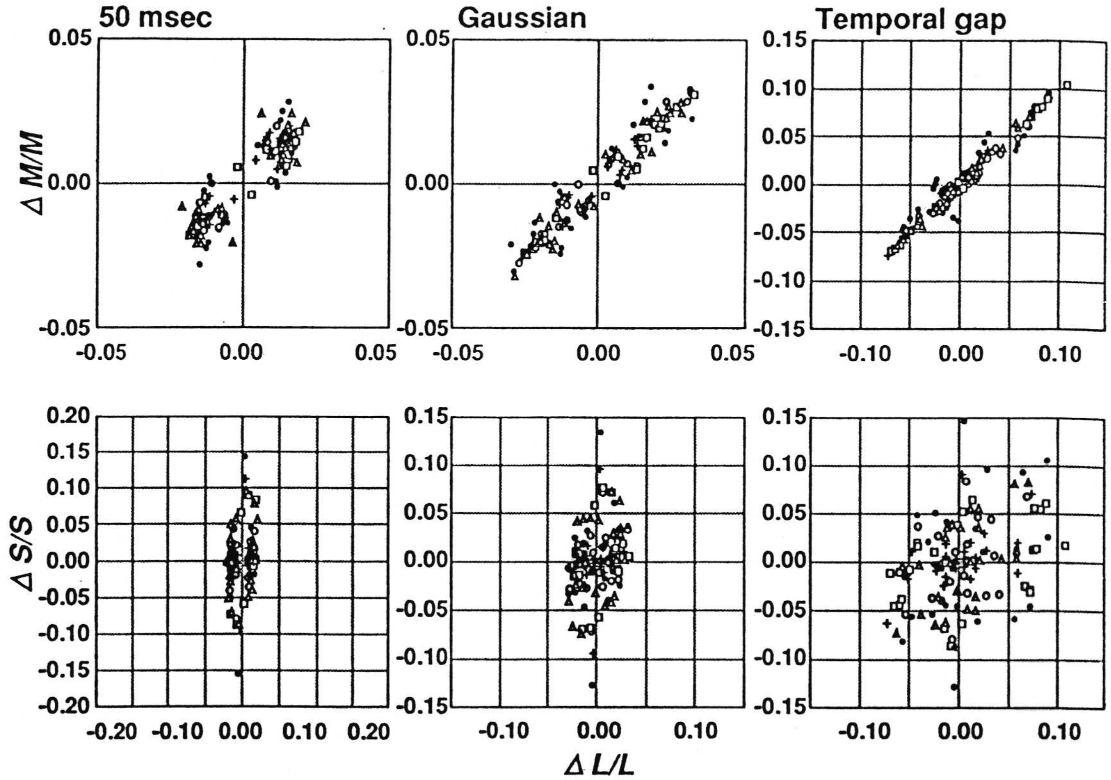

Figure 4.5.2. Discrimination thresholds projected to the $\Delta L/L$-$\Delta M/M$ plane and to the $\Delta L/L$-$\Delta S/S$ plane in the cone-contrast space.

These figures clearly show that the CIELAB space is not uniform in terms of colour discrimination. The differences of L^* between test stimuli and a background colour at discrimination thresholds are less than those of a^*, which means that the value of L^* is underestimated for colour discriminations. Among 26 directions of the test stimulus in the luminance contrast space, we chose three directions that are the closest to the L^*-, a^*- and b^*- axes in order to obtain the cross sections of the discrimination threshold contour and each axis of the CIELAB. Figure 4.5.4 shows ΔL^*, Δa^* and Δb^* at discrimination threshold

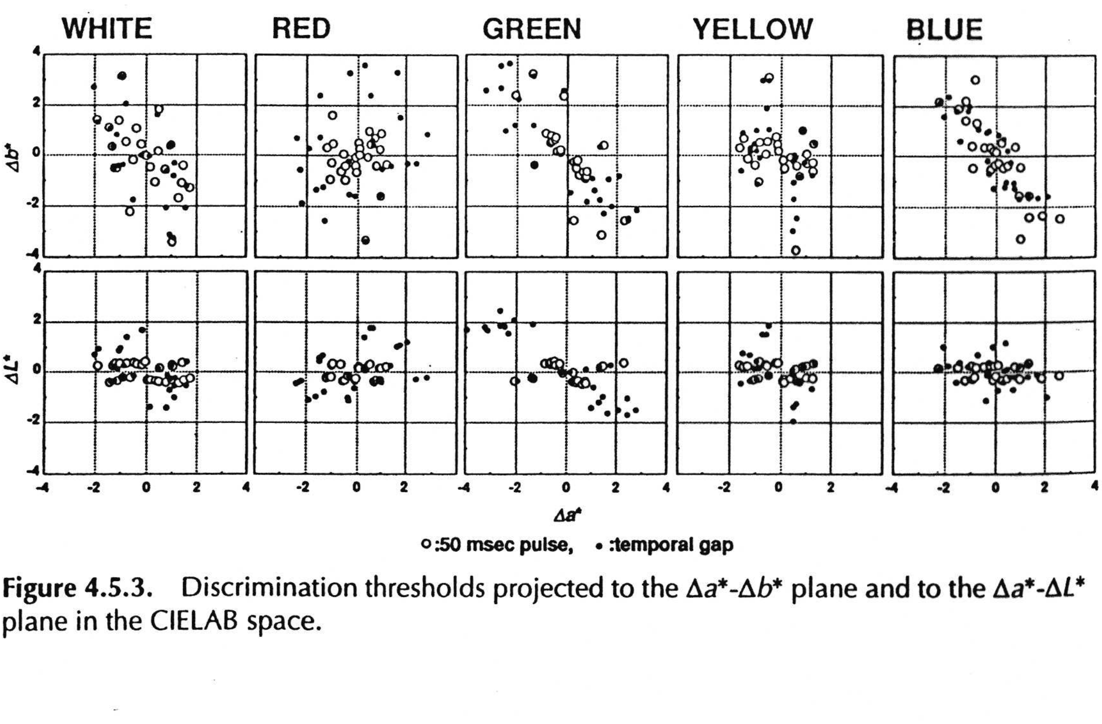

Figure 4.5.3. Discrimination thresholds projected to the Δa^*-Δb^* plane and to the Δa^*-ΔL^* plane in the CIELAB space.

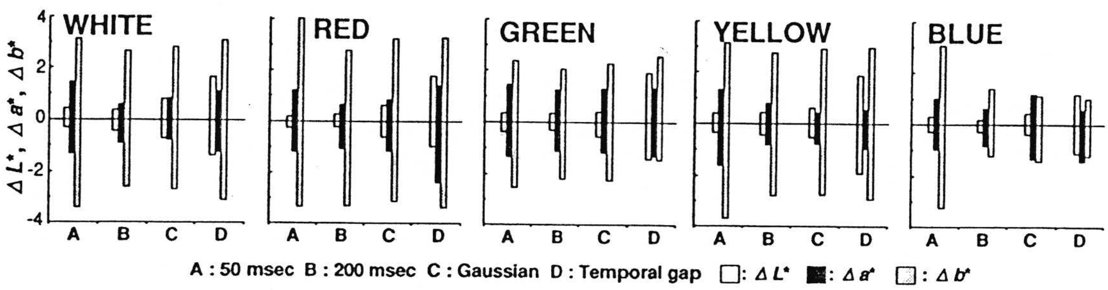

Figure 4.5.4. Differences of L^*, a^* and b^* *between* the test and the background colour at discrimination threshold near L^*-, a^*- and b^*-axis in the CIELAB space, respectively.

near L^*-, a^*- and b^*-axis, respectively. If we compare ΔL^* for different temporal conditions, discrimination thresholds for the test stimuli consisting of a low temporal frequency component such as a temporal gap condition and a Gaussian condition increase toward the L^* direction. On the other hand, discrimination thresholds along the a^*- or b^*-axis were not much affected by changing temporal profile of the test stimulus except for the blue background. Discrimination thresholds for a 50 ms condition with the blue background show an extremely large Δb^* compared with the other conditions. As the deviation of b^* roughly corresponds to changing colour between yellow and blue, the elevation of threshold for a short duration condition seems to reveal the phenomenon of transient tritanopia.

The present study will give a great role in establishing a new formula for evaluation of small colour differences.

4.5.4 REFERENCES

Chaparro, A., Stromeyer III, C.F., Kronauer, R.E. & Eskew Jr, R.T. (1994) Separable red-green and luminance detectors for small flashes, *Vision Research*, **34**, 751–762.

Cole, G.R., Hine, T. & McIlhagga, W. (1993) Detection mechanisms in L-, M-, and S-cone contrast space, *Journal of the Optical Society of America*, **A 10**, 38–51.

Cowan, W.B, Wyszecki, G. & Yaguchi, H. (1984) Probability summation among color channels, *Journal of the Optical Society of America*, **A 1**, 1307.

Kelly, D.H. (1974) Spatio-temporal frequency characteristics of color-vision mechanisms, *Journal of the Optical Society of America*, **64**, 983–990.

Kelly, D.H. & van Norren, D. (1977) Two-band model of heterochromatic flicker, *Journal of the Optical Society of America*, **67**, 1081–1091.

King-Smith, P.E. & Carden, D. (1976) Luminance and opponent-color contributions to visual detection and adaptation and to temporal and spatial integration, *Journal of the Optical Society of America*, **66**, 709–717.

Metha, A.B., Vingrys, A.J. & Badcock, D.R. (1994) Detection and discrimination of moving stimuli: the effects of color, luminance, and eccentricity, *Journal of the Optical Society of America*, **A 11**, 1697–1709.

Noorlander, C. & Koenderink, J.J. (1983) Spatial and temporal discrimination ellipsoids in color space, *Journal of the Optical Society of America*, **83**, 1533–1543.

Smith, V.C. & Pokorny, J. (1975) Spectral sensitivity of the foveal cone photopigments between 400 and 500 nm, *Vision Research*, **15**, 161–171.

Sperling, H.G. & Harwerth, P.S. (1971) Red-green cone interactions in the increment-threshold spectral sensitivity of primates, *Science*, **172**, 180–184.

Thornton, J.E. & Pugh Jr, E.N. (1983) Red/green color opponency at detection threshold, *Science*, **219**, 191–193.