



Effect of field view size and lighting on unique-hue selection using Natural Color System object colors



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ABSTRACT

The aim of this study was twofold, first to determine the effect of field view size and second of illumination conditions on the selection of unique hue samples (UHs: R, Y, G and B) from two rotatable trays, each containing forty highly chromatic Natural Color System (NCS) samples, on one tray corresponding to 1.4° and on the other to 5.7° field of view size. UH selections were made by 25 color-normal observers who repeated assessments three times with a gap of at least 24 h between trials. Observers separately assessed UHs under four illumination conditions simulating illuminants D65, A, F2 and F11. An apparent hue shift (statistically significant for UR) was noted for UH selections at 5.7° field of view compared to those at 1.4°. Observers' overall variability was found to be higher for UH stimuli selections at the larger field of view. Intra-observer variability was found to be approximately 18.7% of inter-observer variability in selection of samples for both sample sizes. The highest intra-observer variability was under simulated illuminant D65, followed by A, F11, and F2.

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1. Introduction

Color perception is a subjective sensory experience. The underlying reasons for our individual experiences are not fully known. We can only describe these experiences in simple metaphorical terms. Of fundamental interest in visual perception is that of color. Of all senses probably most is known about vision yet our understanding of the complex neural mechanisms pertaining to vision is quite primitive (Hubel, 2005). A central issue in the perception of color is that of unique hues (UHs). Among various characteristics of color perception, the existence of the four unique hues is one of the most striking. UHs form an important section of the unsolved color perception puzzle and all attempts to understand and track down the underlying neural processes have so far failed to yield a conclusive mechanism. It has long been postulated from psychophysical studies, that the existence of unique hues depends on signals derived from differences between cone responses. Yet up to now perceptual data pertaining to unique hues cannot be fully expressed by any neurophysiological color vision theories.

According to Ewald Hering's opponent color vision theory (Hering, 1905; Hurvich & Jameson, 1964) there are four fundamental hues (*Urfarben*) which cannot be described by any terms other than their own. These are yellow, red, blue and green. A unique red (UR) for example, is a red that is perceived to be as neither

yellowish nor bluish, its two adjacent neighboring unique hues. A similar description can also be given for the other unique hues based on their respective neighboring unique hues. In Hering's model there are three neurophysiological opponent color channels which form the red–green, yellow–blue, and black–white opponencies. Interpretation of signals from these channels results in a perceived color. The spectral null points of the red–green and blue–yellow opponent processes correspond to the sensation of UHs (Abramov & Gordon, 2005). In a recent study the perceptual prominence of Hering's opponent hues was supported (Kuehni et al., 2010).

However, while Hering first assumed that the Y–B and R–G processes are complementary he then had to concede that the R–G process is not. Since Hering's time many efforts have been devoted to the understanding of the mechanisms pertaining to processing of UHs in eye and brain. An important study in the 20th century is that of Jameson and Hurvich (1955). Their approach employed a hue cancellation method whereby the observers adjusted, for example, the amount of test light perceived as UB (475 nm) until it cancelled or balanced the effect of yellowness in a light of 550 nm, perceived as yellowish green, so that its hue was perceived as UG. Psychological data was thus obtained that allowed selection of a specific wavelength for each observer for UY, UB and UG. The situation is more complex for UR where many observers place it outside the spectrum. In fact they considered light of 700 nm for the average observer to be 80% R and 20% Y and noted that for many observers a spectral selection of UR could not be

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made (Kuehni, 2001; Pridmore, 1999). This study was followed by several other investigations that aimed to determine the linearity, homogeneity and additivity of UHs (Cicerone, Krantz, & Larimer, 1975; Knoblauch, Sirovich, & Wooten, 1985; Larimer, Krantz, & Cicerone, 1974, 1975). It was found that dominant wavelengths of UG, UB and UY are invariant under moderate luminance changes (Knoblauch, Sirovich, & Wooten, 1985; Larimer, Krantz, & Cicerone, 1974). It has also been found that complementarity holds for UY and UB, however, consistent failures of complementarity were observed for UR and UG (Burns et al., 1984; Ikeda & Ayama, 1980; Knoblauch, Sirovich, & Wooten, 1985; Werner & Wooten, 1979).

The curvatures of constant hue loci on chromaticity diagrams indicate that the criteria for constant hue, including those of the unique hues occur after the linear stage of color vision, and hence after the absorption of light in the cones. The fact that UR and UG are not complementary, indicates that the criteria for UR and UG are different from one another and that those for UY and UB may also be different from one another (Hunt, 2009). Lennie and coworkers showed that neurons are tuned to directions other than the cardinal cone-opponent axes in striate (Lennie, Krauskopf, & Schlar, 1990) and Kiper et al. showed the same in the extrastriate areas of the visual cortex (Kiper, Fenstemaker, & Gegenfurtner, 1997).

The detection of a kind of opponent cone signal processing in the lateral geniculate nuclei (LGN) was considered a promising finding in the understanding of UHs (Lennie, Krauskopf, & Schlar, 1990). However, the related spectral responses do not correlate with UHs as was shown by Webster et al. (2000a,b) and Abramov and Gordon (2005). Wuergler, Atkinson, and Cropper (2005) also recently showed that the opponent processes apparently required for processing UHs must be different from those identified in LGN neurons. Additionally, it has been noted (Derrington, Krauskopf, & Lennie, 1984; Hunt, 2009; Wuergler et al., 2005) that high level neural mechanisms presumably can determine the variation in perception of UHs under given conditions in part based on the previous visual experience of the observer. Indeed Mollon and Jordan pointed out that observers' selection of UHs relate to natural light sources like the sun and natural surroundings such as the blue sky (Mollon & Jordan, 1997).

Conway et al. in a recent study of neural processing of color in live macaque monkeys reported resolvable aggregates of cells within a specific layer of extra-striate cortex, indicative of the parallel processing of separate streams of visual information, active across the visual field in the visual cortex, denoted globs, that seemed to be highly tuned to sensations of red, blue and green signals. The findings also showed a relatively indistinct peak for yellow (Conway, Moeller, & Tsao, 2007; Stoughton & Conway, 2008). The recordings were made in the posterior inferior temporal cortex (PIT) which showed that many of the neurons in this part of the brain appear to have sharper chromatic tuning than is found in the early visual system (LGN) and as a population, the tuning does not correspond to the cardinal axes of the early visual system. Since highly chromatic stimuli were used in Conway's study Mollon challenged their inference (Mollon, 2009) and pointed out that a stimulus set consisting of maximally vivid colors results in varying the magnitude of cone contrast measured against the adapting background from one color to the next, with red and blue generating the highest cone contrast. It may be possible that the glob neurons provide inputs to subsequent stages of processing in inferior temporal cortex that may be the immediate neural correlates of UH percepts. Along the visual pathway, the cone signals are presumably transformed from linear responses typical of the LGN into nonlinear responses corresponding to color perception. Nonetheless, a cortical origin for the UHs has not yet been established.

Determinations of UH stimuli are important in the development of perceptually uniform color spaces as well as color appearance models (Kuehni, Hinks, & Shamey, 2008). UH determinations are also important because spectral boundaries of basic hues are confined by UHs (De Valois & De Valois, 1993; Gordon & Abramov, 2001). In order to ascertain the position of UHs in a psychophysical color solid a large number of studies have been carried out (Abramov & Gordon, 2005; Ayama, Nakatsue, & Kaiser, 1987; Kuehni, 2001; Malkoc, Kay, & Webster, 2005; Nerger, Vollbrecht, & Ayde, 1995; Pridmore, 1999; Rubin, 1961; Scheffrin & Werner, 1990; Webster et al., 2002).

Owing to the complex features associated in experiencing color, historically several perceptual color order systems have been introduced. Two important proposals for perceptual representation of object color order include the Munsell system of hue, value and chroma and the Swedish Natural Color System (NCS) (NCS Color AB). The mentioned seminal work by Hering laid the foundations for the development of Natural Color System (NCS). The experimental basis of NCS has been described by Hård & Sivik (1981). According to NCS, any color can be described in terms of its similarity to elementary colors yellow, red, blue, green, as well as white and black. The cardinal axes of the NCS system represent average UH selections by a limited number of Swedish observers.

The process of selecting stimuli representing UHs for an observer from a set of objects, under a given light source sounds relatively simple. However, significant variations in the choices of stimuli for color normal observers under well-controlled environments have been observed. Kuehni examined the large inter-observer differences in UH stimuli selections for several datasets (Kuehni, 2004). Differences between male and females' selections have been found to be statistically insignificant (Hinks et al., 2007; Kuehni, 2004; Shamey, Sedito, & Kuehni, 2010). The possible bases for overall variability include the physical nature of colorants and light sources along with differences in test methodology employed, neurobiological operations in the visual system when processing color signals, and the complex and unknown transition of material stimuli to psychological experiences (Kuehni, 2004; Shamey, Sedito, & Kuehni, 2010). Results indicate the UG selection has the highest variability and that UH selections comprising color chips exhibit lower variation compared to selections involving spectral lights. At this time there is no solid hypothesis for this experimental fact.

From a physiological standpoint an important parameter that may affect the type, quantity and interpretation of signals generated by cones is macular pigmentation (MP) present in the macula, which has the highest density within the central 7 mm² of retina. The spectral sensitivity of MP is highest in the blue-green region (~400–520 nm) and peaks at approximately 460 nm. This absorption occurs before light is incident on the photoreceptors (Davies & Morland, 2004). Therefore, MP acts like a broadband filter that absorbs the short wavelength light and not only affects the S-cone extinction function but also the interpretation of signals in the Y-B opponent chromatic channel (Welbourne et al., 2013). The MP density is not constant and is high in the foveal region (0°) and drops off with increasing eccentricity and reaches almost zero at around 10° field of view. The distribution may be represented by an exponential decay function (Hammond, Wooten, & Snodderly, 1997). Several reports indicate that macular pigmentation optical density (MPOD) varies among color normal subjects (Loughman et al., 2010). This variation may result in differences between observer color responses (Davies & Morland, 2004) and has been linked to the large variability in selections of UG stimuli. Observers with higher MPOD are reported to select stimuli at longer wavelengths as representative of their UG percepts. An increase in MPOD, will reduce the excitation of S-cones which will affect the output generated by chromatic channels (Davies &

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