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Dichoptic colour-saturation masking is unmasked by binocular luminance contrast

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ABSTRACT

We demonstrate a new type of interaction between suprathreshold colour (chromatic) and luminance contrast in the context of binocular, specifically dichoptic vision. A highly saturated isoluminant violet 'mask' disk in one eye greatly elevates detection thresholds for an isoluminant violet 'test' disk in the other eye, an example of dichoptic colour-saturation masking. However when binocular luminance contrast (i.e. luminance contrast matched in the two eyes) is added to the disks, the masking is dramatically reduced. Adding binocular luminance contrast to the test disk on its own, or to the mask and test disks presented together in both eyes had comparatively little effect on test thresholds. The likely explanation for the dichoptic unmasking effect is that the binocular luminance contrast reduced the interocular suppression between chromatic mask and test, in keeping with other recent findings from measurements of the appearance of dichoptic saturation mixtures (Kingdom & Libenson, 2015). We suggest that binocularly matched luminance contrast promotes the interpretation that the dichoptic colour saturations, even though unmatched, nevertheless originate from a single object. Under these conditions the visual system tends to blend the mask and test saturations rather than have them compete, resulting in reduced dichoptic masking. We term this idea the "object commonality" hypothesis.

1. Introduction

The dichoptic masking paradigm has been influential in exploring how the two eyes interact in binocular vision. In dichoptic masking, the threshold for detecting a test stimulus in one eye is measured in the context of a mask stimulus in the other eye (Kim, Gheiratmand, & Mullen, 2013; Legge, 1979; Maehara & Goryo, 2005; Meese, Georgeson, & Baker, 2006). Test thresholds in dichoptic masking are generally higher than in either monocular masking (mask and test in the same eye) or binocular masking (mask and test in both eyes) (Meese et al., 2006). The heightened thresholds found in dichoptic masking are widely believed to result from interocular suppression of the test by the mask.

To date, studies that have examined dichoptic masking for *chromatic* stimuli have focused on cross-orientation dichoptic masking, that is when an oriented grating mask in one eye is paired with a test grating of opposite orientation in the other eye (e.g. Kim et al., 2013). The chromatic analog of dichoptic luminance masking, namely dichoptic colour-saturation masking, using non-oriented stimuli such as disks, has not to our knowledge been studied. The motivation for the experiments reported here however is not primarily the need to examine dichoptic saturation masking for non-oriented stimuli. Rather, it stems from a recent report by Kingdom and Libenson (2015) concerning the effects of binocular luminance contrast on the appearance of dichoptic saturation mixtures. Kingdom & Libenson first found that a dichoptic mixture of colour saturations took on the appearance of the higher of the two saturations, commensurate with previous results from dichoptic luminance mixtures and termed "winner-take-all" (Baker, Wallis, Georgeson, & Meese, 2012). However, when binocularly matched luminance contrast was added to the saturation mixture, the appearance of the mixture shifted away from winner-take-all towards the average of the two saturations. In keeping with the results of other luminance-domain studies of dichoptic interaction (Baker, Meese, & Summers, 2007; Blake & Boothroyd, 1985; Buckthought & Wilson, 2007; Meese & Hess, 2005; O'Shea, 1987), Kingdom and Libenson (2015) opined that the binocularly-matched luminance contrast in their study reduced the interocular suppression between the unmatched colour saturations, resulting in perceptual averaging of the mixture. One might therefore expect binocularly matched luminance contrast to also reduce dichoptic colour-saturation masking. The aim of the present study is to test this prediction.

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In summary, the aim of this communication is to measure dichoptic colour-saturation masking and to examine the influence on it of matched binocular luminance contrast. Brief reports of this study have been given elsewhere (Kingdom, Wang, & Libenson, 2014; Wang & Kingdom, 2014).

Two additional points. First, the experiments reported below use just two stimulus chromaticities: violet for the chromatic component and black for the luminance component. The choice of violet is arbitrary. In their study of dichoptic colour saturation mixture, Kingdom and Libenson (2015) found a similar pattern of results for violet, lime, red and cyan stimuli, so we assume that similar results would be found for these hues. Second, our stimuli are uniform disks on a grey background. The achromatic disks can therefore be considered to vary in either luminance *or* luminance contrast, and the chromatic disks either in saturation *or* colour contrast. We will mainly use the term contrast in reference to our stimuli, but sometimes we will use the term saturation because of its wide use in the colour vision literature.

2. Methods

2.1. Subjects

Five subjects participated, the two authors and three subjects who were naïve as to the purpose of the experiment. All subjects had normal or corrected-to-normal vision and normal colour vision as tested by the Ishihara Colour Plates under binocular viewing conditions. Informed consent was obtained from each participant prior to the beginning of the experimental procedure, and the whole study was carried out in accordance with the Declaration of Helsinki and with the approval of the local institutional ethics committee (Research Ethic Office (IRB), Faculty of Medicine, McGill University, Canada).

2.2. Stimuli – generation and display

The stimuli were generated by a VISAGE graphics card (Cambridge Research Systems) and displayed on a Sony Trinitron F500 flat-screen monitor. The R (red), G (green) and B (blue) gun outputs of the monitor were gamma-corrected after calibration with an Optical photometer (Cambridge Research Systems). The spectral emission functions of the R, G and B phosphors were measured using a PR 640 spectral radiometer (Photo Research), with the monitor screen filled with red, green or blue at maximum luminance. The CIE coordinates of the monitor phosphors were R: $x = 0.624$, $y = 0.341$; G: $x = 0.293$, $y = 0.609$; B: $x = 0.148$, $y = 0.075$. The members of each dichoptic pair were presented either side of the monitor screen and fused via a custom-built 8-mirror Wheatstone stereoscope, with an aperture of 10×10 deg and a viewing distance along the light path of 55 cm.

2.3. Stimuli – colours and contrasts

The chromatic stimulus was a violet disk, whose chromaticity lay along the *S*+ (short-wavelength-sensitive) cone axis of the DKL colour space (Derrington, Krauskopf, & Lennie, 1984). *S*+ cone contrast is defined as $\Delta S/S_b$. The denominator S_b refers to the *S* cone excitation of the background, which was a mid-grey colour with CIE chromaticity $x = 0.282$ and $y = 0.311$ and luminance 40 cd/m^2. The numerator ΔS represents the difference in cone excitation between the disk and background. The *S* cone excitations assigned to disk and background were converted to RGB phosphor intensities using the cone spectral sensitivity functions provided by Smith and Pokorny (1975) and the measured RGB spectral functions of the monitor. Luminance contrast (LUM) was defined as equal cone contrast excitations for all three cones, i.e. $\Delta L/L_b$, $\Delta M/M_b$, and $\Delta S/S_b$, where L = long-wavelength-sensitive and M = middle-wavelength-sensitive. Luminance contrast was defined as the contrast assigned to each cone.

2.4. Stimuli – disks

Example stimuli are shown in Figs. 1 and 2, and the cyclopean views of the four dichoptic conditions shown in Fig. 3. The diameter of each disk was 1.25 deg at the viewing distance of 55 cm. The disks were positioned above and below the fixation point inside a black, circular, fusion ring 1 pixel wide and 6.5 deg in diameter. Each pair of disks was separated by 3 deg along a virtual line connecting their centres. The orientation of the virtual line was randomized on each trial within the range −25 deg to +25 deg from vertical in order to minimize the build up of after-images during trials. The contrast of the violet mask was set to 0.5 throughout the experiment.

2.5. Stimuli – added binocular luminance contrast conditions

Test detection thresholds were measured both at isoluminance and with added, binocular luminance contrast, the latter in the form of a decrement in luminance. 'Binocular' here means that the luminance decrement was added to *all four* disk locations, namely the two left-eye and two right-eye disks and disk locations. The resulting cyclopean views of the disks, both with and without the luminance decrement are shown in Fig. 2. The luminance decrement was an independent variable set to one of five absolute contrasts: 0.0, 0.05, 0.1, 0.15, 0.2 and 0.25.

2.6. Procedure – measurement of isoluminance

Although *S* cones contribute to the luminance mechanism only under extreme conditions (Eskew, McLellan, & Giulianini, 1999; Ripamonti, Woo, Crowther, & Stockman, 2009), there is always the possibility of calibration error with *S* stimuli. Therefore for each observer we measured the isoluminant point for a drifting 0.25 contrast grating modulated along the *S* cone axis, i.e. a violet-lime grating, by requiring subjects to adjust the amount of $L + M$ contrast until a motion null was achieved. The ratio of $L + M$ to *S* contrast needed to make the *S* stimuli isoluminant was 0.068 for DW, 0.104 for FK, 0.082 for JM, 0.078 for SG and 0.074 for LL. These ratios determined the amount of luminance contrast that was added to the violet disks to make them isoluminant.

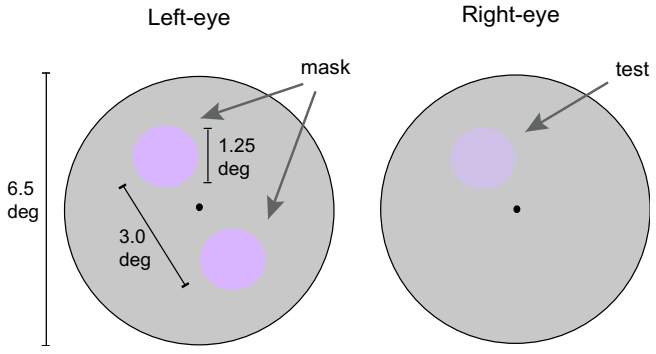

Fig. 1. Stimulus arrangement in the two eyes' views of the isoluminant, dichoptic, mask condition. When fused the task for the subject was to choose the location, above or below the fixation dot containing the test.