Ergonomic Evaluation of Color Breakup in Field-Sequential Color Projection System

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Abstract
A field-sequential color projection system can display color images using a single panel. However, it suffers from a characteristic trichromatic separation known as "color breakup". The viewing of images exhibiting color breakup may cause visual fatigue and mental stress. In this study, the authors examine, from the standpoint of human factors, the objective and subjective symptoms that can result from the viewing of images with color breakup.

1. Introduction

The use of projector systems has recently been increasing in such applications as business and home theaters. This trend is driven by the lighter weight of modern projectors, their lower cost, and their higher screen resolution. Further, rear projection televisions with enlarged screens have been attracting attention as a third type of flat-screen television. Projector can be classified as display devices, and the field-sequential color projection system makes it possible to present color images using a single panel (Figure 1). Although the use of a single panel can reduce projector size and cost, field-sequential color projection may result in observed trichromatic separation during times of rapid eye movement. Called "color breakup" (Figure 2), this phenomenon may cause discomfort and even visual fatigue in the observer.

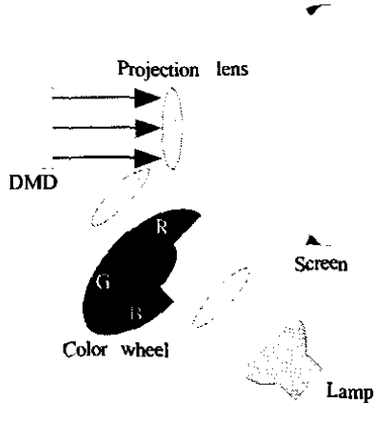

Figure 1 Field-sequential color projection system

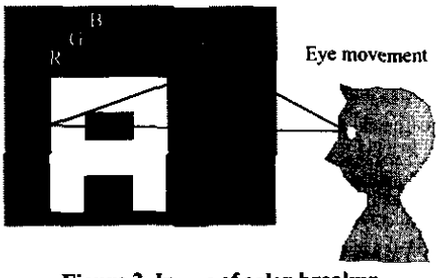

Figure 2 Image of color breakup

Examinations by the authors have confirmed that color breakup caused by field-sequential projection may contribute to temporary visual fatigue and observer discomfort [1]. In this paper, the authors examine the effects of color breakup as manifested through biochemical indices of stress response and subjective symptoms of asthenopia through two experiments. The purpose of the study was to compare and examine the effects of color breakup on such practical activities as viewing movies in a home theater from the viewpoint of the possible mental stress and asthenopia caused.

2. Measurement of Mental Stress

Conventional stress markers are measured cortisol or catecholamine levels in the body. However, the measurement of salivary chromogranin A (CgA) has

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recently received attention as an index of psychosomatic stress response. CgA is a major protein in adrenal chromaffin cells and adrenargic neurons. It is reported that CgA and catecholamines are co-released into the extra-cellular environment during stress [2]. A characteristic of CgA is that it is a response only sensitive to psychosomatic stress. For that reason, the authors decided to measure salivary CgA as an index of psychosomatic stress in this study.

3. Experiment 1

3.1 Purpose

The purpose of experiment 1 was to examine the effects that differences in presentation method and changes in frame frequency of the color wheel have on the observer from the viewpoint of mental stress and asthenopia.

3.2 Methods

A front projector and rear projection television were used in this experiment. The type of projector was taken as the experimental parameter (Table 1). Field-sequential projectors (DLP projectors) with different frame frequencies of the color wheel were used for experimental conditions 1, 2, and 3. A liquid-crystal projector (LCD projector) was used for experimental condition 4. A field-sequential rear projection television (DLP-PTV) was used for experimental condition 5. The frame frequency of DLP-PTV was 120 Hz. A liquid crystal rear projection television (LCD-PTV) was used for experimental condition 6. Each projector was adjusted for equal luminance at the screen center when white was projected over the entire screen.

Table 1 Experimental conditions (1)

Condition 1	DLP projector (120 Hz)
Condition 2	DLP projector (180 Hz)
Condition 3	DLP projector (300 Hz)
Condition 4	LCD projector
Condition 5	DLP - ProjectionTV
Condition 6	LCD- ProjectionTV

The stimulus was the same for all six projectors: images selected because they generated significant color breakup when projected using a DLP projector. The visual targets were square, circle and triangle shapes, and these were alternately presented to the right and left sides of the screen at 5-second intervals. That is to say, the eyes of the subjects were caused to move horizontally to view a new figure every five seconds. The order of presentation of the figures was random. In order to ensure that subjects paid full attention to the visual targets during image presentation, they were required to click a hand-held button whenever the circle was seen. Projectors were selected in random order and images were projected using each projector for 5 minutes. The stimuli were presented on a 100-inch screen that adjusted so its center corresponded to the height of the observer's eyes. Observers were seated in a chair placed directly in front of the screen at a viewing distance of 250 cm. To determine the level of mental stress and visual fatigue suffered by the subjects, saliva samples were taken and subjective asthenopic symptoms characterized both before and after the presentation of the images. The subjective asthenopic symptoms were characterized according to a 5-point self-rating method. Five of Suzumura's subjective symptoms for asthenopia were selected in this evaluation of asthenopic complaints: eye fatigue, eye oppression, eye pain, eye heaviness, and sensitivity to bright light. These symptoms were chosen as characteristic complaints resulting from color breakup as determined in a preliminary experiment by the authors. Experiments were limited to two experimental conditions per day per subject. It was considered that two conditions could be tested in one day if an interval of at least two hours was allowed between tests. Experimental conditions were chosen in random order. The subjects were eight males, all in good health, with normal color perception and not on any medication.

3.3 Results

Measured densities of salivary CgA were corrected for the density of total protein and recorded in mol concentration per mg of protein. The measured values were converted into rates of change based on the value measured before the presentation of images. Figure 3 shows the average rate of change obtained for each condition.

When using the DLP projectors, the rate of change tended to be lower with higher frame frequency. Further, the rate of change when using the LCD projector was the lowest of the four projector types. Among the rear

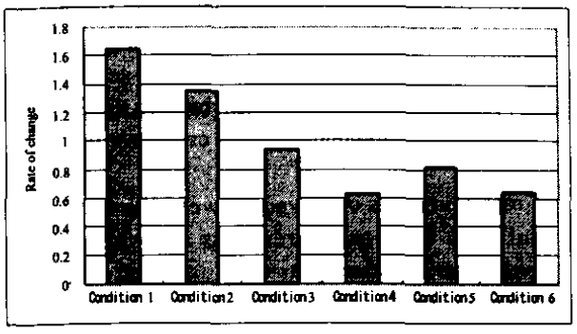

Figure 3 Rate of change of salivary CgA

projection televisions, the rate of change with the LCD-PTV was lower than that with the DLP-PTV -a tendency similar to that obtained with the projectors. Moreover, the results obtained for the subjective asthenopic symptom "sensitivity to bright light" exhibited a similar tendency to rate of CgA change (Figure 4). This symptom is a characteristic response to color breakup. A change in mental stress was indicated even after viewing an image with significant color breakup remarkably for only a short time (five minutes). These results strongly suggest that images exhibiting color breakup cause mental stress in the observer.

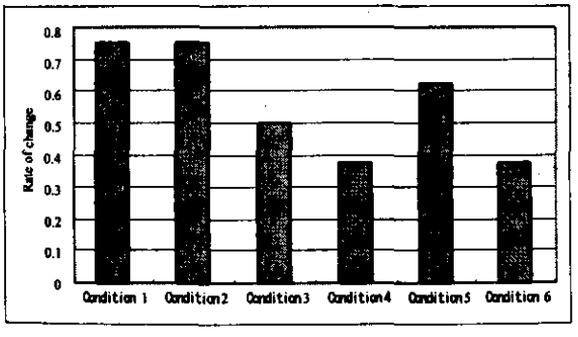

Figure 4 Rate of change of subjective asthenopic symptoms

4. Experiment 2

4.1 Purpose

The purpose of experiment 2 was to examine the effects of different presentation methods on an observer during such practical applications as viewing movies in a home theater from the viewpoint of a mental stress and asthenopia

4.2 Methods

A DLP projector and an LCD projector were used in this experiment. The frame frequency of the DLP projector was 120Hz. The stimuli were 15-minute movie sequences extracted from popular movie and drama titles and chosen for their particularly severe color breakup. Each sequence was prepared in two variants, one with an English soundtrack and Japanese subtitles and the other with a Japanese soundtrack and no subtitles. This extra parameter was included because examinations by the authors have previously suggested the possibility of mental stress being induced by color breakup when subtitles are read from the screen. The experimental conditions are shown in Table 2.

Each experimental condition was tested using two movie sequences (pattern A and pattern B) so as to remove any effect generated by the movie content itself. The experimental environment and the procedure were the same as in experiment 1. Experimental conditions were chosen in random order. The subjects were eight males, all in good health, with normal color perception and not on medication.

Table 2 Experimental conditions (2)

	DLP projector	LCD projector
Japanese subtitles and English soundtrack	Condition 1	Condition 3
No subtitles and Japanese soundtrack	Condition 2	Condition 4

4.3 Results

As in experiment 1, the measured salivary CgA density was corrected for the density of total protein and given in units of mol concentration per mg of protein. Each measured value was converted into a rate of change based on the value measured before the presentation of images. Figure 5 shows the average rate of change for each experimental condition. The average rate of change when the images were presented using the DLP projector (experimental conditions 1 and 2) tended to be greater than when the LCD projector was used (experimental conditions 3 and 4).

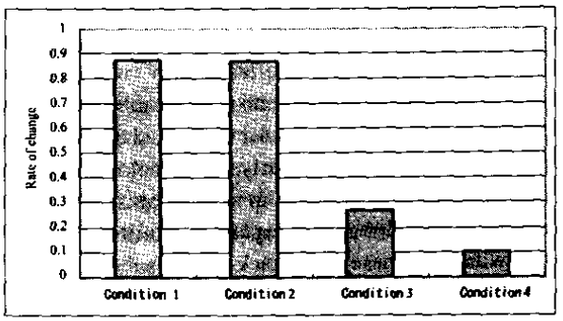

Figure 5 Rate of change of salivary CgA

The interviews indicated that impressions of asthenopia varied according to the content of the sequences presented, even though two kinds of sequence were used with the aim of avoiding variations in stress. As a consequence of this, each stimulus pattern was analyzed (Figure 6). With pattern A, the change rate when presented under experimental conditions 1 and 2 tended to be higher than for experimental conditions 3 and 4. This was inferred to be a difference resulting from the type of projector. With pattern B, the change rate for each condition was little difference. For experimental conditions 1 and 3 when sequences were presented with subtitles, the change rate tended to be low. As for the results by sequence type, the main reason was that there were a lot of scenes where the color breakup happens in the image, and the switch of the scene was fast in pattern A.

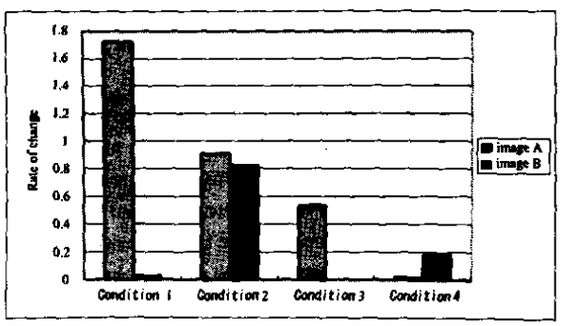

Figure 6 Rate of change of salivary CgA (image pattern A and image pattern B)

5. Conclusion

From the results of these experiments, the following conclusions were drawn:

(1) Color breakup caused by the field-sequential projection system may contribute to temporary visual fatigue and mental stress even over the short term.

(2) Correlation was observed between the results of salivary CgA measurements and subjective symptoms of asthenopia.

(3) The increment in mental stress after image presentation tended to be lower as the frequency of DLP increased.

(4) There was no difference in measured stress according to the type of presentation system (front projector and projection TV).

(5) Color breakup may cause mental stress even while enjoying movies in a home theater.

(6) The effect of the subtitles in presented material is smaller than the effect of the material itself.

Visual stimulation is a very important means of receiving information. Though image sequences were presented for short periods only in this study, the enjoyment of movies in home theaters may in fact continue for extended periods of time. The results of these experiments suggest that extended viewing may have a negative effect. In the future, the authors aim to examine the effect of movie viewing on the observer in greater detail and also look into how visual information is accepted by measuring eye movement.

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