DISTORTION OF COLOR IMAGES ON FLAT COMPUTER SCREEN DUE TO CHROMOSTEREOPSIS

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Abstract

Illusory depth sense observing colour planar image such as images presented on computer screen is studied. The effect is binocular and is based on human stereovision, i.e., stereopsis. The colour difference threshold needed to induce the depth sense is determined. The effect polarity reversal – the source image red plane in front of blue plane is observed by partial covering of eye pupils medially or laterally. It is explain by the changes of eye point spread function taking into account coloured ray source and longitudinal chromatic eye aberrations. Image lightness affects the inducing of colour stereopsis due to changes of eye pupil size. Illusory depth sense is essential when designing colour graphical output on computer screen.

Keywords: Eye, chromatic aberrations, Stiles-Crowford effect, stereovision, binocular disparity, chromostereopsis, design of digital information for colour displays

Introduction

Ability of human vision is amazing in spite the fact that optics of human eye is distinctly non-perfect. Human brain due to prolonged experience during extended evolution process has been adapted to non-ideality of his visual system. Various neural pathways of visual inputs correct our visual perception and do that in the most economic manner. During last decades when life changed relatively suddenly conditions and habits, many problems appear to visual perception. This is partly due to the fact that nowadays persons spend long hours looking at colourful however flat visual stimulus. That makes some specific demands to consider that previously were not at foreground. That concerns also the demonstration and seeing by human eyes of the coloured stimulus on different display devices.

Eye optical structures posses the quality heterogeneities and non-perfection of eye geometry, and heterogeneity of the optical index at different wavelengths. Therefore eye segments posses aberrations, which are described as monochromatic and chromatic, as well as transversal and longitudinal (Gross et al., 2008). Presence of chromatic aberrations are resulting in a person perception of a colourful flat surface as an image, consisting of several layers, each of these layers is characterized by the inherent light wavelength or colour (Siegel et al., 1999; Hong et al., 2011). Such effect is readily observed (it manifests more clearly at night when the pupil diameter is increased) – looking at the map suddenly it seems that the blue river or black highway is "flying" somewhere in air, instead located at the paper plane.

This phenomenon has been known before as (induced) colour stereovision or chromostereopsis (Ye et al., 1992; Thompson et al.,1993). Humans posses the ability to perceive the depth of stimulus both to their experience of image content analysis (cues on stimulus element size or their placement basis) or on the basis of neural processing of left and right eyes input – ability to merge the both eyes slightly different retinal images due to image stereo disparity. Merging of binocular retinal images is described elsewhere for disparities originated from different kind of sources – planar or 3D sources, random dot or continuous, black-white or colour (Howard and Rogers, 2012; Julesz, 1981; Simmons et al., 2002; Ozolinsh et al., 2012). If the source is flat, then the stereo disparity can be created either purposefully showing to both eyes slightly varying images (these images can be separated optically by special devices – i.e., anaglyphs, or by the stereogoggles watching movies demonstrated by special stereoprojectors); or a disparity of retinal images arises due to both eye optical structure inadequacies. Latter perception gaps lying on basis of chromostereopsis can be categorized by the above-mentioned types of aberrations.

In recent times the presence of induced stereopsis is observed in cases where a person actually spends a large percentage of working time at the computer, so the studies of this phenomenon obtain actuality in this aspect (Hayashi et al., 2012). The most commonly induced colour stereovision can be observed if the stimulus contains elements of discrete spatial divisions, and contains the colours of the spectrum far from each other – i.e., blue lettering on a red background. The special features of this visual effect should not be ignored by the persons who deal with visual information design and output to the computer screen (Vos, 2008; Chen et al., 2012). In this moment publications touching the concerned problem analyze the phenomenon on the base of the chromatic aberrations that can be both transversal and longitudinal ones (Kitaoka et al., 2006; Westheimer, 2008, 2013). Longitudinal means that different colour rays are focused in eye in different planes. This phenomenon is also present for rays, which direction coincides with the visual axis of both eyes – rays are aligned with the line of sight.

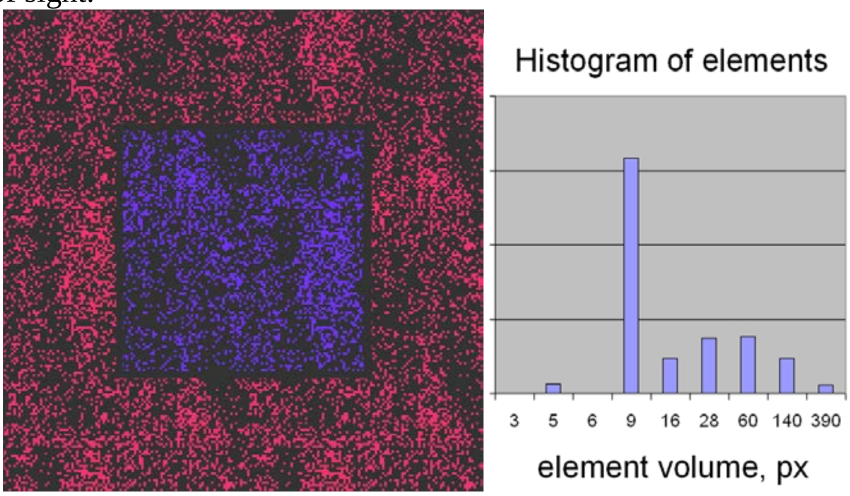

Figure 1. Stimulus presented on planar LED display. Central part 300x300 px, viewing area 600x600 px. Histogram of the coloured element size distribution is shown at the left.

In the case of the lateral aberrations the parallel rays of different wavelengths focus at neighbouring positions of retina. The lateral shift of focus depends on the dispersion of eye optical indices and on the angle between incident rays and the eyesight. These chromatic aberrations are observable for oblique incidence.

Both these phenomena result in different projection of two selected source image points on retinal plane. It can be bilateral effect – then on the left and right eye retinal planes. Mentioned in literature mechanisms of this induced effect – illusory focusing of flat source in various retinal planes depending on radiation wavelength, all are discussing chromostereopsis either for rays of oblique incidence, or for the case of rays coincided with direction of eye sight, however passing the eye pupil which is partially shielded. Here the Stile-Crowford effect – the different eye sensitivity of rays passing the lens central part and those passing lens peripheral zones can be taken into account by analysis of binocular disparity of illusory stereopsis (Ye et al., 1992).

Experimental

The aim of the present paper was: a) to study the binocular perception of colour images and generation of illusory effect of chromostereopsis; b) to find the effect peculiarities due to partial covering of the eye pupils; and – c) to evaluate the threshold of the minimum colour difference necessary to induce chromostereopsis. The image presented to subjects in our studies was the computer generated random dots on black background stimulus. The central part of stimulus was formed as a square of primary colour which size was 300x300px. Surround of this part comprises 600x600px area and was designed of dot structure of another secondary colour. So the minimum elementary point dot was 3x3 px, and the histogram of size distribution is shown in Figure 1. The average filling ratio of coloured pixels $r \approx 0.26$ and the average spot area ≈ 32.

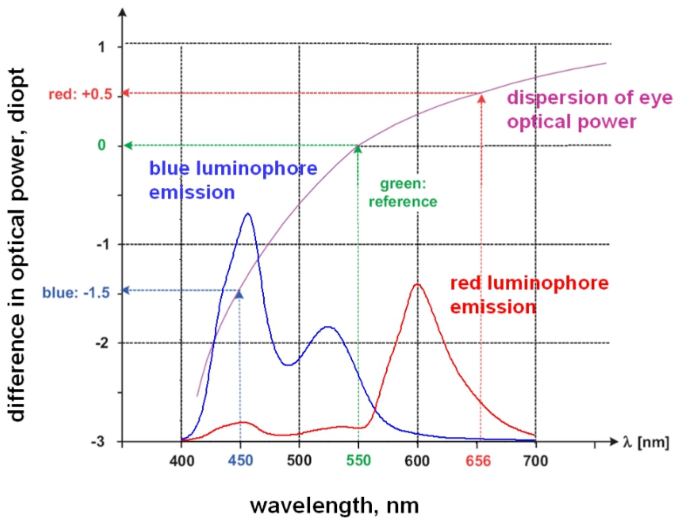

Figure 2. Used in experiments LED screen blue and red pixel emission spectra together with eye refractive power change with emission wavelength (latter data from (Gross et al., 2008)).

Such stimuli were presented in trials where the stimuli primary and secondary colour pair difference varied randomly. Test image colours were created using red and blue luminophore emission from DELL U2412M display witch pixel pitch was 0.27 mm. We used series of trials up to 30 presentations for each colour difference pairs. The multichoice task paradigm was used to evaluate the psychophysical testing. The observers' task was to respond to "Is the Center part closer?", and positive responses were counted as "1" and summated. The psychometric curves R(#N) were fit to sigmoidal function (where the trial sample set number #N was used as ordinate) and the slope parameter σ was used to define the effect threshold.

The trial image set colour pairs were measured and their colours (Fig.2) were drawn in the *CIE xyY* diagram. The threshold value N_{Th} was recalculated to find the threshold of colour difference $\Delta\lambda_{Th}$ (the projections of sample #N central and surround colour coordinates in direction to colour gamut borders from initiating point – O point in *CIE xyY* diagram).

In "regular" viewing conditions eye pupils had no any shielding and the distance to display was 0.8 m. Thus display 1px comprised the angle around visual limit - 1'. In order to diversify experiment conditions we used also partial bilateral covering of eye pupils that can lead to additional kind of retinal stereodisparity. Experiments were carried out in semidarkness. Participants were young students with the stable non-interchanging effect polarity, and an elder presbyope patient using corresponding optical power goggles.

Results and discussion

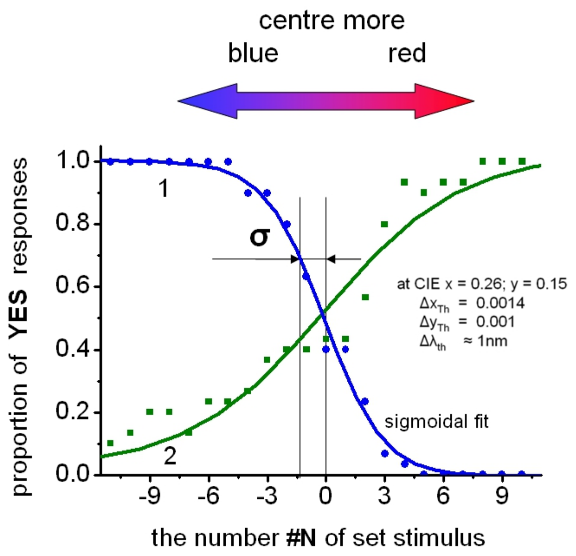

Figure 3. Psychometric curves to determine the threshold of colour difference to detect the induced colour stereoeffect. Curve for viewing with uncovered pupils (1), curve for viewing with lateral shielding (3) that shows the effect "polarity" switching. Data in insert correspond to viewing with uncovered pupils.

We observed the depth sense viewing planar coloured images and proved the binocular nature of this phenomenon. Monocular viewing did not reveal any 3D perception. Binocular stereovision, i.e., stereopsis is detectable if colour difference in trial stimulus is sufficient and if the image texture is optimum.

Perceived stereopsis depends on accommodation habits viewing such composite image, on the geometry of pupil – on pupil distraction degree and the aperture shape. Figure 3 shows the psychometric curve of the results viewing trial set similar to that in Fig.1. Arrows at the top of figure show the direction of corresponding colour increase in the central part of image. Steps of used image colour-pairs are sufficient to obtain sigmoidal fit and to calculate the colour difference threshold.

Patients were asked to respect only their depth sense, ignoring the cues arising from their colour sensation; however one can not completely exclude this argument when interpreting the results. The stereopsis induced in such manner – at "regular" viewing conditions should be explained by transversal chromatic aberrations of oblique rays in eye.

In the case when the eye pupils have not the circular symmetry the chromatic eye lateral aberrations can play the significant role. Figure 3 shows also the psychometric curve of perceived depth if pupils are symmetrically shielded. The effect is binocular. Medial or lateral covering of pupils distinctly switched the "polarity" of the induced depth sense – perceived blue image plane in front of red image plane and vice versa. As the right and left eyes have the mirror symmetry of retinal illumination, also the non-oblique rays due to their lateral aberrations can give contribution to induced stereodisparity.

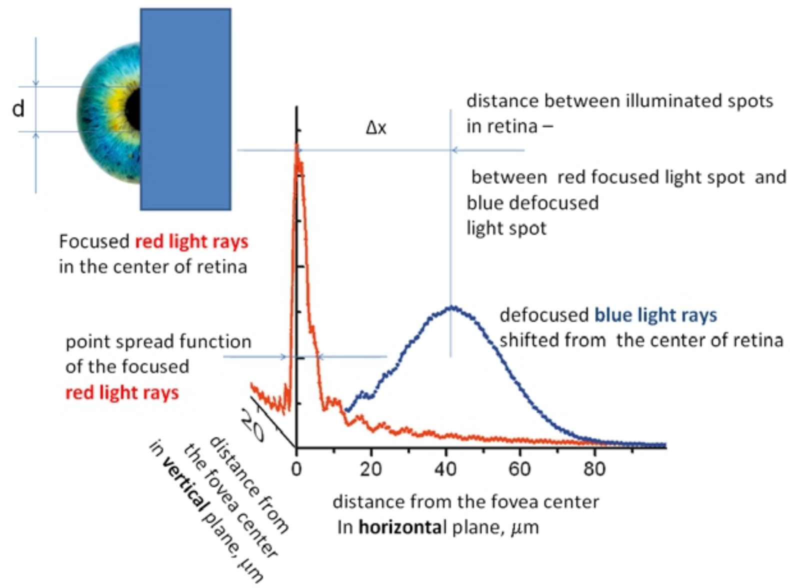

Figure 4. Retinal illumination at eye horizontal and vertical plane from a single display R+B pixel calculated from PSF function and its defocusing for blue emission. Calculations are done for half of pupil covered. Insert shows covering of eye pupils.

To explain the formation of the colour stereodisparity we performed Fourier transformation of the eye pupil of covered eye and calculated the retinal illumination. In Figure 4 the determined point spread function of half-covered eye at focus point for display red emission and defocused illumination for blue emission (the optical power colour shift of eye $\Delta P \approx 1.3$ according to Fig.2) are shown.

Induced depth sense if eyes are partially shielded is distinctly switchable. However the experimental points of the perceived depth psychophysical curve have larger dispersion, at first, and the colour difference threshold of depth sense is at least doubled, secondly. Such variance can be explained perhaps by decreasing of pupil area and retinal illumination.

Summary

Chromostereopsis is an optically illusory effect which causes the distortion of retinal images of flat colour sources. Chromostereopsis caused distortion depends on image elements symmetry and viewing angle, on element colour and on ambient luminance or the retinal illumination. Chromostereopsis can be characterized by the colour difference threshold $\Delta\lambda_{Th}$ of image elements that can induce the depth sense – $\Delta\lambda_{Th} \approx 1$nm. Such values of threshold are for red-blue computer display radiation determined at the difference equilibrium point CIE x = 0.26; y = 0.15 at stimuli averaged luminance Y = 3.9 cd/m^2. These values are determined at viewing condition in lack of any eye pupil shielding obstacles. Symmetrical bilateral screening of both eye pupils allows the reverse switch of the illusory effect – from blue-in-front-to-red to the reverse one. Shielding of pupil can significantly alter both the induced stereopsis depth and the perceived depth image colour difference threshold. Also by shielding of pupil it is easy to operate the depth sense polarity.

Drawn conclusions are important when evaluating the induced stereopsis effects on images produced on planar screen when digital chromatic output consists of saturated short and long wavelength colours. Using of colours with large wavelength span can cause essential distortion of visual information.

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