



Binocular vs. monocular hue perception



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ABSTRACT

Hue perception has been shown to differ for the same stimulus when presented to the temporal and the nasal areas of the retina. The present study investigated perceptual differences in stimuli viewed binocularly or monocularly in the peripheral retina to determine how hue information combines across the two retinas for a stimulus falling on the temporal retina of one eye and the nasal retina of the other. A hue-scaling procedure was utilized to ascertain hue perception for three color- and binocular-normal observers viewing monochromatic stimuli (450–670 nm, 20 nm steps) ranging in size from 1.0° to 3.7°. Peripherally-presented binocular stimuli fell upon the nasal retina of one eye and the temporal retina of the other. Hue-scaling results indicated that peripheral binocular hue and saturation perceptions for smaller stimuli were more similar to those of stimuli falling on the temporal retina in the monocular condition. Hue-scaling data were also used to determine perceptive field sizes for the four elemental hues. Binocular perceptive field sizes were more similar to those obtained for stimuli falling on the temporal retina in the monocular conditions. Eye dominance did not appear to have an effect on hue perception. The results seem to indicate that visual information from the temporal retina is weighted more heavily when information from the two eyes is combined cortically. This finding may relate to differences in V1 cortical activation for stimuli presented to the nasal retina versus the temporal retina.

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1. Introduction

The fact that humans possess two eyes laterally offset from one another affords us the remarkable capacity for binocular vision, enabling us to enjoy a perception of three-dimensional depth. This lateral displacement of the two eyes also allows us to investigate the way binocular signals combine in the visual pathway. Since the time of Sir Isaac Newton's *Opticks* (1704), a substantial body of dichoptic research (e. g., Erkelens & van Ee, 2002; Hecht, 1928; Ikeda & Sagawa, 1979; Kingdom & Libenson, 2015; Lange-Malecki, Creutzfeldt, & Hinse, 1985; O'Shea & Williams, 1996) has investigated how competing color signals from individual eyes combine to yield not only binocular color fusion, but also binocular rivalry. While the dichoptic paradigm can yield a great deal of insight into cortical processes underlying dichoptic viewing, and the general manner in which binocular signals combine under dichoptic viewing conditions, it does not necessarily address the question of how binocular color perception occurs under everyday conditions, where the chromatic input to the two eyes is very similar to each other. Seldom do we spontaneously encounter a visual

scene in which the input to each individual eye differs so starkly as it does in dichoptic paradigms.

In a similar manner, psychophysical color vision research has historically been conducted monocularly, with observers viewing stimuli with only one eye. This general experimental procedure has yielded information regarding the function of the retina and its underlying structures, and has previously shown that there are differences in color perception for stimuli presented to different areas of the retina (e. g., Abramov, Gordon, & Chan, 1991; Buck, Knight, & Bechtold, 2000; Gordon & Abramov, 1977; Nerger, Volbrecht, & Ayde, 1995; Opper, Douda, Volbrecht, & Nerger, 2014; Stabell & Stabell, 1979; Thomas & Buck, 2006; Volbrecht, Nerger, Imhoff, & Ayde, 2000; Volbrecht, Nerger, & Trujillo, 2011). These differences in hue perception across the retina are not entirely unexpected, as photoreceptor and ganglion cell distributions across the retina are neither uniform nor symmetrical within a single eye (Curcio & Allen, 1990; Curcio, Sloan, Kalina, & Hendrickson, 1990).

The aforementioned variations in the photoreceptor mosaic across the retina also underlie differences in hue perception between the fovea and the peripheral retina. Although the specific effects of retinal location depend on a number of factors, such as wavelength, stimulus size, and retinal illuminance (Abramov et al., 1991; Buck et al., 2000; Pitts, Troup, Volbrecht, & Nerger, 2005; Volbrecht, Clark, Nerger, & Randall, 2009), generally the fovea

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displays the strongest chromatic response (e. g., Abramov et al., 1991; Gordon & Abramov, 1977; cf. Opper et al., 2014). As the size of a peripherally-presented stimulus increases, however, peripheral hue perception becomes more “fovea-like” (e. g., Abramov et al., 1991; Gordon & Abramov, 1977), until the stimulus is of sufficient size to yield an asymptotic hue percept. Continuing to increase the stimulus size beyond this point produces relatively little improvement in hue perception (Abramov et al., 1991). The size at which this hue percept is achieved is referred to as filling a perceptive field, which may be conceived of as the perceptual equivalent of a receptive field (Abramov et al., 1991; Pitts et al., 2005).

Perceptive fields increase with increasing retinal eccentricity as one moves from the fovea toward the periphery of the retina (Abramov et al., 1991; Nerger et al., 1995). Due to differences in photoreceptor distribution between the nasal and temporal retinas at 10° retinal eccentricity (Curcio & Allen, 1990; Curcio et al., 1990), perceptive fields tend to be larger in the nasal retina than in the temporal retina (Volbrecht et al., 2009) and appear to be influenced by rod contribution to hue. The greater the ratio of rods to cones in a retinal area, the larger the size of the perceptive field (Troup, Pitts, Volbrecht, & Nerger, 2005; Volbrecht et al., 2009).

Although hue-scaling and perceptive field data obtained with the traditional monocular method have granted us a great deal of insight about how the eyes function individually, in everyday life we seldom use only one eye to gain an impression of the world around us. Given the variability in the photoreceptor mosaic underlying different parts of the retina (Curcio & Allen, 1990; Curcio et al., 1990), the differences in hue perception for different retinal areas (Abramov et al., 1991; Buck et al., 2000; Gordon & Abramov, 1977; Nerger et al., 1995; Opper et al., 2014; Stabell & Stabell, 1979; Thomas & Buck, 2006; Volbrecht et al., 2000, 2011) and the fact that under some circumstances stimuli viewed binocularly will fall on different areas of the retina for each eye, it remains to be seen how color information from the two retinas combines in binocular pathways. Evidence has been found for a neural pathway specifically responsible for integrating chromatic information between the two eyes to achieve a perception of depth (Simmons & Kingdom, 1997). It has been hypothesized that chromatic information pertaining to stereopsis may be carried at least as far as V1 by the parvocellular pathway, the neural pathway thought to be responsible for conveying red-green opponent information. This may indicate that red and green chromatic signals are processed differently for stimuli viewed with two eyes than for stimuli viewed monocularly, although the exact nature of this difference is unclear. Another study (Wong & Freeman, 1999) has reported a separate pathway for chromatic information presented to both eyes; specifically, that there is a difference in the way binocular chromatic information and binocular luminance information is spatially integrated, with chromatic information “cooperating” (i.e., combining) across the two retinas while no such cooperation occurs for luminance information. Simmons and Kingdom (1998) and Simmons (2005) have also obtained results indicating differences in binocular summation of chromatic versus luminance signals, with greater summation occurring for chromatic information. A previous study (Ciganek, 1970) found evidence that redundant information from the foveas for stimuli viewed binocularly may be discarded along the visual pathway as input from the two eyes combines. This combining of spatial chromatic information across the two retinas may imply that perceptive field sizes are smaller for stimuli viewed binocularly, because each eye is viewing the same scene from a slightly different angle and redundant information between the two eyes is being discarded along the visual pathway, removing extraneous information from the analysis of the visual scene.

Further complicating matters is the fact that most people possess a “dominant eye”, which tends to exert a greater influence

over the perception of a scene viewed binocularly. Research on how eye dominance affects binocular color perception has yielded mixed results, with some studies finding support for a prevailing influence of the dominant eye (e. g., Johannsen, 1930; Newman, Wolfe, Stewart, & Lessell, 1991; Peirce, Solomon, Forte, & Lennie, 2008) and others finding that eye dominance is not a factor (e. g., Costa, Ventura, Perazzolo, Murakoshi, & Silveira, 2006; Ikeda & Sagawa, 1979; Verriest, Laethem, & Uvijls, 1982). To sort out possible effects of eye dominance, a series of studies using a dichoptic paradigm (Crovitz & Lipscomb, 1963; Leat & Woodhouse, 1984; Stanley, Carter, & Forte, 2011) investigated whether one area of the retina, as opposed to one eye, consistently dominated perception when stimuli of short duration (100–1000 ms) were presented to different areas of the retina in each eye. While results were mixed, one study (Crovitz & Lipscomb, 1963) clearly demonstrated that in a binocular rivalry paradigm, the stimulus falling on the nasal area of the retina tended to dominate perception: the stimulus that fell on the temporal retina was typically not perceived at all. Others (Leat & Woodhouse, 1984; Stanley et al., 2011) found similar results, although the effect was weaker, with participants exhibiting a range of possible dominance patterns (nasal dominates temporal, temporal dominates nasal, or neither location reliably dominates). For stimuli presented continuously there was no clear dominance pattern based on retinal location (Leat & Woodhouse, 1984).

The current experiment investigated color perception both monocularly and binocularly to determine how information from each individual eye combines to yield a binocular color perception when a stimulus fills or does not fill a perceptive field. Based on previous studies, it was predicted that: 1) binocular peripheral color perception would approach foveal color perception at smaller stimulus sizes than monocular peripheral color perception, i.e., binocular peripheral perceptive field sizes would be smaller than monocular peripheral perceptive fields (Landisman & Ts'o, 2002; Newman et al., 1991; Peirce et al., 2008; Simmons & Kingdom, 1997; Ts'o, Roe, & Gilbert, 2001; Wong & Freeman, 1999); and 2) of the two monocular peripheral conditions, binocular color perception would be most similar to that of a stimulus monocularly presented to the nasal retina of the dominant eye (Crovitz & Lipscomb, 1963; Stanley et al., 2011).

2. Method

2.1. Participants

Observers were AL, a 22-year-old female; AW, a 23-year-old male; and VV, a 57-year-old female. All observers had normal color vision in both the right and left eyes as assessed with the Farnsworth-Munsell 100-hue panel test, D-15 panel test, desaturated D-15 panel test, and the Neitz anomaloscope (OT-II). Binocular perception was assessed using the Distance Randot Test (Stereo Optical Company, Inc., Chicago, Ill.); all observers were able to perceive the shapes at all retinal disparities. Eye dominance was assessed using the Miles test of ocular dominance (Miles, 1930). All binocular-normal observers were right-eye dominant. All observers except AL were myopic and wore corrective lenses when viewing stimuli. This experiment was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all observers.

2.2. Materials

2.2.1. Apparatus

Stimuli were presented via a 6-inch diameter integrating sphere (F of Fig. 1; Gooch & Housego OL IS-670-LED) connected to a fiber

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