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Analysis of the Difference between the Normal Vision and the Experiencing Cataract Vision on Binocular Color Fusion Limit

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ABSTRACT
The optical instruments design for binocular vision has become an earnest demand towards the arrival of an ageing society. It is necessary to measure how color difference between left and right images by elderly people, which the color rivalry occurs. In this study, we measured the limit of binocular color fusion in the normal vision and the cataract experiencing vision which is aiming to simulate the elderly vision. The result shows that the color fusion limit curve in cataract experiencing vision are very similar with those in normal vision. Compared with the binocular color fusion limit in normal vision $\Delta\lambda_{dn}$, the binocular color fusion limit in cataract experiencing vision $\Delta\lambda_{dc}$ is approximately 3~39nm increased on the central vision, 4~22nm on the retinal eccentricity of 3°, 5~23nm on the retinal eccentricity of 6°, and 5~24nm on the retinal eccentricity of 9°. The results also reveal that a similar limit is observed in the range of 520~560nm in both normal and cataract experiencing visions, which might give some potential evidences for designing 3D equipment. In addition, the minimum value of the binocular color fusion limit exists at 590nm either in the normal vision or the cataract experiencing vision during all retinal eccentricities.
***Keywords* -** Binocular color fusion limit, Cataract experiencing vision, Color rivalry, Normal vision

I. Introduction

When different images are presented to the two eyes, they compete for perceptual dominance, such that one image is visible while the other is suppressed. This binocular rivalry is thought to reflect competition between monocular neurons within the primary visual cortex [1]. When we view a stereogram whose left and right images are of different, but uniform, colors, we perceive a stereoscopic image whose color differs from the color of either image. This property is explained by the theory of binocular color mixing. During the last century, many experiments have been performed using a wide variety of stimuli to investigate the factors for binocular color fusion [2,3]. One of the fundamental problems in understanding the color rivalry process was to measure how much difference of color was permitted before the visual field turns inhomogeneous. Many experiments have already been performed [4-6]. Thomas et al. [4] observed that dichoptic color mixtures were more stable with small stimuli than that with large stimuli. Although some qualitative statements had reported previously, quantitative investigations were firstly carried out by Ikeda and Sagawa [5], who measured the wavelength difference of binocular color fusion (i.e. $\Delta\lambda$) qualitatively for a 1° field at a low luminance level of 0.4cd/m^2 less than 10~50 nm depending on the spectral region with wavelength regions from 420 nm to 680 nm. More recently the conditions for binocular color fusion with non-spectral colors were studied systematically by Qin et al [6]. The range of binocular color fusion limit was qualitatively measured, suggesting that its value was less than 10~80 nm with the wavelength regions from 450 to 650nm. The limit of binocular color fusion became smaller with the increase of the brightness of the stimulus.

All previous studies were based upon the natural color system. Along with the problem of the coming acceleration of global population ageing, population ageing in nowadays is unprecedented and pervasive. Therefore, the optical instruments design for binocular vision has become an earnest demand towards the arrival of an ageing society. It is necessary to measure how color difference between left and right images by elderly people, which the color rivalry occurs. It is well known that human visual functions decline with ageing. To be specific, the crystalline lens transmission in the visible spectrum decreases with ageing, and such decrease is greater for short wavelengths. In this study, a cataract experiencing goggle is used to provide the vision as close appearance of age-related (senile) cataract as possible. It is evident that the main cause of visually significant cataracts is ageing, and age-related cataracts are the focus of many seminars. Moreover, in order to check the consistency of our measurements with the results in the previous studies, the color fusion limit was compared with that obtained in previous studies [5,6]. By doing so, we expect that our quantification of the color fusion limit can be useful for further assisting the design of many optical instruments, such as optical microscopes and three-dimensional displays.

II. Apparatus and Stimuli

The experiment was spatially divided into two parts: one was for experimenter and the other was for the subjects as shown in Fig. 1(a). The subject seated in front of the table and set his chin and forehead on the trestle to fix his head. In the other part, a console computer connected with the 3D display device through a video cable in dark room was used. A special device of 3D display (SANYO, THD-10P3) was used for the measurement in the experiment. The 3D display requiring no special viewing glasses was generated by controlling the path of travel of light from the display so that slightly different images reached the left and right eyes; in other words, the right eye saw only the image intended for it, and so did the left eye. The switching LCD can establish an optical parallax barrier. By displaying the image intended for the left eye and the image for the right eye as a stereographic pair on a TFT LCD, each eye saw only the image intended for it and the brain combined the images and perceives them as a 3D representation. In this experiment we used a cataract experiencing goggle as shown in Fig. 1(b) to simulate the aged-related cataract vision over 70 years old. This goggle was used to simulate the aged-related cataract vision with low spectral transmittance. Incidentally it was evident that the vision which with the cataract experiencing goggle was similar to the appearance before underwent the cataract surgery. In order to check the consistency of our measurements with the results of previous studies, the color fusion limit for 21 point as illustrated in Fig. 1(c) was compared to that in previous studies [4-6].

The range of the dominant wavelength of stimuli was also set from 450 nm to 650 nm with intervals of 10 nm. Twenty-one experimental points being the same with those used in previous studies for non-spectral colors were utilized, and these points with the chromaticity coordinates were plotted in the chromaticity diagram in Fig. 1(c). We carried out the experiments on central and peripheral visions with five subjects. Furthermore, the retinal eccentricity of 3º, 6º and 9º were set to respectively study the relationship between $\Delta\lambda_{dn}$ or $\Delta\lambda_{dc}$ and the multiples of the retinal eccentricity which was set to be linearly increasing.

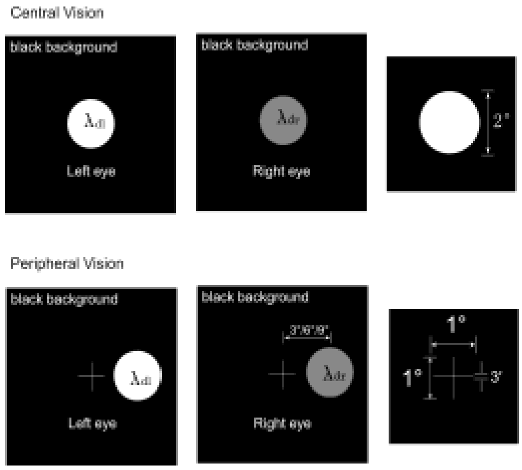

Figure 2. experimental stimulus for each eye comprising a pair of circular patches and cross fixation.

III. Experimental Procedure

The experiment consisting of two steps was carried out in a dark room. Each subject was required to adapt to the dark environment for about 30 min. before the experiment, which has shown to be long enough to remove the chromatic adaptation. In the first step, the stimuli were presented to normal subjects. The exposure time of the stimuli was 15 sec., which was long enough to recognize the perception that was either “fusion” or “non-fusion”. After the response, a new λ_{dr} was selected randomly from 21 experimental points and used for the next exposure, while the dominant wavelength λ_{dl} was kept constant. About one minute interval was required between the two adjacent exposures. Each point was presented 10 times to constitute one session. Totally twenty-one sessions were implemented. In the visual field of peripheral vision, a pair of white cross fixations, which were simultaneously projected on the central fovea of the left and right eye retina, was presented for 3 seconds. The fixation cross was kept constant. Thereafter, the stimulus targets with different dominant wavelength appeared at the retinal eccentricity of 3º, 6º or 9º. Then, the same procedure as on the central vision was carried out. To find out the difference of the fusion limit of two eyes between the normal vision and the elderly vision, a comparative experiment was conducted in the second step, where each subject wearing the cataract experiencing goggle for simulating the elderly vision. The subjects included 5 students aged average of 23 years old with normal or corrected-to-normal visual acuities. Each subject performed a number of trails with the stimuli before manipulating the actual experiment to be familiar with the experimental situation and to insure that they could recognize the stimulus clearly.

(a) (b) (c)

Figure 1. a schematic plan of the apparatus (a), the cataract experiencing goggle to simulated the elderly vision of which over 75 years with cataract (b), and the chromaticity coordinates of 21 experimental stimuli (c).

IV. Results and Discussions

Three examples of the percentage P_d of the uniform homogeneous appearance versus λ_{dr} were shown in Fig. 3, where the results were illustrated for the wavelength of left eye stimulus λ_{dl}=450nm (a), 550nm (b) and 650nm (c). The probability of fusion at each wavelength was calculated as follows:

$$p_d = \frac{\text{Number of homogeneity colour}}{\text{Number of inhomogeneus /alternant colour}}$$

The results show that, with λ_{dr} far from λ_{dl}, whether towards a shorter or longer wavelength, the probability of color fusion decreases and finally became 0% either in normal vision or in cataract experiencing vision. In other words, the visual view of the subject became inhomogeneous or alternate along with the value of the difference between λ_{dr} and λ_{dl} being larger. On the contrary, when λ_{dr} was close to λ_{dl}, the color fusion probability P_d approached to 100%, suggesting that the subject perceived a uniform homogeneity color view. The results in Fig. 3 was quite illuminating to illustrate the characteristics of P_d. In Fig. 3(a), when the stimuli whose wavelength of left eye was 450nm and right eye was 460nm were displayed to both eyes in central vision, all the subjects respond that they could receive the same one single color image. However, when the wavelength of left eye was kept constant and the wavelength of right eye was increased to 470nm, someone began to create one impression with multiple colors rather than only one color, and the color rivalry started to take place once differences increased. Moreover, we also found that the color fusion probability increased with the increment of the retinal eccentricity in cataract experiencing vision.

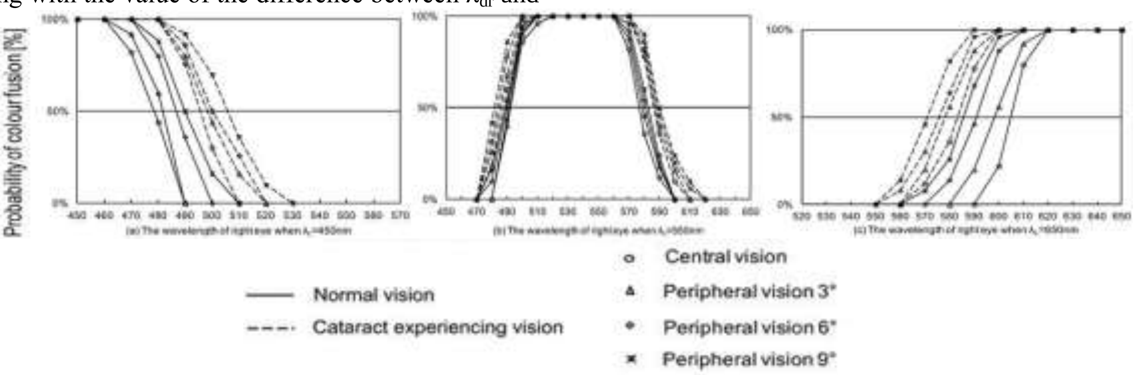

Figure 3. probability curves of color fusion versus λ_{dr} with λ_{dl} =450nm (a), 550nm (b) and 650nm (c).

In order to find out the relationship between fusion limits at each dominant wavelength with the retinal eccentricity, the same calculation used in many previous experiments was adopted [5,6]. The calculation with a 50% fusion criterion was used as the usual specifying threshold. By defining $\Delta\lambda_d$= λ_{dr}-λ_{dl}, two binocular colour fusion limits, i.e., $\Delta\lambda_d$+ and $\Delta\lambda_d$- were measurable. It should be note that, while λ_{dl} locates at the ends of the spectrum, only one $\Delta\lambda_d$+ or one $\Delta\lambda_d$- could be obtained. For example, when λ_{dl} = 450nm, any dominant wavelength λ_R below 450nm could fuse with λ_{dl}, therefore, only one $\Delta\lambda_d$+ was obtained. Similarly, when λ_{dl} = 650nm, only one $\Delta\lambda_d$- was obtained. Color fusion limit curves $\Delta\lambda_d$+ and $\Delta\lambda_d$- with the retinal eccentricity of 0° (central vision), 3°, 6° and 9° were plotted against λ_{dl} in the normal vision and the cataract experiencing vision respectively in Fig. 4.

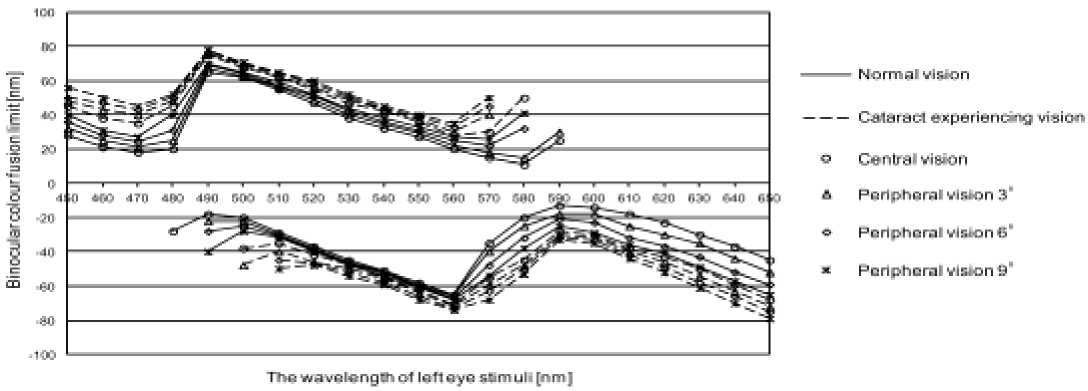

figure 4. binocular color fusion limits in the normal vision and that in the cataract experiencing vision on each visual fields as a function of λ with the fusion probability above 50%.

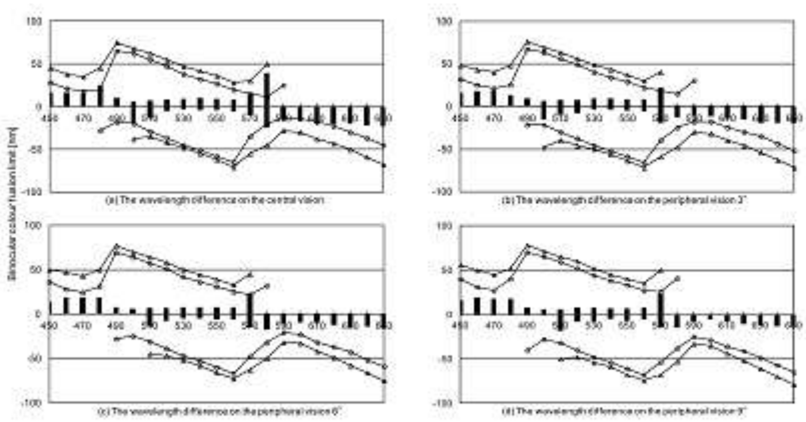

figure 5. the wavelength difference of the binocular color fusion limit between the normal vision and the cataract experiencing vision at each retinal eccentricity.

On the contrary, we tried to find the relationship between $\Delta\lambda_{dn}$ and $\Delta\lambda_{dc}$ with the multiples of retinal eccentricity which was set linearly increasing. The results revealed that there was no relevance arithmetic progression and binocular color fusion limit. Then, we plotted the wavelength difference of the binocular color fusion limit between the normal vision and the cataract experiencing vision at each retinal eccentricity in Fig. 5 (a)~(d). We noticed that the growth of $\Delta\lambda_d$ at the two ends of spectrum was faster than that at the middle section of spectrum with the increment of the retinal eccentricity both in the normal vision and the cataract experiencing vision. The columns show the wavelength difference between the normal vision and the cataract experiencing vision. Moreover, several experiments were conducted to make a qualitative investigation. Compared with the binocular color fusion limit of the normal vision $\Delta\lambda_{dn}$, the binocular color fusion limit in cataract experiencing vision $\Delta\lambda_{dc}$ was approximately 3~39nm increased on the central vision, 4~22nm on the retinal eccentricity of 3°, 5~23nm on the retinal eccentricity of 6°, and 5~24nm on the retinal eccentricity of 9°. We noticed that the $\Delta\lambda_d$ increased steadily with the decrease of the retinal eccentricity of stimuli.

V. Conclusions

In the experiment, the range of the binocular color fusion limit $\Delta\lambda_{dn}$ (or $\Delta\lambda_{dc}$) was investigated. The argument that the binocular fusion became more stable along with $\Delta\lambda_d$ decreasing was confirmed. The presented results also indicated that, the binocular color fusion occurred more stably on the central visual filed than that on the peripheral vision. The stable mixtures were more difficult to be obtained as hue difference increased. Generally, the study of the binocular color fusion limits between the normal vision and the cataract experiencing vision revealed that, the value of such fusion limits in cataract experiencing vision was wider than those in the normal vision. To the best of our knowledge, this was the first report to find out such revelation. It is worth emphasizing that, although the subjects were not the actual elderly, the equipment was able to simulate the conditions as likely as possible.

References

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