



The effects of luminance contribution from large fields to chromatic visual evoked potentials



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ABSTRACT

Though useful from a clinical and practical standpoint uniform, large-field chromatic stimuli are likely to contain luminance contributions from retinal inhomogeneities. Such contribution can significantly influence psychophysical thresholds. However, the degree to which small luminance artifacts influence the chromatic VEP has been debated. In particular, claims have been made that band-pass tuning observed in chromatic VEPs result from luminance intrusion. However, there has been no direct evidence presented to support these claims. Recently, large-field isoluminant stimuli have been developed to control for intrusion from retinal inhomogeneities with particular regard to the influence of macular pigment. We report here the application of an improved version of these full-field stimuli to directly test the influence of luminance intrusion on the temporal tuning of the chromatic VEP. Our results show that band-pass tuning persists even when isoluminance is achieved throughout the extent of the stimulus. In addition, small amounts of luminance intrusion affect neither the shape of the temporal tuning function nor the major components of the VEP. These results support the conclusion that the chromatic VEP can depart substantially from threshold psychophysics with regard to temporal tuning and that obtaining a low-pass function is not requisite evidence of selective chromatic activation in the VEP.

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1. Introduction

Chromatic Visual Evoked Potentials (cVEP) are important in both basic and clinical vision research, providing noninvasive measures of cortical response. Analysis of VEP signals allows for objective verification of color deficits as well as differentiation of neural mechanisms responding to changes in stimulus brightness and chromaticity (e.g., Berninger et al., 1989; Crognale et al., 1993; Kulikowski et al., 1989; Murray et al., 1987; Rabin et al., 1994; Regan, 1973; Regan & Spekreijse, 1974). Moreover, the VEP response is sensitive to other stimulus properties such as spatial frequency content (Campbell & Kulikowski, 1971), size and orientation (Crognale, Adams, & Switkes, 1997; Rabin et al., 1994).

It has long been noted that achromatic patterned stimuli produce strong correlations between VEP and psychophysical measures of temporal sensitivity (e.g., Regan & Beverly, 1973). Furthermore, the correlation between VEP and pattern, motion or contrast thresholds appears stronger when gratings rather than checkerboards are used (Kulikowski, 1974; Robson & Kulikowski, 2012). Also, the amplitude of the VEP signal increases with

stimulus size up to about 18 deg (e.g., Parry & Robson, 2012; Rabin et al., 1994). The latter finding makes large-field stimuli a valuable tool in measuring chromatic responses in subjects who may have reduced color responses such as infants and clinical patients (e.g., Crognale et al., 1993; Schneck et al., 1997).

Onset stimuli produce larger VEP amplitudes than do stimuli that are continuously reversing (Berninger et al., 1989; Murray et al., 1987; Rabin et al., 1994; Regan, 1988). Furthermore, VEP signals appear more robust when recording is conducted during relatively short onset periods approximately 200 ms in the case of stimuli modulated along S-cone color axis and around 155 ms when the stimuli is modulated along LM-cone color axis (Korostenskaja et al., 2001; Rabin et al., 1994). Although onset presentation seems to be more suitable for obtaining large and reliable responses, pattern reversals can more easily be employed to investigate the temporal characteristics of the cVEP (Crognale, Adams, & Switkes, 1997; Rabin et al., 1994). Previous studies have shown that responses using large-field sinusoidal gratings can preferentially activate color specific pathways (Crognale, Adams, & Switkes, 1997; Crognale et al., 1993; Parry & Robson, 2012; Rabin et al., 1994). Crognale et al. (1993) used an 18 deg in diameter sinusoidal grating with smoothed edges and observed that cVEP can detect color losses in protan, deutan, tritan, and diabetic participants. Of particular note is that the tritanopic subjects produced little to no response to S-cone selective stimuli. Observers with normal vision showed a large negative peak and longer latencies for VEPs

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recorded for onset S-cone stimuli in comparison to stimuli modulated along LM, L and M color-axis in MacLeod–Boynton, Derrington–Krauskopf–Lennie (MBDKL) color space (Derrington, Krauskopf, & Lennie, 1984; MacLeod & Boynton, 1978) (see also Crognale, Adams, & Switkes, 1997; Rabin et al., 1994). Similar findings regarding differences in latencies between particular color axes recorded during onset presentation of chromatic stimuli were noticed when using a smaller 3-deg square-wave grating stimuli (e.g., Korostenskaja et al., 2001; Robson & Kulikowski, 2012).

Although large-field stimuli may be desirable for many applications of the chromatic VEP, they can result in departures from isoluminance, particularly along the tritan direction. These luminance contributions are due to retinal inhomogeneities, the most salient being the higher foveal concentration of macular pigment. Psychophysical measures of threshold are particularly sensitive to small amounts of luminance contribution. However, the degree to which these contributions are reflected in the chromatic VEP has been a topic of some debate (e.g., Kulikowski, Robson, & McKeefry, 1996; Switkes et al., 1996). In addition, a positive peak at around 100 ms in the onset response waveform is sometimes taken as evidence of luminance intrusion, but for substantial amounts of intentional luminance contribution, the presence of this component appears to have little effect on the large negative wave that is the hallmark of the cVEP (Crognale et al., 1993; Rabin et al., 1994).

Results from prior experiments have shown that the cVEP has temporal properties that are characterized by non-linearities such as ringing, which cause the cVEP to depart from the results of psychophysics (Crognale, Adams, & Switkes, 1997; Rabin et al., 1994). Of particular interest to the present investigation is that temporal tuning functions measured with the cVEP amplitudes are band-pass in nature, and differ markedly from the low-pass tuning functions observed with threshold psychophysics using chromatic modulations (e.g., Burr & Morrone, 1993; Green, 1969; Kelly, 1974; Parry & Robson, 2012). The band-pass results have been attributed by some investigators to interactions between the chromatic response and intrinsic cortical rhythms such as alpha (e.g., alpha entrainment) (Crognale, Adams, & Switkes, 1997). Despite the fact that these band-pass functions were obtained with both large and small fields, some investigators have claimed that the band-pass tuning results from luminance intrusion, and further claim that low-pass tuning is one of the defining characteristics of selective chromatic responses since that is what psychophysics predicts (e.g., Kulikowski, Robson, & McKeefry, 1996; Robson & Kulikowski, 2012). Interestingly, these claims have never been tested directly (e.g., by measuring the tuning functions with luminance intrusions removed from the large-field stimulus).

Parry and Robson (2012) developed a large-field (18 deg) pan-isoluminant grating (PIG) stimulus that greatly reduced luminance contaminations inherent in large-fields. They used minimum border and heterochromatic flicker photometry procedures to adjust concentric rings of a sinusoidal grating for isoluminance at each eccentricity. As in prior studies, they reported a chromatic specific negative component for both large-field PIG and small isoluminant stimuli (3 deg) around 200 ms of the stimulus onset. They also identified a luminance component as a positive peak around 133–140 ms in their achromatic stimuli. As in prior studies, they further attributed this positive peak in the waveforms as luminance intrusion (see also, Kulikowski, Robson, & McKeefry, 1996; Robson & Kulikowski, 1998). However, they did not report temporal tuning functions for the cVEP using their novel stimulus. To date there are only few studies that have measured temporal tuning of the cVEP to reversing stimuli. Those that have, concur that reversing S-cone specific and in some cases L–M cones specific stimuli result in band-pass tuning with a peak near 8 rev/s (Crognale, Adams, & Switkes, 1997; Fiorentini, Burr, & Morrone,

1991; Rabin et al., 1994) consistent with interaction with intrinsic cortical rhythms such as alpha (e.g., Bartley, 1940; Crognale, Adams, & Switkes, 1997; Regan, 1988).

The present study was conducted to directly test the claim that luminance artifacts can explain band-pass temporal tuning of the cVEP using large-field stimuli. It has been hypothesized that if luminance artifacts are responsible for band-pass temporal tuning then band-pass tuning should not be observed when these luminance artifacts are removed. We also wished to test whether or not the presence of any small early positive component was contingent upon luminance intrusion, and if present whether or not this component affects the latency or amplitude of the signature negative going component of the response. We followed Parry and Robson (2012) by creating large-field stimuli that should greatly reduce the degree of luminance intrusion. Our stimuli were large arrays of horizontally oriented Gabor patches that were each individually adjustable for isoluminance. The use of Gabor patches instead of the concentric rings of a grating as employed by Parry and Robson, further removed possible luminance intrusion from the sharp edges of the rings. In addition, the capacity to adjust each Gabor patch individually further controlled for inhomogeneities that might not be uniformly distributed at a given eccentricity. Here we compare tuning functions measured with these stimuli and those measured with traditional large-field uniform gratings. In addition, we use these stimuli to characterize the effects of luminance intrusion on the onset response.

2. Methods

2.1. Participants

Five observers (one female) aged 24–54 years participated in this study. Written informed consent was obtained. The procedures were approved by the Office of Human Research Protection of the University of Nevada, Reno and conformed to the declaration of Helsinki. Normal color vision was verified using the Ishihara 38 plate test and an Oculus HMC anomaloscope. Two of the authors were participants (RMS and MAC). The other subjects had some experience in vision research but were naïve to purpose of the study.

2.2. Stimuli

The stimuli subtended 20 deg and were displayed on 20" CRT monitor (Sony Trinitron Multiscan 20 sc II) with refresh rate of 60 Hz, and were viewed from 57 cm. The monitor was calibrated using an Optical photometer (Cambridge Research Systems Ltd., Rochester, UK), and a PR-650 photospectroradiometer (Photo Research Inc., Chatsworth, CA).

The stimuli were created using Matlab (Mathworks, USA) and Psychtoolbox software packages on a PC (NVIDIA GT8800 video card). All patterns had a luminance of 25 cd/m². Two stimulus pattern classes were used: (1) 20 deg field sinusoidal gratings (2 cpd)

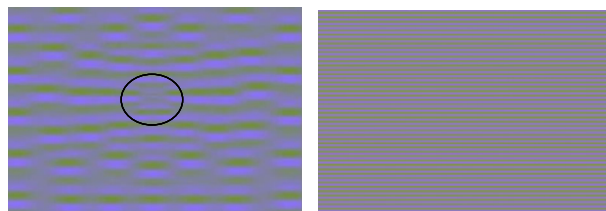


Fig. 1. The Multi Gabor Field (MGF) stimulus (left) and 20 deg sinusoidal grating stimulus (right). The black circle on the MGF stimulus represents the size of the 4 deg field used to generate centrally isoluminant MGF stimuli.

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