Empirical and EEG Evidences On the Fusion Limit of Binocular Vision in Cataract Experiencing Vision

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Abstract

The optical instruments design has become an earnest demand towards the arrival of an aging society. It is necessary to measure the vision difference that can be permitted before the rivalry occurs for elderly people. In this study, we measured the limit of vision fusion in the normal vision and the cataract experiencing vision which is used to simulate the elderly vision. The result shows that, the limit was within a range of 28~75nm in cataract experiencing visions which is approximately 3~39nm increased compared with that in normal visions. It also reveals that similar limit values are observed in the range of 520~560nm both in normal and cataract experiencing visions, which might give some potential evidences for designing three-dimensional equipment. In addition, EEG-based experimental results show that the middle alpha-variant rhythm is bigger than the fast alpha-variant rhythm when binocular fusion appears, while becomes smaller when binocular rivalry appears.

Keywords: Binocular visions, cataract experiencing vision, normal vision, fusion limit, goggle

1. Introduction

Over a century of research has revealed the richness of stereoscopic vision in generating percepts of the three dimensional (3D) form (Anderson and Nakayama 1994). Science Wheat stone's (1838) invented the stereoscope; it has been known that the different views projected to our two eyes contain information that is used to recover depth. It also had been realized that the two eyes have slightly different views of the world contribute to the perception of depth. Many of the organisms, including humans, perceive the outside world with both eyes, grasping a two-dimensional retinal image that is captured by each eye as a common single image. This phenomenon is known as binocular fusion which means that similar images presented to the two eyes appear as one and are processed simultaneously rather than successively (Howard and Rogers 1995). Fusion limit (i.e. diplopia threshold) denotes the largest retinal disparity between two images for which the impression of a single fused image can be maintained. It has a pronounced influence on the generation of the percepts of 3D because goods are sterically recognized by the deviation of the retinal image generated in the position of the two eyes (i.e. binocular parallax).

In contrast, viewing dissimilar images yields perceptual alternations competing for dominance, and this is known as binocular rivalry (Blake 1989; Blake and Logothetis 2002). Although various techniques have recently received much attention in the broadcast research community as a promising technology for three-dimensional television (3D TV) systems (Zhang and Tam 2005), the dominant problem associated with binocular vision still was that of explaining how a single unified visual percept is formed from the inputs from two eyes (Takase et al. 2008) since any optical instrument, especially 3D displays, should be designed to avoid the unpleasant and annoying binocular rivalry.

It is greatly required to investigate and quantitatively determine the fusion limit of binocular vision, which could provide fundamental guidelines to create optical instruments, to design 3D TV, etc. Much attention has paid in recent years to determine the quantitative fusion limit for normal vision. Extensive color mixture data for a wide range of spectral and non-spectral colors were reported in the literature (Thomas et al. 1961; Weert and Levelt 1976). The color fusion limits of spectral colors and white light were studied by Ikeda et al.

(Ikeda and Sagawa 1979; Ikeda and Nakashima 1980). The experiments were conducted to find out the wavelength difference permissible before the fusion disappears. The color fusion limit was quantified as a function of the wavelength for the spectral colors. The results showed that the wavelength difference for the binocular fusion limit could be measured by gradually separating two wavelengths until the colored visual field turned inhomogeneous and that it varied from 10 nm to 50 nm depending upon the wavelength regions investigated. They also reported that the binocular color rivalry would occur whenever mutually opposing color components were perceived in the respective eyes. Recently, Qin et al. (2009) developed the works of Ikeda by verifying the effects of luminance and size of stimuli upon the binocular fusion limit. They reported that the binocular color fusion ceased when the color difference introduced between the left and right eyes exceeded a certain threshold value, and the fusion limit became smaller with the increase of the luminance of stimuli. Previous works concerning the fusion limit of binocular vision are all based on normal visions. Rare works are reported upon the cataract vision. Along with the arrival of the aging society, the optical instruments design for elders has become an earnest demand (Asbell 2005). In this study, we measured the limit of vision fusion in the normal vision and the cataract experiencing vision which is used to simulate the elderly vision, using a 3D display connected to a computer to present experimental stimuli conveniently. Thus, the spectral stimuli including shape, size, position and color for both eyes can be accurately controlled. The range of the dominant wavelength of all stimuli was set from 450 nm to 650 nm. By doing so, we intended to study the difference of the fusion limit between normal vision and cataract vision, which might give some suggestions for the design of optical instruments for elders. In addition, we also carried out EEG based experiments to further find out the relationship between the fusion limit and the brainwave rhythm.

2. Experimental Method

A SANYO micro-polarizer type 3D display device (THD-10P3, resolution 640×480, refresh rate 60Hz) was used to present experimental stimuli dichoptically. The Active Two System produced by Bio Semi Inc. with 64 channels were employed to acquire the signals of the brain activity. The original data is analyzed by the EEG lab which is the toolbox for processing continuous and event-related EEG using independent component analysis (ICA), time/frequency analysis, artifice rejection, and several modes of data visualization. The experimental environment was design as shown in Fig. 1, where the subject seated in front of the display device and was presented dichoptically a binocular view through the optical polarization action of the image splitter installed behind the liquid crystal display panel. The distance between the subject and the display device was set to 70 cm. The diameter of circular stimuli was approximately 2.5 cm, subtending the visual angle 2°. A chin-rest and head-rest system was utilized to fix the head of the subject against sliding. All experiments were carried out in a darkroom and each subject was required to adapt for the dark environment about 15 min. within the darkroom (Qin et al. 2009). A specialized goggle (produced by the government of Ontario, Canada) was used for simulating the cataract. Considering brightness reduction caused by the spectral transmittance of the crystalline lens of the elderly (Van Den Berg and Tan 1994), the intensity of the simulation light was set to 30cd / m2.

A left eye stimulus with wavelength of $\lambda_L$and a right eye stimulus with wavelength of $\lambda_R$were set respectively. The subject gradually increases the disparity in fused dischoptic stimuli until the subject reports diplopia. Then starting with the stimuli well separated, disparity is decreased until the subject reports fusion. In addition, in EEG based experiments, the fast and middle alpha-variant rhythms (Markand 1990) on the front of the brain (locations Fp1, Fpz and Fp2) were recorded and analyzed. The fast alpha-variant rhythm (11~13 Hz) is reported to be related with the state of conscious concentration, while the middle alpha-variant rhythm (9~11 Hz) appears when the subject is under relaxation. In the experiment, the wavelength of the stimuli for the left eye in blue colors was set to be 450~650 nm with equal intervals of 10 nm, and that for the right eye in yellow colors was also set to be 450~650 nm with the same interval. Thus, we obtained 21 experimental points whose chromaticity coordinates can be plotted in the CIE 1976 chromaticity scale diagram. First, a white fixation cross mark which was subtended a visual angle of 1° arc was presented for 3 seconds. Thereafter, the fixation dot was kept constant. The stimulus targets (i.e. the two circular patches) appeared and lasted for 15 seconds at the same time. Five subjects aged average of 25 years old with normal visions were asked to wear the specialized goggle and the EEG equipment. Then all subjects were required to respond “fusion” or “non-fusion”. After the response, the experiment was repeated 10 times, and afterward another experiment was successively carried out based on another experimental point.

3. Results and Discussions

Fig. 2 summarized three examples of the experimental results when the wavelength for the left eye was set to λ_L=450 nm (Fig. 2(a)), λ_L=550 nm (Fig. 2(b)), and λ_L=650 nm (Fig. 2(c)) respectively. In Fig. 2, the horizontal axis represents the wavelength of stimuli for the right eye (λ_R), and the vertical axis denotes the probability of the binocular fusion, which is calculated by the ratio of the response of "fusion". The value of 0% means that all subjects responded "non-fusion" for a single experimental point, while the value of 100% indicates the consistence of the binocular fusion. Comparative experiments were performed by asking the subjects to put on or put off the goggle, aiming to establish the experimental environment of normal vision or cataract experiencing vision respectively.

The experimental results in Fig. 2(a) showed that when λ_R belongs to 450~470 nm, the binocular fusion rate is nearly 100% when λ_L=450 nm, suggesting that binocular fusion appears when the difference of wavelength for both eyes are within a small disparity. In other words, with λ_R very close to λ_L, the color fusion probability becomes 100% and the subjects perceived an uniform homogeneity color view. In contrast, with λ_R far fromλ_L, no matter it is towards a shorter or longer wavelength, the probability of color fusion approaches to 0%. In these conditions, the subjects experienced an inhomogeneous appearance. Similar results can be observed from Fig. 2(b) and (c). It is worth pointing out that the color fusion forms the inverse relation with the wavelength difference of two eyes for both the normal vision and the experiencing cataract vision. Furthermore, to further quantitatively investigate the fusion limit, we define $\Delta\lambda = \lambda_R - \lambda_L$ since there are transitions of the probability from 0% to 100% and 100% to 0% in both sides of λ_L. Fig. 3 illustrated the binocular fusion limits of the normal vision and the experiencing cataract vision as a function of λ_L with the fusion probability above 50%, where two binocular color fusion limits Δλ+ and Δλ- are determinable using a probability of 50% as the usual specifying fusion threshold. In Fig. 3 the inner distance of the curves denotes the difference of wavelength permissible before the binocular fusion disappears. The horizontal axis represents the wavelength of stimuli for the left eye and the vertical axis shows the binocular color fusion limit. The length of the bar graph denotes the difference of the fusion limit between the normal vision and the experiencing cataract vision. The upper and lower trend lines indicates the Δλ+ and Δλ- respectively.

From Fig. 3, it can be found that the binocular fusion limit for normal vision is 11~65 nm at the side of Δλ+, and 13~65 nm at the side of Δλ-. That is to say, the interval of the binocular fusion limit for normal vision is 11~65 nm. On the other hand, for cataract experiencing vision, the fusion limit is 28~75 nm at Δλ+ and 28~71 nm at Δλ-, indicating the interval of the fusion limit for cataract vision is 28~75 nm. The comparative results suggested that the fusion limit in cataract experiencing visions is approximately 3~39nm increased compared with that in normal visions, which would give some guidelines for designing optical instruments for the elderly. Besides, experimental results in Fig. 3 also showed that the minimum fusion limit for both normal and cataract visions appears when λ_L is 520~560 nm. To give more certification on the fusion limit, EEG based experiments were carried at the same time with the above experiments. The fast and middle alpha-variant rhythms on the front of the brain (locations Fp1, Fpz and Fp2) were recorded and analyzed. Fig. 4showed the EEG based energy variation diagram obtained by EEGlab (left figure) and the locations Fp1, Fpz and Fp2 used in the experiment (right figure).From this figure, it is clear that the binocular fusion of cataract experiencing vision shows strongly correlation with the EEG. To be specific, the data were depicted in Fig. 5 where the horizontal axis denotes the rhythms of the EEG in hertz, and the vertical axis represents the value of the energy calculated by EEGlab. The left subfigure in Fig. 5 illustrates the diagram obtained when binocular fusion appears, while the right one shows the diagram of the binocular rivalry (i.e. when the subjects respond "non-fusion"). Fig. 5 clearly indicates that middle alpha-variant rhythm (9~11 Hz) is bigger than the fast alpha-variant rhythm (11~13 Hz) when binocular fusion appears, while becomes smaller when binocular rivalry appears on all tested electrodes.

4. Conclusion

In this study, we measured the limit of vision fusion in the normal vision and the cataract experiencing vision which is used to simulate the elderly vision. Experimental result shows that, the limit was within a range of 28~75nm in cataract experiencing visions which is approximately 3~39nm increased compared with that in normal visions. It also reveals that similar limit values are observed in the range of 520~560nm both in normal and cataract experiencing visions, which might give some potential evidences for designing three-dimensional equipment.

In addition, EEG-based experimental results show that the middle alpha-variant rhythm is bigger than the fast alpha-variant rhythm when binocular fusion appears, while becomes smaller when binocular rivalry appears.

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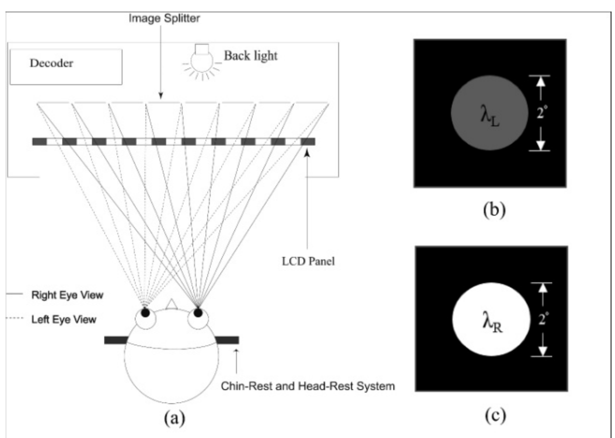

Fig.1: A schematic plan of three-dimensional display (a), and experimental stimuli consisted of a left eye stimulus with wavelength of λ_L (b) and a right eye stimulus with wavelength of λ_R (c).

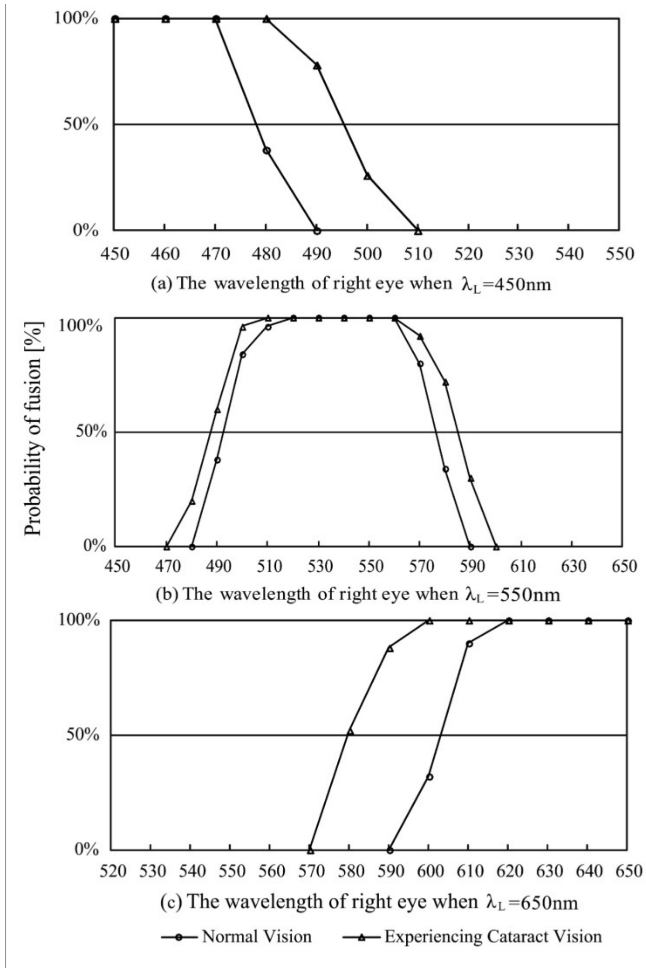

Fig. 2: Probability curves of color fusion versus λ_R with λ_L =450(a), 550(b) and 650nm(c).

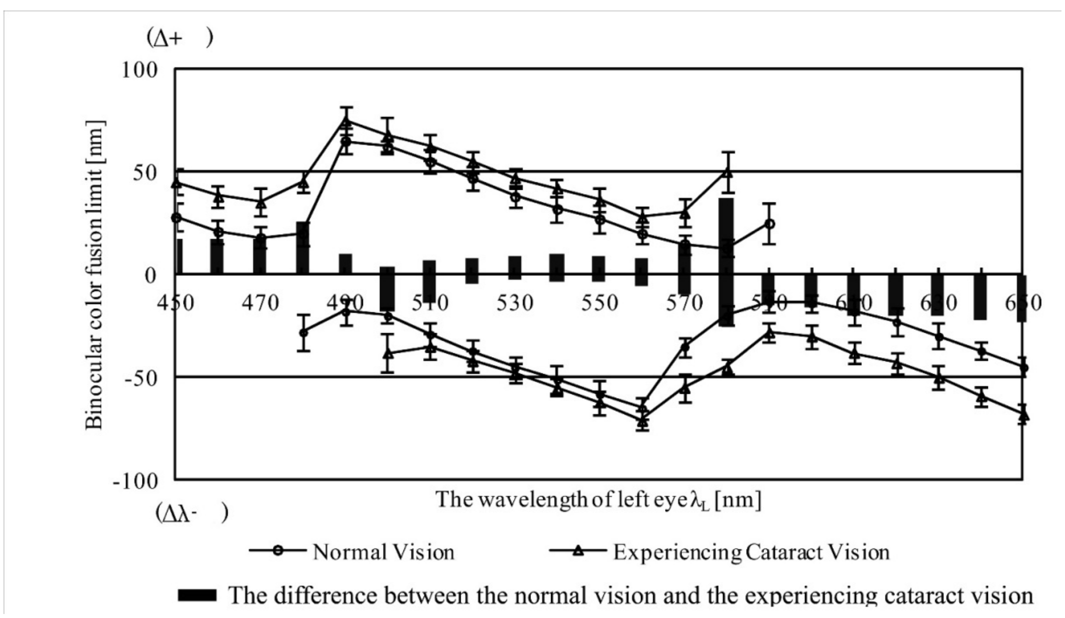

Fig. 3: Binocular fusion limits of the normal vision and the experiencing cataract vision as a function of λ_L with the fusion probability above 50%.

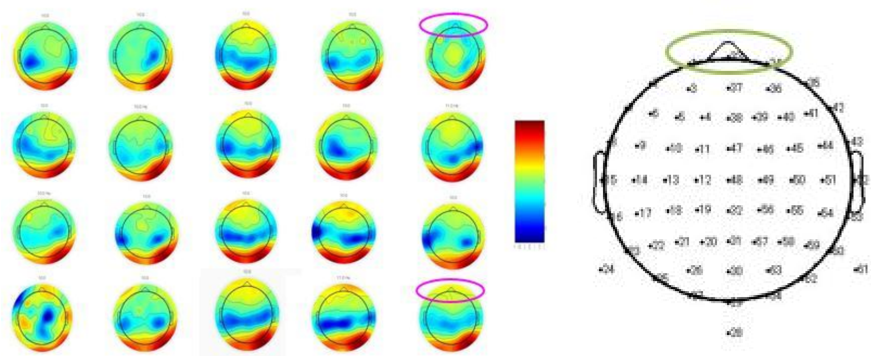

Fig. 4: The EEG based energy variation diagram obtained by EEGlab (left) and the locations Fp1, Fpz and Fp2 used in the experiment (right).

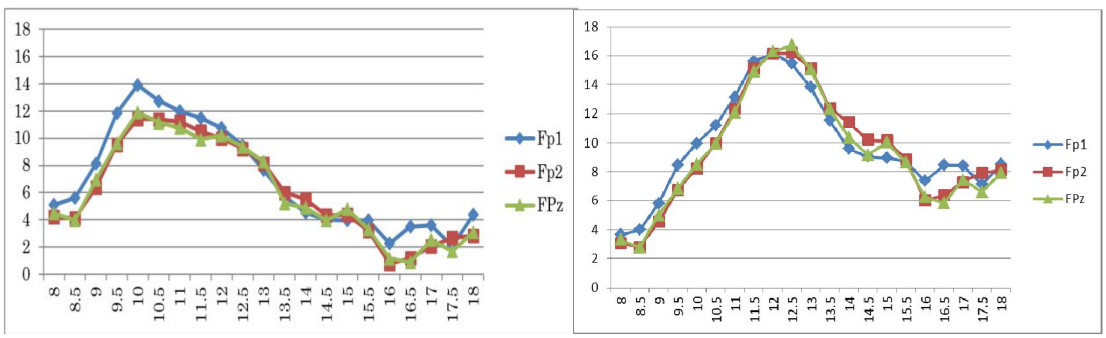

Fig. 5: The values of energy variation diagram of EEG recorded on Fp1, Fp2 and Fpz. (left): binocular fusion; (right): binocular rivalry.