Achromatic Induction of Contrast Threshold in Spatial Frequency Modulation

E. Jafarzadehpur[*]*, S.M.P. Firoozabadi*[**]*, B. Hashemi*[**]*,*
S.M.M Shushtarian[***]*, and A. Kazemnezhad*[**]
[*]*Iran University of Medical Science, Tehran, Iran*
[**]*Tarbiat Modares University, Tehran, Iran*
[***]*Azad University Medical Center Tehran Iran*

Introduction

Dynamic range of human visual system is one to billion. This expanded range provides a good capability for human visual system discriminate color, spatial and temporal changes in different luminous conditions. One of the psychophysical methods for evaluation of visual system function is contrast sensitivity. The contrast sensitivity function not only is used in visual system evaluation but also for image processing.[1] The contrast sensitivity is "minimum luminance differences that is necessary for edge detection".[2] Three mechanisms 1- pupil size changes 2- ascending nerve activation changes and 3- photo pigment level in retina[3] can affect the contrast sensitivity function.

Material and Methods

In this study, spatial luminance changes and visual system responses have been evaluated in different background conditions. Twenty-six normal young male volunteers were tested in this study. The subjects sat on a comfortable chair at the distance of 4.5 meter from a 17" flat monitor. They were tested in the photopic condition. The horizontal angle of the pattern was 4 degrees and its vertical angle was 3 degrees. Every subject was encountered randomly to a black or white background. Some definite points were changed from black or white, to white or black (figures 1,2) according to a Pattern Generator Program.[4] Contrast was calculated by Michelson equation.[5] Three spatial frequencies (2 cpd, 5 cpd and 25 cpd) were chosen randomly for the first, second and third exam.

Results

The average of contrast for black background in 25 cpd spatial frequency is 5.8% and for white background in the same spatial frequency it is 8.1%. Analysis of variance and LSD test shows that there is a significant difference ($p<0.01$) between black and white backgrounds in 25-cpd spatial frequencies.

In the 5-cpd spatial frequency contrast threshold for black background is 1.2% while it is 1.8% for white. The t-test indicates a significant difference between them ($p<0.0001$). But in pooled data, as the 25 cpd is very high small changes cannot be differentiated significantly.

Similar result can be seen in the 2-cpd spatial frequencies. The t test indicates that the average of contrast threshold for black background (1%) is significantly ($p<0.0001$) less than that of the white background. But in the pooled data with 25 cpd as the average and standard deviation of the 2 cpd is prominently less than that of 25 cpd, the comparison of white and black background in the 2 cpd doesn't show any significant difference ($p=0.07$) by the LSD test.

Comparison of different spatial frequencies by LSD test shows significant differences ($p<0.01$) between the 25 cpd and the 5 cpd and also between the 25 cpd and the 2 cpd. But the LSD test shows no significant difference between the 5 cpd and the 2-cpd spatial frequencies. The t-test shows a significant difference between the 2 cpd and the 5 cpd only in black background ($p<0.04$).

Discussion and Conclusion

The result show that there are significant differences in contrast threshold in different background (figures 1,2) color and spatial frequencies as consequences of different responses of visual system. It is consequence of three mechanisms that mention above.[3] As we consider the method in this respect, it can be deducted that the second mechanism is the most important mechanism in our experiment. Because the environmental light and adaptive condition (photopic) were constant for all of the subjects, therefore papillary size and pigment density has been the same.

One of the most important criteria for second mechanism is a Weber-Fechner criterion (Eq. 1)

$$\Delta I/I = cte \qquad (1)$$

In this equation, "I" is background luminance and ΔI is the luminance that is added to the background luminance for discriminating spot light from background. According to this equation the perceived luminance depends on background luminance.[6] In addition, if the luminance of background increases, the difference of background and foreground (ΔI) will be increased proportionaly. In the white background, the luminance of background was more than that of the black background; therefore, base on the above equation ΔI must be increased proportional to I. As the ΔI increases the contrast will be increased. However, the contrast threshold that recorded in the white background was higher than that of the black background in all the situatios.

As we set the spatial frequecy modulation and contrast induction in a way that they change gradually in ascending (ΔI+I for black background) and descending (I-ΔI for white background) manner, based on Wber-Fechner equation we expect that the ΔI/I ratio would remain constant, while this was not seen for the descending procedure and can be used only for the ascending mechanism. In fact Weber- Fechner equation predicts that in a fixed and definite luminance and background condition for the cone function the contrast responce must be constant. But as we showed there are significant differences in the contrast threshold in different spatial frequencies. Therefore, Weber – Fechner equation and Baker function[7] can not describe the results completely. Other phenomena such as lateral inhibition may help to explain the result.[8] This phenomenon increases the contrast sensitivity and decreases the threshold. This phenomenon that explain Mach Band[9] and contrast enhancement, may be useful to describe depression of contrast threshold by decreasing spatial frequency.

The results show that as the spatial frequency increases, the contrast threshold increases nonlinearly. Threshold changes are more prominent in high spatial frequency. Another point is that we used the square wave pattern in this study instead of the sine wave used usually in routine clinical examination. When the sine wave pattern is used, the contrast threshold increases as the spatial frequency goes down from 5-cpd.[10] But in this study, with the square wave pattern, we saw a similar band pass filtration only for the white background, while a low pass filtration was observed for the black background.

In psychophysical tests primary stimulation and background could be very important to the final response. On the other hand final results should be reported with respect to the primary situation, otherwise, the results might not be very useful for the description of visual system.

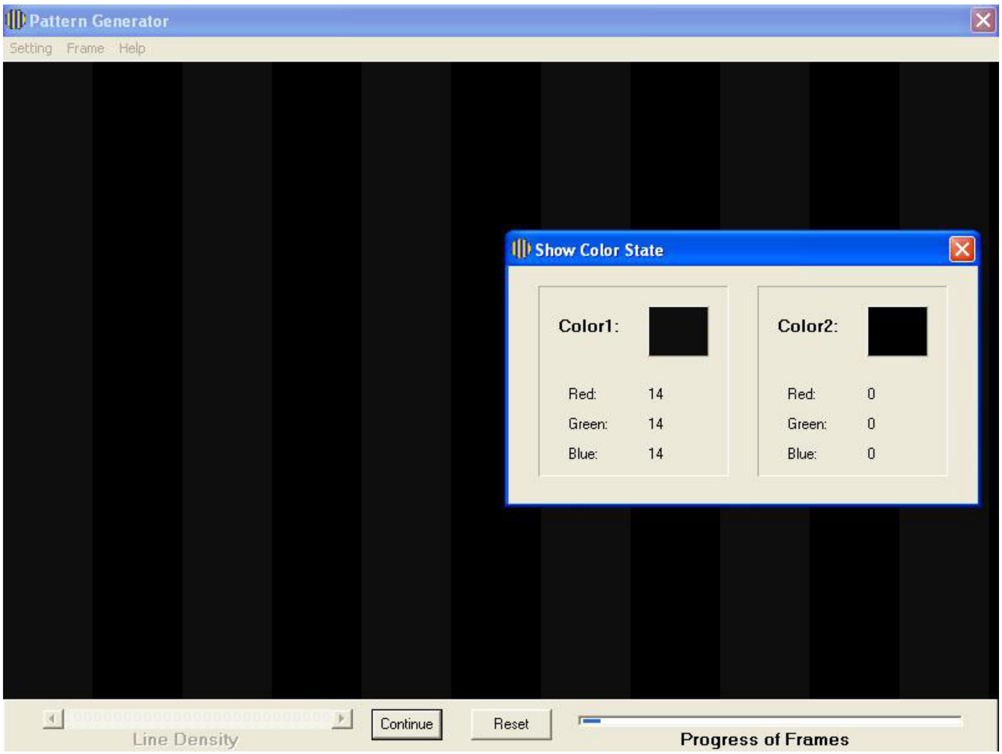

Figure 1. Black background needs more contrast for pattern recognition.

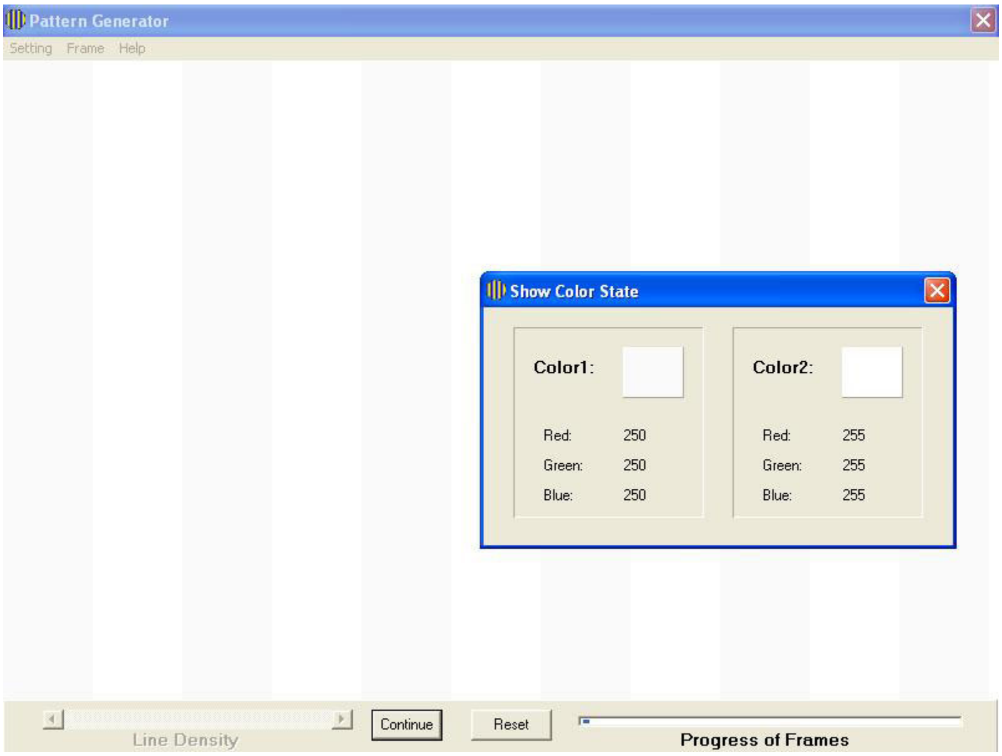

Figure 2. White background needs less contrast for pattern recognition.

References

1. Marr, D., Visual information Processing, Bio. Sci., 1980, 290:199-218.
2. Berkley M.A., Kitterle F., Grating visibility as a function of orientation and retinal eccentricity, Vis. Res 1975; 15:239-44.
3. Gvardovski V.I., Calvert P,D., Photoreceptor lights adaptation, J Eur. Physiol. 2000, 116:6: 791-4.
4. Jafarzadehpur E., Firuzabadi S.M., Hashemi B., Design and establishment of soft ware and hard ware for pattern generation in VEP, The fifth Iranian congress of medical physics proceeding 19-20 May 2002, pp. 83-84.
5. Arden G.B., Testing Contrast sensitivity in clinical practice, Clin Vis. Sci. 1988,2:213-224.
6. Johnson K.O., Stao H., Neural coding and the basic low of psychophysics, Neuroscientist, 2002, 2: 111-21.
7. Hamer R.D., Computational analysis of vertebrate phototrasduction, Vis. Neurosci 2000, 5:679-99.
8. Tardif E., Richer L., Spatial resolution and contrast sensitivity of single neurons in area 19 of split – chiasm cats. Eur. J. NeuroSci. 1997, 9: 1929-39.
9. Sjostrand E.S., A neural mechanism improving visual acuity by contrast enhancement, J. Submicrosc. Cyto. Pathol., 2001, 33(1-2) 1-5.
10. Georgeson M.A., Sullivan G.D., Contrast constancy, J. Physiol 1975, 252, 625-656.

Biography

E. Jafarzadehpur was born on 1966/Oct/28 in Tehran. After high school he studied Optometry in Shahid Beheshti University where he graduated in 1989 as a first rank student. He became academic staff of Optometry department at the same university. In 1992 he began to study Medical Physics in Tarbiat Modares University for M.S. where he graduated as the first rank student in 1995. In 1998 he began to study Ph.D. of Medical Physics in Tarbiat Modares University

He is currently on the academic staff of Iran University of Medical Science. He has published many papers in journals and congresses.