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Research on medical applications of contrast sensitivity function to red–green gratings in 3D space

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ABSTRACT

Contrast sensitivity function (CSF), which is a quick and valid index to measure human visual performance, can be applied into medical monitoring and various retinal disease diagnosis. However, there is a lack of researches on CSF in three-dimensional (3D) space. In this paper, CSF of human color vision to red–green chromatic gratings in 3D space is fully investigated. Based on the typical chromatic contrast sensitivity test system, in which the screen is parallel to human face, four inclined planes in 3D space are taken into consideration. Contrast thresholds for chromatic gratings of inclined planes are measured within 20 individual subjects. Experimental results show that the contrast sensitivity of each inclined plane is a low-pass function for red–green gratings. In order to fully utilize chromatic contrast sensitivity in 3D space, a visual model of red–green contrast sensitivity in 3D space is well fitted. Simulation results demonstrate that the proposed model achieves high consistency with human chromatic visual characteristics.

1. Introduction

Nowadays, multimedia based on human visual properties is becoming a hot topic in medical treatment, which helps the exploration of useful diagnostic information from multiple sources, including video streams, images, voice, heartbeat and blood pressure data [1–3]. With the help of immediate perception, analysis and evaluation of multi-dimensional data, disease diagnosis, rehabilitation, health monitoring, assisted surgery and other medical areas become much more reliable and convenient [4–6].

Contrast sensitivity, which serves as a quick and valid index to measure human visual performance and various retinal diseases, has been fully investigated for several decades. CSF to sinusoidal modulated patterns has not only been exhaustively studied with achromatic patterns [7–10], but also with chromatic patterns [11–16]. For luminance-modulated achromatic or monochromatic gratings, contrast sensitivity refers to the inverse of Michelson contrast at threshold. The spatial contrast sensitivity function for luminance gratings has a band-pass shape [17,18]. A chromatic equiluminous grating with red–green modulation consists of the red luminance-modulated monochromatic grating, as well as a green one, with a phase difference of π between them. For these chromatic gratings, contrast sensitivity is calculated as the inverse of Michelson luminance contrast at the threshold for one chromatic component grating against its own background luminance [19]. Spatial contrast sensitivity function for chromatic gratings is low-pass in shape [20].

Van der Horst and Bouman [21] did first reliable sine-wave color CSF measurements. They confirmed, as well as Granger [22], that the chrominance CSF has low-pass characteristics. Kelly [11] used only isoluminant red–green gratings and provided an incomplete set of chrominance CSF. Mullen [19] presented measurements for red–green and blue–yellow gratings. More and more researchers are paying attentions to study human chromatic visual characteristics [23–25], such as orientation response [26–28], cross-orientation masking [29], and so on. There are also evidences in the animal world indicating the spatial tuning of achromatic and chromatic vision [30,31].

Early researches on CSF mainly focus on the luminance contrast sensitivity, and luminance CSF has great applications in 2D space. Researchers have proposed many effective quality assessment methods by incorporating CSF [32,33], which can well reflect human visual perception. From other perspectives, such as image and video coding [34–36], video processing [37,38] etc., CSF based approaches have been well applied [39]. Researches and applications of human chromatic CSF in 2D space have only begun recently. For example, in order to study the image compression algorithm, Nadenau [40] measured contrast sensitivity of human vision to red–green and blue–yellow colors, in CIELAB and YCrCb color spaces respectively. Johnson et al. [41] designed a spatial

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filter specifically for image color difference calculation based on human color CSF. Takagi et al. [42] proposed a novel method to evaluate the mura grade of electronic displays using the color CSF. Besides, human color CSF also achieved great applications in image compression [43,44].

Recently, with the development of 3D technology [45,46], the effect of luminance contrast on stereo acuity has been investigated in a number of researches and indicated that perceivable disparity thresholds decreased with increasing luminance contrast magnitude [47,48]. Similar results were obtained for narrow-band-filtered random-dot stereograms by Cormack et al. [49]. Lee et al. [50] measured the impact of luminance frequency on disparity perception for band-pass-filtered random-dot stereograms, and so on. Many researchers also attempted to establish a chromatic stereopsis mechanism and characterize its properties [51–56]. These studies indicate that there exists a rudimentary chromatic stereopsis mechanism.

However, there are few researches in which contrast sensitivity is directly applied into red–green gratings to 3D space, and CSF of inclined planes to red–green gratings in 3D space is barely studied. Most researches take the binocular disparity as the start point but not the single eye in luminance and chromatic CSF experiment. So far, no existing perception model considers the influence of chromatic CSF of inclined planes on depth perception in 3D space. Intuitively, according to corresponding model of inclined planes, visual perception quality of each inclined plane in 3D space will be strengthened as in 2D space. Also the stereoscopic depth would be increased. What is more, some people blinds to the third dimensional sight may be stereo blindness. This study also intends to build a vision model or method to check this type visual characteristic. Chromatic CSF, which is an effective index to measure human visual performance in 2D space, cannot be directly applied into the measurement of human stereo visual performance. Based on the above-mentioned problem, we extend chromatic spatial sensitivity characteristic to 3D space. The spatial sensitivities to red–green gratings of four inclined planes are measured by isoluminant red–green gratings. In order to effectively apply 3D chromatic CSF, we propose an effective visual chromatic CSF model based on the inclined angles and spatial frequency.

2. Experiment

2.1. Subject

20 adults participated, including the first author. Each has normal vision and normal color vision according to the Farnsworth-Munsell 100-Hue test. The age ranges from 20 to 36 years. The observers are required to view the gratings monocularly with the fellow eye occluded (shown in Fig. 1), the right eye is used for measurements. The experiments are undertaken with the understanding and written consent of each subject.

2.2. Apparatus and stimuli

Stimuli are displayed on a CRT color monitor (Mitsubishi Diamond Pro 2070SB, resolution of 1024×768 and a frame rate of 120 Hz), which is connected to a graphics card (Cambridge Research Systems, VSG 2/5) in a generic PC. This graphics card has over 14 bits of contrast resolution and is specialized for the measurement of visual thresholds. The gamma nonlinearity of the luminance output of the monitor guns is corrected in look-up tables using a Cambridge Research Systems Optical photometer. The spectral outputs of the red, green, and blue phosphors of the monitor are calibrated using a PhotoResearch PR-645 SpectraScan spectroradiometer. The CIE-1931 chromaticity coordinates of the red, green, and blue phosphors are ($x = 0.631$, $y = 0.340$), ($x = 0.299$, $y = 0.611$), and ($x = 0.147$, $y = 0.073$), respectively. The background is achromatic with a mean luminance of 34 cd/m^2 at the screen center. The dominant wavelengths of the red, green, and blue phosphors are 610, 550, and 462 nm, respectively. Visual stimuli consisted of horizontal red–green equiluminant gratings are displayed in π phase reversal, and seven horizontal spatial frequencies from 0.05 to 5 c/d are evaluated.

Stimuli are represented in a three-dimensional cone-contrast space [57,58] in which each axis is defined by the incremental stimulus intensity, and for each cone type, stimulus is normalized by the respective intensity of the fixed adapting white background. We apply Judd modified values to obtain tristimulus values, and the Smith and Pokorny [59] cone fundamentals are used to calculate cone contrast. As a single measurement of cone contrast, we calculate the pooled value:

$$C = \sqrt{\frac{C_L^2 + C_M^2 + C_S^2}{3}} \quad (1)$$

where C is the pooled cone contrast, and C_L, C_M, C_S are the cone contrast for the L, M, and S cones, respectively. The use of pooled cone contrast provides an objective measurement for a color stimulus and has been used in a variety of researches of the human color vision to represent not only chromatic stimuli but also color discrimination thresholds. In addition, cone contrast is taken into account in the first stage of color processing, i.e., the absorption of

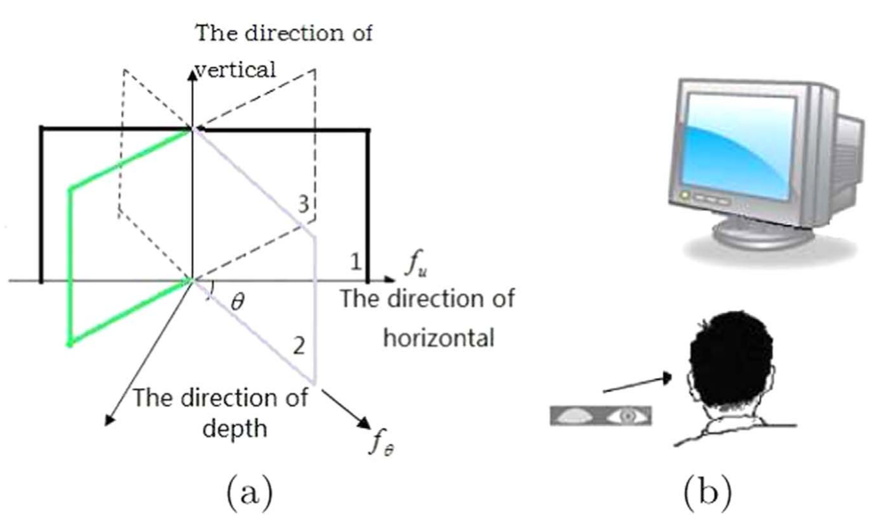

Fig. 1. (a) Inclined planes scheme in 3D space. (b) The experiment condition when the screen clockwise rotated.