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The effects of selective attention on chromatic processing; pattern-onset VEP responses

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Psychology

by

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Abstract

Intro: Electrophysiological and behavioral studies show that attention improves visual processing. Studies of chromatic steady-state and pattern-reversal visual evoked potentials (VEPs) support this. Typically in these studies VEP stimuli are displayed at one spatial location while distracter stimuli are displayed at a different spatial location. Waveform characteristics are shown to be attenuated when the VEP is unattended. More difficult distractor tasks have also shown to cause decrements in waveform characteristics. Typically, responses from extrastraite visual areas show robust effects with attentional modulations. Recording from lower visual areas such as V1 has not shown consistent attentional effects. Chromatic pattern-onset VEPs are thought to be low-level visual responses recorded over the primary occipital area. They have not been studied under conditions of selective attention. It is important to understand the effects of attentional shifts on the chromatic evoked potential because it has potential importance as a diagnostic tool in clinical settings where monitoring of attention can be difficult.

Purpose: The present study measured the effects on the chromatic pattern-onset VEP with spatial and difficult, task-relevant attentional manipulations to show the sensitivity of this response to attentional shifts and the level of this response in the visual system. This study also aimed to determine if participant or patient monitoring is necessary when recording chromatic pattern-onset VEPs.

Methods: Pattern stimuli were used to selectively activate the L-M and the S-(L+M) visual pathways. Waveform amplitudes and latencies were compared while attention was modulated with distractor tasks. In experiments one through four distractor stimuli were X's and O's presented out of synch with the VEP stimuli. In experiment one the VEP and distractor stimuli were spatially contiguous. In experiment two the VEP and distractor stimuli were spatially separated. In experiment three an achromatic pattern-reversal VEP was recorded with a spatially separate distractor. In experiment four VEP fixation was centrally located with the distractor presented in the periphery. In experiment five the VEP and distractor were presented in the same manner as experiment two, however the distractor was chromatic pattern-onset VEP stimuli identical to the recorded VEP stimuli but presented out of phase with the recorded stimuli.

Results: Achromatic responses showed significant changes in amplitude and latency with attentional shifts. No significant changes were found for chromatic response in experiments one two, and four. In experiment five there was a marginally significant increase in amplitude for the VEP attention condition in the S-(L+M) pathway only. These results support the idea that chromatic pattern-onset responses may be low-level in the visual system. Additionally, for this response, it may not necessary to monitor attention in a laboratory or clinical setting.

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1. Introduction

When visual attention is selectively allocated to a visual stimulus in one spatial location, the stimulus at the attended location will elicit enhanced neural responses as compared to the unattended stimulus. This enhancement is believed to be due to the limited processing resources in the visual system (Desimone, 1998; Kastner & Ungerleider, 2001). Modulations in neural activity are found under conditions of selective spatial attention and correspond to behavioral data using similar paradigms (e.g. Kastner & Ungerleider, 2001; Eason, Harter, & White, 1969; Van Voorhis & Hillyard, 1977; Heinz et al., 1994). This has been demonstrated with imaging and electrophysiological measures, such as functional magnetic resonance imaging (fMRI) (Geng et al., 2005; Kastner & Ungerleider, 2001), event related potentials (ERP) (Heinze et al, 1994), and visual evoked potentials (VEP) (Clark & Hillyard, 1996; Muller & Hillyard, 2000; Di Russo & Spinelli, 2002).

Electrophysiological and behavioral studies have used spatial manipulations when studying effects of selective attention (Magun, Hillyard, & Luck, 1993; Heinze et al., 1994; Muller et al., 1998; Muller & Hillyard, 2000; Di Russo, Spinelli, & Morrone 2001; Di Russo & Spinilli 1999 a & b, 2000), these studies show that waveform characteristics attenuate and behavioral performance suffers when dividing attention across regions in space. In other studies spatial manipulations are used in conjunction with more difficult distractor tasks, such as task-relevant distractor stimuli, which are stimuli that are similar or identical to the target stimuli or behavioral tasks and require more cognitive load (Lichenstein-Vidne, Henik, & Safadi, 2006; Gronau, Cohen, & Ben-Shakhar, 2003; Spitzer & Richmond, 1991). In these studies robust effects of attention are found. In

VEP studies, the impact of selective attention has typically been measured using only spatial manipulations of achromatic VEPs with relatively simple distractor tasks (i.e. letters, color) to divert attention away from the recorded VEP stimulus (Heravian-Shandiz, Douthwaite, & Jenkins, 1992; Muller et al., 1998; Muller & Hillyard, 2000; Di Russo & Spinelli, 2002; Di Russo, Spinelli & Morrone, 2001).

From these studies it appears that for achromatic VEPs, attention is important. Attending to the VEP stimulus location over the distractor enhances the waveform components for the attended VEP stimulus as compared to when attention is shifted to the distractor stimulus. Achromatic steady-state and pattern-reversal VEP stimuli have been used to test the effects of selective attention with spatial manipulations, however more difficult manipulations, such as task-relevant or cognitively taking distractor tasks, have not been extensively studied using VEP stimuli. Chromatic VEPs have not been extensively tested under conditions of selective attention. One study (Di Russo & Spinelli, 1999) measured chromatic (red/green) steady -state VEP stimuli with spatial manipulations and found changes in waveform amplitude with attention but no latency changes as compared to achromatic steady state VEP stimuli. VEPs typically show enhanced responses for amplitude and shorter latencies with attention.

While steady-state chromatic VEPs have been used to look at attentional modulations, the effects of selective attention using spatial manipulations along with a more difficult, task-relevant distracter task has not been extensively studied with chromatic stimuli. Chromatic pattern-onset VEPs provide a robust measure of the functioning of the S-(L+M) pathway in the koniocellular system and the L-M pathway in the parvocellular system measured over the occipital area (Murry et al., 1987; Rabin et al., 1993; Switkes et al., 1996). These responses have not been tested under any conditions of selective attention.

Investigating the effects of selective attention using these stimuli is clinically relevant. Chromatic pattern-onset VEPs can be used in a clinical setting as a measure of the integrity of the chromatic visual pathways and color vision (Crognale et al., 1993; Crognale et al., 1992). Any attentional modulations causing changes in waveform responses should be considered to ensure proper testing procedure and to asses whether monitoring of attention is necessary.

Additionally, examining the effects of the spatial and difficulty level parameters of visual attention on the chromatic pattern-onset VEP response is important for understanding how attentional shifts affect these particular visual pathways.

Manipulations with selective attention using chromatic pattern-onset VEPs would also give insight into whether this response is generated at earlier or later levels in the visual system, or is affected by feedback from higher areas in the visual system. It is not completely understood if the chromatic onset response is generated from the primary visual cortex (V1) only or has contribution from higher visual areas. Previous studies suggest that effects of attentional manipulations are not typically seen at V1 as compared to higher visual areas (Kastner & Ungerleider, 2001; Magnum et al., 1997; Muller et al., 1998). Attentional shifts affecting these responses could indicate that they are higher level response or that feedback is modulating the early response (e.g. Geng et al., 2006). Finding no difference with attentional manipulations for chromatic pattern-onset VEPs could indicate that it is indeed a low-level response not affected by feedback from higher visual areas.

Results from this study also test the claim that the chromatic and achromatic visual pathways are different in their responses to attentional manipulations, as was suggested by Di Russo & Spinelli (1999). In sum, the present study on effects of manipulations of selective attention on chromatic pattern-onset VEP responses inform us about the nature of visual evoked responses from an experimental and clinical perspective and also contribute to the understanding of the neural basis of selective attention.

1.1. Background

1.1.1 Selective Attention

It is believed that attention is important for accurate performance on visual tasks (Duncan, 1984; Cave & Pashler, 1995; Osman & Moore, 1993). When attending to one stimulus over another in a visual task, responses for the attended stimulus are enhanced, and decrements in performance may arise when the unattended stimulus is unable to be completely filtered out or when the task is cognitively taxing. Traditionally, studies of selective attention used psychophysical means to measure sensitivity to the stimuli with and without attention (e.g. Brodbent, 1958; Treisman 1969). Psychophysical measurements of sensitivity are thought to correlate with neuronal activity and more recent attention studies using imaging and electrophysiological techniques confirm that selective visual attention modulates neural responses in different parts of the visual cortex (Desimone, 1998; Kastner & Ungerleider, 2001; Desimone & Duncan, 1995; Luck et al., 1997; Chelazzi et al., 1993). Both the ventral (object recognition) and dorsal (spatial recognition) streams of the visual system show effects with attentional modulations thought to be due to neural competition (e.g. Desimone, 1998). Primary visual cortex typically shows the least amount of neural response modulation in single cell recordings

(Reynolds, Chelazzi, & Desimone, 1999) and human fMRI studies (e.g. Kastner & Ungerleider, 2001) with selective attention.

1.1.2. Biased Competition and Bottom-up, Top-down Processing

Performance decrements are thought to arise because of biased competition (Desimone, 1998; Desimone & Duncan, 1995) or limited processing resources due to competition between neurons for representation of a visual object. The neural receptive field is the area in the visual field that produces a response in the neuron. When two simultaneously presented stimuli fall in the same region of the visual field, the neurons sensitive to that information will initially activate in parallel (e.g. Kaster & Ungerleider, 2001). When independent objects activate a local area of cortex in which neural receptive fields are sensitive to the same area of space, or overlap, the result is typically mutual neural suppression of the response. This is why neural competition is said to be highest when competing stimuli occupy the same region of the visual field (Kaster & Ungerleider, 2001; Desimone & Duncan, 1995). This may account for why lower areas in the visual system (i.e. V1) don't show consistent effects (e.g. Geng et al., 2006; Kaster & Ungerleider, 2001; Magnum et al., 1997) with attentional manipulations where neural receptive fields are small and less overlapping. This would be considered a bottom-up influence effecting visual processing. Other bottom-up or stimulus driven influences include changes in contrast and saliency of a stimulus. These influences allow for temporary biasing in favor of that stimulus at the neural level, which can result in attentional capture. Additionally there can be top-down influences on visual processing. Top-down influences, or feedback mechanisms from higher visual areas, usually arise because the stimulus has some behavioral relevance (i.e. predetermined position in space or similarity with other stimuli). These influences can also bias competition for neural representation and capture attention.

1.1.3. Electrophysiological Studies and Selective Attention

The majority of electrophysiological studies that show robust attentional effects are thought to reflect higher levels of processing measured by components such as the posteriorly distributed N1 component (140-200ms), N2 component (200-300ms), and the P3 component (300-500ms) (e.g. Vogel & Luck, 200; & Hillyard, 2000). Responses thought to originate at lower levels in the visual system and pass information along to higher levels of processing, such as P1 (80-130ms) and sometimes the N1 (140-200ms), can also be enhanced with attention (Hillyard et al., 1998; Di Russo & Spinelli, 1999a; Di Russo & Spinelli, 1999b; Heravian-Shandiz et al., 1992 exp1). However, much of the VEP signal recorded over the occipital and parietal areas is thought to originate in extrastriate visual areas and reflect processing happening at higher visual areas (e.g. Magnum 1995). Additionally, changes in waveform characteristics may also reflect feedback from higher visual areas, which may enhance attentional shifts (e.g. Geng et al., 2006).

Using spatially separated stimuli presented to opposite hemifields when measuring low-level responses (i.e. V1) may not show consistent attentional effects because visual information is projected to contralateral hemispheres and may not compete for processing of stimuli (e.g. Kastner & Ungerleider, 2001; Geng et al., 2006; Desimone & Duncan, 1995). However, biased neural competition for resources may not only be related to spatial location. Neural representation may also be biased in favor of stimuli that are behaviorally relevant even if stimuli are separated between hemifields and responses reflect lower-level visual processes (Desimone, 1998).

While there have been many VEP studies looking at the effects of selective attention with spatial modulations, few have used difficult or task-relevant manipulations where VEP and distractor stimuli are similar or identical. These distractor stimuli are thought to use up more neural resources and show more robust attentional effects (e.g. Spitzer & Richmond, 1991; Lichenstein-Vidne, Henik, & Safadi, 2006; Geng et al., 2006; Desimone, 1998). Therefore, more difficult or task-relevant attentional manipulations with VEP recordings thought to originate in V1 must also be considered. Spatial attentional manipulations may not bias neural competition enough to produce robust attentional effects at the early stages of visual processing. Adding a difficult or task-relevant component to the attentional task may increase competition between neurons in separate hemifields.

Studying the effects of selective attention with tasks of varying degrees of difficulty aids in the understanding of how selective attention modulates the visual evoked potential. The present study used spatially different and difficult, task-relevant distractor tasks to assess the extent of these manipulations on the responses of the chromatic pattern-onset VEP.

1.1.4. Spatially Separate Vs. Spatially Contiguous Paradigms

Achromatic and chromatic steady-state as well as achromatic pattern-reversal VEP studies report enhanced waveform characteristics when attention is selectively focused on VEP stimuli (Clark & Hillyard, 1996; Magun, Hillyard, & Luck, 1993; Hillyard, et al., 1997; Heinze et al., 1994; Magnum et al., 1998; Muller et al., 1998;

Muller & Hillyard, 2000; Di Russo, Spinelli, & Morrone 2001; Di Russo & Spinilli 1999a and b, & 2002). In these studies the VEP and distracter stimuli are spatially separated. Typically the VEP stimuli are presented to one visual field and the distracter stimuli (e.g. letters, colored LEDs) presented to the other visual field. These studies show that performance measures are enhanced during attention to the VEP and attenuated when the distractor is attended to. These effects are most typically seen when VEP and distractor stimuli are spatially separated across visual fields and responses are thought to originate in extrastriate visual areas (e.g. Magnum 1995) where input from neurons in each visual field are thought to overlap.

In a selective attention study where achromatic pattern-reversal VEP stimuli and distracter stimuli were spatially congruent, or occupied the exact same position in space, no significant changes in waveform characteristics were seen (Heravian-Shandiz et al., 1992). In this study distracter stimuli were LED's superimposed over the VEP stimuli. In VEP attention conditions, subjects ignored distractor stimuli and made judgments on VEP stimuli. In distractor attention conditions subjects made judgments on the distracter stimuli and ignored the VEP stimuli. With VEP and distractor stimuli that are visually distinct and occupy the same position in space, neural competition is limited and no effects of attentional shifts are seen. In general for achromatic responses, spatially separated stimuli produce more attentional effects than do spatially congruent stimuli (Hughes & Zimba, 1987; Rizzolatti et al, 1987). The present study used both spatially congruent and spatially separated conditions to study effects of selective attention on the chromatic pattern-onset VEP.

1.1.5. Clinically Relevant Manipulations with Selective Attention

To the best of our knowledge, one spatial manipulation that has not been reported in the VEP selective attention literature puts VEP and distractor stimuli in separate spatial locations, but keeps both eyes fixated on the VEP stimuli. This is different from the above mentioned attentional manipulations because it does not completely divide visual information across hemifields, however it does spatially separate the stimuli. This is a clinically relevant manipulation. In a clinical setting VEP stimuli are typically presented to both hemifields. However, it could be possible for a patient to have both eyes fixated on the VEP stimuli and be attending to a point in space away from the screen. The patient could be overtly fixating on the VEP stimuli, however not be actively attending to or thinking about it. It is necessary to know what impact, if any, this type of attentional shift would have on the VEP response. This is especially important when working with infants or other nonverbal populations, where attention can only be inferred from gaze. This manipulation assesses any change to chromatic pattern-onset VEP responses under conditions of spatially divided distractor and VEP stimuli, without completely dividing the visual information across hemifields.

1.1.6. Difficult and Task-relevant Distracter Stimuli

It has been shown for behavioral and electrophysiological measures that performance during selective attention tasks suffers more when the distracter task or stimulus is similar to the target (Lichenstein-Vidne, Henik, & Safadi, 2006; Gronau, Cohen, & Ben-Shakhar, 2003; Spitzer & Richmond, 1991). In these studies visual fixation rests on a center point between two stimulus presentations. Attention is selectively allocated toward one side and a task is performed. When the distractor stimulus is very similar or identical to the task stimulus performance is worse than when the unattended stimulus is not related. It is claimed that this happens because there is more neural competition for similar stimuli especially when spatially separated. The mechanism is believed to be a top-down bias of neural resources toward distractor stimuli that are relevant to the target stimulus eliciting brain responses (Desimone, & Duncan 1995). The task-relevant distractor stimulus uses up the neural resources for the target stimulus producing more attentional modulations at lower visual areas where receptive fields may not overlap. This type of manipulation has not been studied using VEP stimuli. Changes in waveform characteristics might occur for the chromatic pattern-onset VEP if the distracter stimuli are also chromatic on-set gratings. Additionally, adding a task that is more difficult may show further changes in neuronal activity (Spitzer & Richmond, 1991). Changes in neuronal activity have been seen even as early as primary visual cortex in single cell recordings with more difficult tasks (Chen et al., 2008). A more difficult distractor task such as detecting a slight change in contrast of the distractor stimuli may cause more neural resources to be consumed by creating further competition between neurons at V1 resulting in more top-down activation and attentional effects.

1.1.7. Visual Evoked Potentials

VEPs are an objective measure of the functioning of the visual system at the cortical level (Campbell & Kulikowski, 1972; Regan, 1989; Kulikowski, 1991). VEP signals reflect information transmitted from the retina thorough the lateral geniculate nucleus of the thalamus (LGN) and originate from visual cortical cells. These signals are typically recorded over posterior-occipital areas of the scalp (Fahle & Bach, 2006). Different types of visual evoked potentials have been used for years in clinical settings to assess visual problems throughout the visual system. The responses to VEP stimuli are well documented and generally consistent across subjects, making them a good tool to measure neural activity under conditions of selective attention.

Many selective attention studies using spatial manipulations have been done with VEP stimuli (Di Russo, Spinelli, & Morrone, 2001; Di Russo & Spinilli, 2000; Muller & Hillyard, 2000; Muller et al., 1999; Di Russo & Spinelli, 1999 a & b; Heravian-Shandiz et al., 1992). Typically achromatic steady-state & pattern reversal VEP stimuli are used and have shown changes in waveform characteristics with spatial attentional manipulations when measuring components thought to originate at extrastriate visual areas (Magnum et al., 1997). Only one study (Di Russo & Spinelli, 1999) measured chromatic steady-state VEPs using L-M (red/green) stimuli over Oz. They found no latency changes for chromatic stimuli with attentional manipulations, but did find changes in amplitude. This result is interesting because it is thought that attention increases efficiency and speed of processing (e.g. Di Russo & Spinelli, 2002) possibly leading to changes in perceived contrast of stimuli which usually result in enhanced amplitude and reduced latency responses. Likewise, lack of attention could potentially reduce perceived contrast leading to attenuated responses.

1.1.8. Chromatic Pattern-onset VEP

The chromatic pattern-onset VEP has not been studied under any conditions of selective attention. The chromatic pattern-onset VEP is robust measure of the functioning of the two predominant chromatic pathways believed to processes color information in the visual system (Rabin et al., 1993; Murray et al., 1987; Crognale et al., 1992; Crognale et al., 1993). Red/green color information is processed by the L-M pathway in the parvocellular system, which responds best to stimuli that modulate the L or M cones out of phase. Blue/yellow information is processed by the S-(L+M) pathway in the koniocellular system. This pathway is best isolated by stimuli that selectively modulate the S cones. The stimuli that isolate these color pathways are effectively specified by the Derrington et al. (1984) theoretical color space. This three-dimensional color space (Appendix A: Figure A-1) is based on cone activation and has different axes representing the L-M and S-(L+M) chromatic opponent pathways. The luminance pathway is also represented in this color space and takes into account activation from the combined L and M cones. From points on these axes cone activation, or an estimation of cone contribution for a given stimulus, and chromatic stimulus contrast can be calculated, allowing activation of the two different chromatic pathways as well as individual cones. Equivalent contrasts should be used so that the respective stimuli equally activate the two different color pathways. Nonequivalent contrasts could result in different amounts of amplitude and latency shifts for the two pathways, which would make comparison across the pathways difficult. Contrasts can be equated perceptually using suprathreshold contrast matching (Switkes & Crognale, 1999).

The component of interest for the chromatic pattern-onset response, CII, is a negative going response at about 100-200ms, thought to arise from lower-level responses of the chromatic visual pathways (Figure 1 & 2). This test is able to measure the functioning of the L-M pathway as well as the S-(L+M) pathway, which has not been measured in response to attentional manipulations. Because the chromatic pattern-onset VEP is a sensitive measure of the chromatic visual pathways it can be used to test and assess congenital color vision disorders and general parvocellular pathway dysfunction due to disease or other pathological problems (Crognale et al., 1993; Crognale et al., 1992). Therefore, as described above, from a clinical standpoint it is important to understand the implications of attention on this measure.

1.2. Question/Significance

The present study aimed to explore the effects of several different selective attention manipulations on amplitude and latency responses of the chromatic pattern-onset VEP. The effects of attentional modulations on the chromatic pattern-onset VEP are not only important for clinical purposes, as this test can be used as a diagnostic tool to measure the functioning of the color visual pathways, but also for electrophysiological attention research. Since modulations in attention have been shown to impact behavioral and other electrophysiological visual measures, inadequate control of attention could lead to inaccurate results for VEPs in a clinical or laboratory setting. Therefore researchers would benefit from knowing what affect attentional modulations may have on the chromatic pattern-onset VEP. Additionally, chromatic VEPs are thought to be low-level visual responses (Kulikowski & Walsh, 1993). Results from this study give insight into this suggestion and provide further details about the extent of feedback from higher visual areas on this response.

Five different experiments were done to assess the effects of spatial, difficulty, and task-relevant manipulations on the chromatic pattern-onset VEP. This study draws from methods used in previous VEP studies on selective attention. All of these conditions were tested using the chromatic pattern-onset VEP, which has not been previously studied under different conditions of selective attention. Achromatic pattern-reversal stimuli have shown attentional shifts with similar methods in previous studies (e.g. Heravian-Shandiz et al., 1992). Consequently, responses to achromatic pattern-reversal VEP (experiment three) were also measured using the same spatial manipulation and distractor as in experiment two (see below). This was done to ensure the distractor stimuli and manipulations are capable of eliciting a change in waveform responses with attentional shifts.

2. General Procedure

2.1.1 Participants

Each experiment had 8 participants. Each participant provided written informed consent. All participants were screened for normal color vision using the Neitz pseudo-isochromatic test (Cotter, Lee, & French, 1994) and had 20/20 corrected visual acuity as measured by a Snellen chart. Participants with strabismus or amblyopia were excluded from participation. In each experiment three baseline trials and three trials of each condition were recorded for each participant. The baseline trials were used in all experiments to measure any possible changes between the typical passive VEP viewing and the attentional condition. Behavioral measures of attention were also collected. Participants were instructed to press a button each time a predetermined stimulus appeared. Button presses were recorded and reaction times were measured. This was done to monitor attention as well as to compare behavioral performance to the electrophysiological measures.

2.1.2. Chromatic Pattern-onset VEP Stimuli

VEP stimuli were recorded in a similar manner for all experiments with chromatic stimuli using1 cycle/degree horizontal sine wave, gratings with S-axis stimuli used to selectively activate the S-(L+M) (blue/yellow) pathway and L-M-axis stimuli used to selectively activate the L-M (red/green) pathway. These stimuli have been shown to independently activate the opponent blue/yellow and red/green pathways of the koniocellular and parvocellular system (Regan, 1977; Rabin et al., 1994; Switkes et al., 1996). Perceptually equated contrasts for the L-M and S-(L+M) stimuli were used. This was done using suprathreshold contrast matching (Switkes & Crognale, 1999) to ensure L-M and S-(L+M) axis stimuli appeared equally visible. A lab average of these contrast settings using 10 participants was used for all participants in all experiments. L-M cone contrast was 6.7% (root mean square -RMS), and the S-(L+M) cone contrast saw 42.2% RMS. The following formula was used to calculate RMS cone contrast.

$$\sqrt{\left(\frac{L_{max}-L_{min}}{L_{max}+L_{min}}\right)^2+\left(\frac{M_{max}-M_{min}}{M_{max}+M_{min}}\right)^2+\left(\frac{S_{max}-S_{min}}{S_{max}+S_{min}}\right)^2}.$$

A lab average of 10 observers was employed as isoluminance settings for both L-M and S-(L+M) axis stimuli. Individual adjustments for isoluminance were not used since prior research has shown that small luminance contribution due to retinal inhomogeneities and individual differences in isoluminance have little or no effect on the amplitude and latencies of the major component (N1) of the chromatic onset VEP (e.g. Rabin et al., 1994; Porciatti & Sartucci, 1999) The robust nature of this chromatic response can be contrasted with psychophysical measures of threshold wherein small luminance contributions have a large effect.

The overall luminance of the stimuli was fixed at 25 cd/m2 and the CIE endpoints for the L-M stimuli were x = 0.36, y = 0.29 (red), and x = 0.25, y = 0.35 (green), for the S-(L+M) stimuli x = 0.27, y = 0.23 (blue) and x = 0.40, y = 0.52 (yellow) and the average chromaticity was x = 0.31, y = 0.31. Onset VEP stimuli were presented 100ms on/400ms off, 60 times for each recording. The different color axes were randomly interleaved for a total of 120 presentations lasting 1 min per trial. Participants were positioned so that the VEP stimuli subtended 19.5 degrees width x 13.5 degrees height. VEP stimuli and distractors were generated using a PC and presented on a Sony Trinitron Multiscan 20seII monitors. In experiments one, through four the distractor stimuli were highly visible letters that appeared randomly on the screen (desynchronized from the VEP stimuli, 250ms on/400ms off). A predetermined letter appeared with a probability of 0.33 in series of other letters. Letter stimuli subtended 1degree width x 1.18 degrees height. The average luminance of the letters was 8.81 cd/m^2. The letters were displayed on a black screen so that the overall luminance of the chromatic gratings was not changed appreciably when the screens' images were superimposed (e.g. experiment one). The average chromaticity of the letters was x = .33, y = .33. In experiment five, the distractor stimuli was chromatic pattern-onset VEP stimuli nearly identical to the stimuli used for the recorded VEPs and desynchronized from the VEP stimuli (200ms on/500ms off). During the distracting task a grating with a slightly lower L-M contrast appeared with a probability of .33. Subjects responded with a key press when they saw the lower contrast grating. Control recordings were made for desynchronized letter and VEP distractor stimuli with no detectable interference.

2.1.3. Achromatic Pattern-reversal VEP Stimuli

In experiment three the VEP stimulus was an achromatic checkerboard grating. Participants were positioned so the checks were 60 min of arc in size. The pattern subtended 19.5 degrees width x 13.5 degrees height and was presented at 5 degrees in the periphery. VEP Stimuli subtended 19.5 degrees width x 13.5 degrees height and check size was 60min of arc with a reversal rate of 2 per second and 50 presentations per trial. Stimulus contrast was set to maximum (approximately 99% Michelson) with a mean luminance of 40 cd/m^2 in accordance with the International Society for Clinical

Electrophysiology of Vision (ISCEV) standards for achromatic pattern-reversal VEP (Odom et al., 2003). Distractor stimuli were the same as in experiments one and two.

2.1.4. Chromatic Pattern-onset VEP Recording and Data Analysis

VEPs were recorded using Grass gold electrodes and a Grass P511 amplifier input into a National Instruments IO Board in a PC. The active electrode was placed over Oz based on the international 10-20 placement system with the reference and ground on the ears. Electrode impedances were kept below 10 kΩ (measured at 30 Hz). Individual presentations of stimuli for each pathway were averaged over the 60 presentations and stored in an Excel spread sheet program for off-line analysis. VEP recording bandwidth was 1 to 300 Hz and sampled at 500 Hz according to ISCEV Standards.

Each condition was run three times and averaged together for individual subject averages. Changes in amplitude and latency for the negative CII component (see Figure 1 & 2) were analyzed for the chromatic response for all conditions. This is the most robust common component of the chromatic pattern on-set response. The latency is contrast dependant and usually appears between 100 and 200ms (Rabin et al., 1994). Amplitudes and latencies for the baseline, VEP attention, and distractor attention conditions in each experiment were compared within subjects. Amplitude was determined by taking the difference between the largest negative deflection, CII (between 100- 200ms) and the largest positive component, CIII (between 150 and 300ms) (see Figure 1 & 2). Latency was measured from stimulus onset to the first negative component (CII). Within subjects t-tests were done to check for significant differences between conditions for each experiment. This was done for both the amplitudes and latencies of the waveforms.

2.1.5. Achromatic Pattern-reversal VEP Recording and Analysis

In experiment three VEPs were recorded using Grass gold electrodes. The active electrode was placed over Oz with reference over Fz and ground on the earlobe. Electrode impedances were kept below 10 kΩ (measured at 30 Hz). The VEPs were recorded with an Espion E^2 Diagnosys system. The recording bandwidth was 1 to 500 Hz and sampled at 1000 Hz in accordance with ISCEV Standards. Individual reversal responses were averaged over 50 presentations and input into an Excel spread sheet program for off-line analysis.

Three trials for each condition were recorded and averaged for each participant. The P100 amplitude (around 100ms) was measured peak to trough by taking the difference between the N75 and the P100 (Figure 3). Latency was measured from stimulus onset to the P100 component. This is the main component associated with the pattern-reversal achromatic responses. The P100 amplitude remains consistent across subjects and its latency is affected by changes in stimulus contrast, size, and fixation (e.g. Odom et al., 2003).

2.1.6. Behavioral Measures

For all experiments subjects were instructed to press a button when a predetermined stimulus appeared. Percent correct and reaction time were recorded for the VEP attention and distractor attention tasks. Additionally an ANOVA comparing performance measures was done to assess any differences between conditions within an experiment and differences between each experiment. Behavioral measures also were taken to see if the intended increased difficulty of the task-relevant experiment (five) was evident in the behavior.

2.2. Experiment 1: Spatially Contiguous Stimuli

In this experiment letter stimuli and VEP stimuli occupied the same position in space (spatially superimposed). The letter stimuli (X's and O's) were generated on a separate monitor, and superimposed with a beam-combiner cube onto the VEP stimuli. A baseline measure was taken first with the participants looking at the VEP stimuli through the cube and no letter stimuli present. This was a control measure to assess waveform components while looking through the beam-combiner. The order for the experimental conditions was randomly presented for each subject. In each experimental condition participants were instructed to look through the cube until they could see that the images of the two screens were superimposed with the X's and O's in the center of the screen. Both the letters and the VEP stimuli were visible for each condition excluding baseline.

In the VEP attention condition the participants attended to the gratings (ignored the X's and O's) and pressed a button every time they saw an S-(L+M) grating. This was done to ensure that attention was being paid to the grating and not the X's and O's. In the letter attention condition participants attended to the randomly presented X's or O's and pressed a button on the keypad when they saw an O. This was done to ensure that attention was being paid to the letters and not the VEP stimulus.

In this experiment the overall luminance of the stimuli was decreased because of the optical properties of the beam-combiner cube providing for an average luminance of

7.5 cd/m^2 for the VEP stimuli and 2.61 cd/m^2 for the letter stimuli. However, the size of the VEP and distractor stimuli remained the same for the conditions of the experiment.

2.3. Experiment 2: Spatially Separated Stimuli

In this experiment the trial randomization and tasks regarding the attended and unattended conditions were the same as in experiment one; however no beam splitter was used. The VEP gratings were presented to one hemifield and the letter stimuli were presented in the other on another monitor. Once again a baseline measure was taken where participants fixated at a center cross between the two monitors and the recorded VEP stimuli were presented to one visual field. In the VEP attention condition participants fixated at a cross between the two monitors without moving their eyes and covertly attended to the VEP gratings in one hemifield and pressed a button every time they saw an S-(L+M) grating while the letters appeared on the other monitor. In the distractor attention condition participants fixated at the cross between the two monitors and covertly attended to the X and O stimuli and pressed a button on the keypad when they saw an O while the VEP gratings appeared on the other monitor. All participants were monitored for proper eye gaze. Participants were randomly assigned to receive the recorded VEP stimuli in either the left or right hemifield. The VEP and letter stimuli were presented at 5 degrees in the periphery and had the same width and height as in the previous experiment.

2.4. Experiment 3: Achromatic Pattern-reversal VEP with Spatially Separate Distractor

In this experiment the achromatic pattern-reversal VEP stimuli and distractor presentations were the same as in experiment two. Participants viewed the VEP stimulus in one visual field and the distractor letters were presented to the other visual field. Three trails in each condition were recorded. In the baseline condition the participants passively fixated at the center point between the monitors as the VEP stimuli were displayed in one hemifield, with no distractor present. In the VEP attention condition participants fixated at a central point between the monitors and attended to the VEP stimuli. To ensure attention was directed to the VEP stimuli participants pressed a button when they detected a predetermined number of reversals. In the distractor attention condition participants again fixated between the monitors but attended to the letter stimuli. The distractor stimuli were letters identical to the distractor stimuli in the first three experiments.

2.5. Experiment 4: Centrally Displayed VEP with Spatially Separate Distractor

This experiment spatially separated attention between the VEP and letter stimuli but displayed VEP stimuli to both visual fields. In this experiment the trial randomization, presentation, and tasks regarding the VEP attentional and letter attentional conditions were the same as in experiment two. A baseline conditions was recorded where participants passively viewed the VEP with both eyes. In the VEP attention condition participants fixated both eyes on the monitor with the VEP stimuli and attended to the gratings while the letter stimulus was displayed on the other monitor 10 degrees in the periphery. In the distractor attention condition participants fixated both eyes on the VEP gratings while covertly attending to the letter stimuli on the other monitor. The same button press task as in the first two experiments was also used to ensure participants' attention to the appropriate stimuli. All participants were monitored for proper eye gaze. The stimulus contrast, chromaticity, and luminance were the same as in experiment two. The stimulus size was the same as in experiment one and two. This experiment though more complicated in design better represents a worrisome clinical scenario i.e. proper gaze but divided or inadequate attention.

2.6. Experiment 5: Task-relevant Distractor with Difficult Distractor Task

In this experiment trial randomization and tasks regarding the attended and unattended conditions were presented in the same manner as experiment two. VEP and distractor stimuli were spatially separated between the two hemifields. Chromatic VEP stimuli were identical to the previous experiments. Distractor stimuli were asynchronous pattern-onset VEP stimuli presented to the opposite hemifield as the recorded VEP stimuli. The distractor stimuli were task-relevant (the same as the recorded VEP stimuli). A baseline condition was recorded where participants passively viewed the fixation point between the two monitors with only the recorded VEP stimuli present. In the VEP attention condition participants fixated on the center cross but attended to the recorded VEP stimuli while the non-recorded distractor stimuli were presented in the other monitor. In the distractor attention condition participants fixated on the center cross but attended to the distractor stimuli while the recorded VEP stimuli were presented in the other monitor. The distractor stimuli were the same as the recorded stimulus except a lower contrast L-M grating appeared with a probability of 0.33. Participants pressed a button each time they saw the L-M axis stimuli presented at a lower contrast in the monitor with the non-recorded VEP stimuli. The L-M contrast reduction was 60% of the full contrast (4.2 RMS), CIE coordinates for the endpoints were for L-M stimuli x =0.34, y = 0.30 (red), x =0.27, y = 0.33 (green) and for the S-(L+M) stimuli x =0.28, y =0.26 (blue), x =0.35, y =0.41 (yellow). This contrast was chosen because participants were able to detect the contrast difference; however it required vigilant attention and was reported by participants to be difficult. Gaze was monitored by the experimenter. The recorded and distractor VEP stimulus had the same luminance, contrast, and chromaticity as experiments two & four as well as the same geometry as experiment two.

3. Attentional Shifts Have Little Effect on the Waveform of the Chromatic Onset VEP

Below is the publication (Highsmith & Crognale, in press) of experiments one, two, and three. The following experiments showed increases in amplitude and decreases in latency for the achromatic pattern-reversal response with spatially separated attentional manipulations, which has been repeatedly shown in the literature (e.g. Clark & Hillyard, 1996; Muller, et al., 1998; Muller & Hillyard, 2000; Di Russo & Spinelli, 2002, Di Russo et al., 2001; Di Russo, & Spinelli, D, 1999; Heravian-Shandiz et al., 1992). This study also showed that chromatic pattern-onset responses were not affected when using spatial attentional manipulations. Data showing basline measurments was not icluded in the publication. Figure A-2 in Appendex A shows baseline results for experiment one, figure A-3 shows those results for experiment two, and figure A-4 shows those reslusts for experiment three. There was no significant difference in waveform characteristics between conditions for the chroamtic pathways (experiemnts one and two). The achromatic responses did show an increase in amplitude and decrease in latency for the VEP attention conditon as compared to both baseline and distrator attention conditions. Behavior results for this experiment were not included in the publication but are presented in chapter 6 and discussed in the general discussion (chapter 7). These results support the claim that the chromatic pattern-onset response is a low-level response, not affected by simple attentional manipulations. Furthermore it may not be necessary to monitor attention in a clinical or laboratory setting.

Attentional shifts have little effect on the waveform of the chromatic onset VEP

Jennifer R. Highsmith & Michael A. Crognale

3.1. Abstract
Attention is important for sufficient performance on many visual tasks. This has been shown using achromatic steady-state and pattern-reversal VEPs. Waveform characteristics typically attenuate when VEP stimuli are ignored and distractor stimuli attended to. Chromatic pattern-onset responses have not been tested under conditions of selective attention and can be used in clinical settings to test color vision, therefore, it is important to know what effects attentional shifts would have on this response. In the present study chromatic pattern-onset VEPs were recorded using spatially divided and spatially contiguous VEP and distractor stimuli.
VEP Stimuli were l cycle/degree horizontal sine wave patterns (on-set mode 100ms on/400ms off) used to selectively modulate the L-M and S-(L+M) visual pathways. Distracter stimuli were letters. Subjects attended to either the letters or the gratings and pressed a button when a predetermined stimulus appeared. In experiment one VEP and distractor stimuli were superimposed and spatially contiguous. In experiment two stimuli were presented to different hemifields. No significant changes in waveform amplitude and latency were found between VEP and distractor attention conditions for either visual pathway. For the chromatic pattern-onset response, modulation of attention does not change responses either with spatially contiguous or spatially separate selective attention manipulations. Consequently, it may not be necessary to monitor attention during recording of this response.

Key Words: Attention, Chromatic visual evoked potentials, Visual pathways, Spatially contiguous, Spatially separate

3.2. Introduction

When visual attention is selectively allocated to a stimulus in one spatial location, the stimulus at the attended location will often elicit enhanced neural responses as compared to those from unattended stimuli. Changes in neural activity are found under conditions of selective spatial attention (Desimone, 1998; Desimone & Duncan, 1995) and correspond to behavioral data using similar paradigms (e.g. Kastner &

Ungerleider, 2001; Eason et al, 1969). This has been demonstrated with achromatic steady-state pattern-reversal and transient pattern-reversal visual evoked potentials (VEPs) (Clark & Hillyard, 1996; Muller, et al., 1998; Muller & Hillyard, 2000; Di Russo & Spinelli, 2002, Di Russo et al., 2001; Di Russo, & Spinelli, D, 1999). These studies find that when stimuli are spatially separated, attending to the VEP stimulus location enhances the waveform components for the attended VEP stimulus as compared to when attention is shifted to the distractor stimulus. Another study found no changes in waveform characteristics with attentional shifts when VEP and distractor stimuli were spatially contiguous (Heravian-Shandiz et al., 1992). Chromatic VEPs have not been extensively tested under conditions of selective attention. One study (Di Russo & Spinelli, 1999) measured chromatic (red/green) steady-state VEP stimuli with modulations in spatial attention and found changes in waveform amplitude with attention but found no latency change as measured by phase, as compared to achromatic steady state VEP stimuli. However, prior research has suggested that steady-state pattern-reversal stimuli may not be optimal for isolation of chromatic pathways (e.g. Murray et al., 1987; Kulikouski et al., 1989; Rabin et al., 1994). Consequently, the current study also addressed whether or not the transient chromatic pattern-onset VEP would reflect changes reported for the chromatic steady-state pattern-reversal VEP under comparable attentional manipulations.

The transient chromatic pattern-onset VEPs provide a robust measure of the functioning of the S-(L+M) pathway in the koniocellular system and the L-M pathway in the parvocellular system measured over the occipital area (e.g. Murray et al., 1987;

Kulikouski et al., 1989; Berninger et al., 1989; Rabin et al., 1994; Switkes et al., 1996). These responses have not been tested under any conditions of selective attention.

The present study explored the effects of selective attention manipulations on the chromatic pattern-onset VEP responses. Two different experiments, with chromatic stimuli, using spatially congruent (experiment one) and spatially separated (experiment two) VEP and distractor stimuli were done to assess the effects of attentional manipulations on the chromatic pattern-onset VEP. A third experiment using transient achromatic pattern-reversal stimuli, and spatially dividing attention was conducted to determine if these distractors affect attention in a manner consistent with previous experiments using achromatic stimuli (e.g. Clark & Hillyard, 1996; Muller, et al., 1998; Muller & Hillyard, 2000; Di Russo & Spinelli, 2002, Di Russo et al., 2001; Di Russo, & Spinelli, D, 1999; Heravian-Shandiz et al., 1992).

Investigating the effects of selective attention using these stimuli is clinically relevant since chromatic pattern-onset VEPs can be used in a clinical setting as a measure of neural integrity and color vision (e.g. Crognale et al., 1993; Crognale et al., 1992). If distracting attention attenuates the chromatic VEP waveform or if focusing attention enhances the response it becomes necessary to monitor the attentional state in clinical patients. However, it is often difficult to monitor attention in a clinical setting, particularly with non-verbal patients such as children. Additionally, examining the effects of visual attention on the chromatic pattern-onset VEP response is important for understanding how attentional shifts affect the L-M and S-(L+M) visual pathways. If attention does have an affect on the pattern-onset response we expect to see an overall increase in amplitude and decrease in latency when participants are attending to the VEP and compared to when they are attending to the distractor stimuli. Results from this study could also test the claim that the chromatic and achromatic visual pathways are different in their responses to attentional manipulations, as was suggested by Di Russo & Spinelli (1999).

3.3. General Procedure

3.3.1. Participants

Participants for experiments one and two were adults with a mean age of 23 yrs, (N = 8). Participants in experiment three were adults with a mean age of 26yrs (N = 8). In all experiments participants provided written informed consent. The research protocol was approved by the University of Nevada, Reno Biomedical Institutional Review Board (protocol B98/99-28). All participants were screened for normal color vision using the Neitz pseudo-isochromatic test (Cotter et al., 1994) and had 6/6 corrected visual acuity as measured by a Snellen chart. In each experiment three trials of each condition (VEP attention, distractor attention) were recorded and averaged for each participant.

3.3.3. Stimuli Presentation

In both chromatic VEP experiments stimuli were 1 cycle/degree horizontal sine wave gratings with S-axis stimuli used to preferentially modulate the S-(L+M) (blue/yellow) pathway and L-M-axis stimuli to preferentially modulate the L-M (red/green) pathway (Rabin et al., 1994; Switkes et al., 1996). Perceptually equated contrasts for the L-M and S-(L+M) stimuli were calculated using suprathreshold contrast matching (Switkes & Crognale, 1999). A lab average of these contrast settings using 10 participants were used for all participants in all experiments. Contrasts were 6.7% root mean square (RMS) for L-M stimuli, and 42.2% S cone contrast for the S-(L+M). The following equation shows the formula used to calculate chromatic contrast: $\sqrt{\left(\frac{L_{max}-L_{min}}{L_{max}+L_{min}}\right)^2+\left(\frac{M_{max}-M_{min}}{M_{max}+M_{min}}\right)^2+\left(\frac{S_{max}-S_{min}}{S_{max}+S_{min}}\right)^2}$ For LM contrast the S values are equal to zero, for S contrast the L and M terms are equal to zero.

A lab average of 10 observers was employed as isoluminance settings for both L-M and S-(L+M) axis stimuli. Individual adjustments for isoluminance were not employed. However, prior research has shown that small luminance contribution due to retinal inhomogeneities and individual differences in isoluminance have little or no effect on the amplitude and latencies of the major negative component (CII) of the chromatic onset VEP (e.g. Rabin et al., 1994; Porciatti & Sartucci, 1999). The robust nature of this suprathreshold chromatic response can be contrasted with psychophysical measures of threshold wherein small luminance contributions can have a large effect (Switkes et al., 1988; Berninger et al., 1989; Lee et al., 1990; Mullen et al., 1994). For chromatic stimuli, the overall luminance was 25 cd/m2 and the CIE endpoints for the L-M stimuli was x = 0.36, y = 0.29 (red), and x = 0.25, y = 0.35 (green), for the S-(L+M) stimuli x = 0.27, y = 0.23 (blue) and x = 0.40, y = 0.52 (yellow) and the average chromaticity was x = 0.31, y = 0.31. Onset VEP stimuli (100ms on/400ms off) were presented 60 times for each recording. The different color axes were randomly interleaved for a total of 120 presentations lasting 1 min per trial. Subjects were positioned so that the VEP stimuli subtended 19.5 degrees width x 13.5 degrees height. VEP stimuli and distractors were generated using a PC and presented on a Sony Trinitron Multiscan 20seII monitor, running at a refresh rate of 100Hz. Chromatic VEP stimuli were generated with a VSG card (Cambridge Research Systems) and calibrated using a PR-650 Spectrascan spectral radiometer (Photo Research). RGB and luminance values were used to generate gamma corrections curves.

In all experiments the distractor stimuli were highly visible letters that appeared randomly on the screen and were desynchronized from the VEP stimuli (250ms on/400ms off). Letter stimuli subtended 1degree width x 1.18 degrees height. The average luminance of the letters was 8.81 cd/m^2. The average chromaticity of the letters was x = .33, y = .33. Control recordings were done for desynchronized letter and VEP distractor stimuli with no detectable responses. In all experiments participants pressed a button every time a predetermined stimulus appeared to ensure proper attention. In experiment three an achromatic checkerboard stimulus was used. The black and white checks were generated with an Espion E^2 Diagnosys system and presented according to ISCEV standards. VEP Stimuli subtended 19.5 degrees width x 13.5 degrees height and check size was 60min of arc with a reversal rate of 2 per second and 50 presentations per trial. Stimulus contrast was set to maximum (approximately 99% Michelson) with a mean luminance of 40 cd/m^2. Distractor stimuli were the same as in experiments one and two.

3.3.3. VEP Recording and Analysis

Chromatic VEPs were recorded using Grass gold electrodes and a Grass P511 amplifier input into a National Instruments IO Board in a PC. The active electrode was placed over Oz based on the international 10-20 placement system with the reference and ground on the ears. Electrode impedances were kept below 10 kΩ (measured at 30 Hz). Individual presentations of stimuli for each pathway were averaged over the 60 presentations and stored in an Excel spread sheet program for off-line analysis. VEP recording bandwidth was 1 to 300 Hz and was sampled at 500 Hz according to ISCEV Standards.

In experiment three VEPs were recorded using Grass gold electrodes. The active electrode was placed over Oz with reference over Fz and ground on the earlobe. Electrode impedances were kept below 10 kΏ (measured at 30 Hz). The VEPs were recorded with an Espion E^2 Diagnosys system. The recording bandwidth was 1 to 500 Hz and sampled at 1000 Hz according to ISCEV Standards. Individual onset responses were averaged over 50 presentations and input into an Excel spread sheet program for off-line analysis.

In all experiments each condition was run three times and averaged together for individual participants' averages. A repeated measures t-test was used to compare the difference between the mean amplitude and latency of all participants for the VEP attention, and distractor attention conditions. The mean difference between conditions for the amplitude measures were found by subtracting the distractor attention condition individual data from the VEP attention individual data. The mean difference between conditions for the latency measure was found by subtracting the VEP attention condition individual data from the distractor attention individual data (see participant individual data see tables 1-5). This allowed for a measure of how much waveform characteristics increased or decreased between conditions. It was expected that if attention had an effect on the responses, there should be overall enhancement of waveform measures in the VEP attention condition as compared to the distractor attention condition.

For chromatic stimuli changes in amplitude and latency for the CII component (Figure 1 & 2) were analyzed for the chromatic response for all conditions. The CII component is the most robust common feature of the chromatic pattern-onset response. The latency is contrast dependant and usually appears between 100 and 200ms (e.g. Murray et al., 1987; Kulikouski et al., 1989; Rabin et al., 1994). Peak-to-trough amplitudes for chromatic stimuli were determined by taking the difference between the largest negative deflection, CII (between 100- 200ms) and the largest following positive component, CIII (between 200-300ms), (Figure 1 & 2). Latencies were measured from stimulus onset to the first negative component (CII). For the achromatic response, trough-to-peak amplitudes were measured for the P100 response by taking the difference between the large negative response around 75ms (N75) and the large positive response around 100ms (P100). Latencies were measured from stimulus onset to the large positive P100 response (Figure 3).

3.3.4. Experimental Procedure

In experiment one letter stimuli and VEP stimuli occupied the same position in space (spatially contiguous). The letter stimuli (X's and O's) were generated on a separate monitor, and superimposed with a beam-splitter cube onto the VEP stimuli. In each experimental condition participants were instructed to look through the cube at the image of the two superimposed screens. The X's and O's appeared in the center of the screen. Both the letters and the VEP stimuli were visible for each condition.

In the VEP attention condition participants were instructed to attend to the gratings and to press a button every time they saw the S-(L+M) grating, which appeared with a probability of .5. In the distractor attention condition participants were instructed to attend to the letters and press a button each time they saw an O, which appeared with a probability of 0.33. For this experiment the overall luminance of the stimuli was decreased due to beam combination, providing for an average luminance of 7.5 cd/m^2 for the VEP stimuli and 2.61 cd/m^2 for the letter stimuli. The size of the VEP and distractor stimuli remained the same for the conditions of the experiment.

In experiment two the trial randomization and tasks regarding the attended and unattended conditions were the same as in experiment one; however no beam splitter was used. The VEP gratings were presented to one hemifield on one monitor and the letter stimuli were presented on another monitor to the other hemifield. Participants fixated at a center cross between the two monitors and were instructed to attend to the VEP or the distractor stimuli. The VEP and distractor stimuli were presented at 5 degrees in the near periphery and had the same width and height as in the previous experiment. All participants were monitored for proper eye gaze.

In experiment three the achromatic pattern-reversal checkerboard stimulus was presented in the same manner as experiment two with the same monitor size and stimulus eccentricity. Fixation was held at a cross between the two monitors. In the VEP attention condition participants were asked to press a button each time they counted a random number of reversals of the checkerboard stimulus. The distractor task was the same as in the previous experiments. Proper eye gaze was monitored.

3.4. Results

In experiment one no significant changes in waveform amplitude or latency were found between attentional conditions for the L-M and S-(L+M) pathways (Figure 1). The L-M pathway showed an average decrease in amplitude in the VEP attention condition as compared to the distractor attention condition of 0.3μV (SEM = 0.3), ($p > .05$) (Figure 1a). Amplitude changes for the S-(L+M) pathway (Figure 1b) were also insignificant, with and average decrease of 0.1 μV (SEM = 0.3) in the VEP attention condition as compared to the distractor attention condition ($p > .05$). The average amplitude for each subject in both attentional conditions along with the percent change between the conditions is reported in table1. As shown, subjects showed no consistent increase in amplitude in the VEP attention condition as compared to the distractor attention condition. Latency measurements between conditions also showed no significant change with attentional manipulations (Figure 1). For the L-M pathway there was a decrease in latency of 2.2ms (SEM = 2.3) for the VEP attention condition as compared to the distractor attention condition, ($p > .05$). No significant changes in latency were found for the S-(L+M) pathway (Figure 1b). The S-(L+M) pathway showed an average decrease in latency of 1.0ms (SEM = 2.1) for the VEP attention condition as compared to the distractor attention condition, ($p > .05$). The average latency for each subject in both attentional conditions along with the percent change between the conditions is reported in table 2. Subjects showed no consistent change in response latency between the two conditions.

In experiment two, again, no significant increase in waveform amplitude or decrease in latency was found for the VEP attention condition as compared to the distractor attention condition for the L-M or S-(L+M) pathways (Figure 2 and Table 3). No measurable change in amplitude was found in the VEP attention condition as compared to the distractor attention condition (0.0μV, SEM = 0.3), ($p > .05$). The changes in amplitude for the S-(L+M) pathway were also insignificant, with an average decrease of 0.2 μV (SEM = 0.2), ($p > .05$) in the VEP attention condition as compared to the distractor attention condition. Latency measurements between conditions also showed no significant decrease in the VEP attention condition (Table 4). For the L-M pathway there was an average decrease in latency of 1.5ms in the VEP attention condition (SEM = 1.6), ($p > .05$). No significant changes in latency were found for the S-(L+M) pathway (Table 4). The S-(L+M) pathway showed an average increase of 2.8ms (SEM = 1.5) for the VEP attention condition as compared to the distractor attention condition, ($p > .05$).

In experiment three, significant increases in waveform amplitudes and decreases in latencies were found in the VEP attention as compared to the distractor attention conditions with achromatic pattern-reversal stimuli (Figure 3). There was a significant average increase in amplitude of 1.8μV (SEM = 0.4) in the VEP attention condition as compared to the distractor attention condition ($p = 0.003$) and a significant decrease in latency of 4.3ms (SEM = 2.3) for the VEP attention condition as compared to the distractor attention condition ($p = 0.034$) (Table 5).

3.5. Discussion

It appears that the chromatic pattern-onset VEP response is not affected when attention is divided between spatially contiguous VEP and distractor stimuli (experiment one). This is consistent with previous studies using similar spatial attention manipulations and using achromatic pattern-reversal VEP stimuli (Heravian-Shandiz et al., 1992). Monitoring of attention to chromatic pattern-onset VEP stimuli does not appear to be necessary to obtain robust responses as long as both eyes are fixated near the center of the stimulus.

In experiment two, no consistent changes in waveform characteristics were found for the chromatic pattern-onset VEP with spatial attentional manipulations. The higher waveform variability between subjects in experiment one may have been caused by the decreased visibility of the stimulus when viewed through the beam-splitter. Nonetheless, focusing attention on the VEP stimuli over the distractor stimuli does not appear to enhance the response. Thus, it appears that monitoring of attention for these tests in a clinical setting is not crucial. Additionally, as reported previously, when using the same attentional manipulations with achromatic pattern-reversal stimuli (experiment three), significant enhancements in amplitude and decreases in latency were found when attending to the VEP as compared to when participants attended to the distractor.

These findings support the conclusion that attention has different effects on the chromatic and achromatic visual pathways, as has been suggested in previous studies (e.g. Di Russo & Spinelli 1999). In that study amplitude shifts were found for the chromatic stimuli, but changes in both amplitude and phase were found for the achromatic response. VEP amplitudes in general, are notoriously variable between subjects. This could account for the insignificant amplitude findings of the present study. However, in the present study the chromatic response showed no overall or consistent increases in amplitude in the VEP attention conditions even when comparing within subjects. Differences between the chromatic onset and steady state reversal responses may be another possible source for differences between the present results and those of Di Russo and Spinelli as suggested in the introduction. While responses from chromatic onset stimuli have been unambiguously linked with preferential modulation of the chromatic mechanisms, such links have not been as compelling for reversal responses. It is possible that losses in amplitude with attention reported for reversal stimuli may reflect attentional effects on some small contribution from achromatic mechanisms.

Because many variables such as electrode impedance and skin conductance can affect the amplitude of the VEP, latency is often the preferred measure when assessing changes in VEP responses. In the present study VEP latencies showed no overall decrease in the attention condition as compared to the distractor condition for the chromatic responses. Additionally, the consistent increases in amplitude and decrease in latency found when subjects were attending to the achromatic VEP stimuli in experiment three shows that attention does affect the achromatic pattern-reversal response and that the distractor task was sufficient to reveal these attentional effects.

The present findings support the conclusion that attention has different effects on the chromatic and achromatic visual pathways. The results further suggest that attentional focus is not necessary for robust chromatic pattern-onset responses and that careful monitoring of attention in the clinic may be unnecessary for such stimuli.

3.6. Tables

Table 1
Amplitude CIII-CII (µV)

L-M	Attentional Condition			S-(L+M)	Attentional Condition		
Participant	VEP	Distractor	Ratio Change	Participant	VEP	Distractor	Ratio Change
1	8.1	7.7	0.05	1	10.5	11.0	0.05
2	4.1	3.2	0.22	2	3.2	2.7	0.16
3	4.1	4.6	0.12	3	2.1	2.5	0.19
4	8.0	8.5	0.06	4	8.9	9.4	0.06
5	8.0	8.7	0.09	5	7.1	8.5	0.20
6	3.2	2.6	0.19	6	3.2	2.7	0.16
7	3.1	3.5	0.13	7	1.9	2.0	0.16
8	7.1	8.9	0.25	8	6.9	6.0	0.13
Average	5.7	6.0	0.14	Average	5.5	5.6	0.12
SEM	0.8	0.9	0.03	SEM	1.1	1.2	0.02

Table 1. Amplitudes. This table shows amplitudes for all participants in each condition (experiment 1). The ratio change between the two conditions is also shown. This was

calculated by taking the absolute difference between the two conditions and dividing it by the VEP attention condition. The average amplitude and standard error are also shown.

Table 2

Latency to CII (ms)

L-M	Attentional Condition			S-(L+M)	Attentional Condition		
Participant	VEP	Distractor	Ratio Change	Participant	VEP	Distractor	Ratio Change
1	125	127	0.01	1	131	136	0.04
2	133	125	0.06	2	148	145	0.02
3	137	132	0.04	3	161	169	0.05
4	125	122	0.03	4	133	133	0.01
5	126	114	0.10	5	155	158	0.02
6	108	118	0.09	6	132	126	0.05
7	110	110	0.00	7	147	137	0.07
8	117	115	0.01	8	145	140	0.04
Average	122	120	0.04	Average	144	143	0.03
SEM	3.4	2.4	0.01	SEM	3.7	4.7	0.01

Table 2. Latency. This table shows latencies for all participants in each condition (experiment 1). The ratio change between the two conditions is also shown. This was calculated by taking the absolute difference between the two conditions and dividing it by the VEP attention condition. The average latency and standard error are also shown.

Table 3

Amplitude CIII-CII (μV)

L-M	Attentional Condition			S-(L+M)	Attentional Condition		
Participant	VEP	Distractor	Ratio Change	Participant	VEP	Distractor	Ratio Change
1	1.8	2.8	0.56	1	1.8	4.3	1.37
2	3.5	3.8	0.09	2	4.7	4.8	0.03
3	2.2	2.2	0.01	3	2.3	2.4	0.06
4	7.1	6.8	0.04	4	8.0	5.7	0.29
5	4.3	3.2	0.26	5	3.5	4.2	0.21
6	4.0	4.9	0.23	6	4.9	5.7	0.16
7	4.4	3.2	0.27	7	3.5	3.1	0.11
8	2.8	3.1	0.11	8	2.8	3.0	0.07
Average	3.9	3.9	0.20	Average	4.1	4.3	0.29
SEM	0.6	0.5	0.07	SEM	0.7	0.4	0.16

Table 3. Amplitude. This table shows amplitudes for all participants in each condition (experiment 2). The ratio change between the two conditions is also shown. This was

calculated by taking the absolute difference between the two conditions and dividing it by the VEP attention condition. The average amplitude and standard error are also shown.

Table 4
Latency to CII (ms)

L-M	Attentional Condition			S-(L+M)	Attentional Condition		
Participant	VEP	Distractor	Ratio Change	Participant	VEP	Distractor	Ratio Change
1	108	110	0.02	1	104	96	0.08
2	91	93	0.01	2	91	92	0.00
3	84	84	0.00	3	90	92	0.02
4	95	93	0.03	4	95	95	0.00
5	89	88	0.02	5	89	88	0.02
6	85	88	0.03	6	103	100	0.02
7	88	87	0.02	7	94	84	0.11
8	96	108	0.12	8	93	92	0.02
Average	92	94	0.03	Average	95	92	0.03
SEM	2.7	3.5	0.01	SEM	2.0	1.7	0.01

Table 4. Latency. This table shows latencies for all participants in each condition (experiment 2). The ratio change between the two conditions is also shown. This was calculated by taking the absolute difference between the two conditions and dividing it by the VEP attention condition. The average latency and standard error are also shown.

Table 5

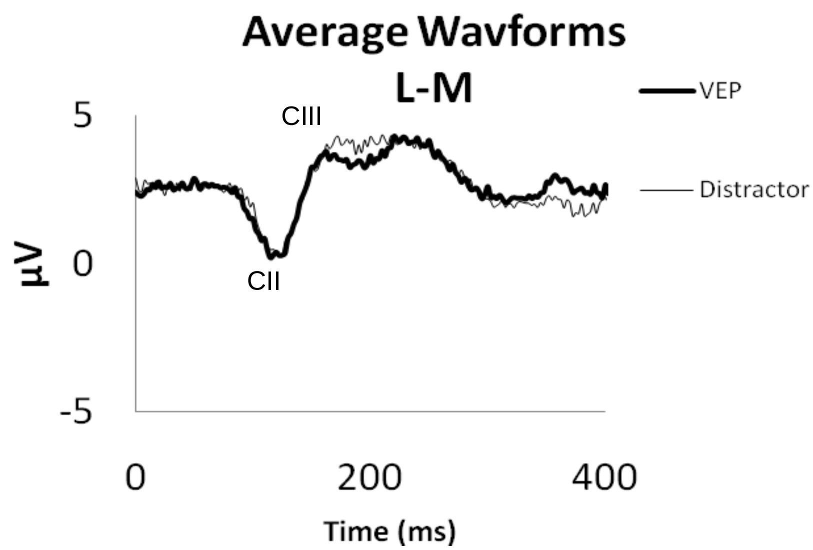
Achromatic Pattern-reversal

Amplitude P100-N75 (μV)				Latency to P100(ms)			
	Attentional Condition				Attentional Condition		
Participant	VEP	Distractor	Ratio Change	Participant	VEP	Distractor	Ratio Change
1	9.1	4.8	0.48	1	95.0	104.0	0.09
2	2.8	1.2	0.57	2	93.0	95.0	0.02
3	4.5	2.8	0.39	3	99.5	102.0	0.03
4	2.5	1.7	0.33	4	118.0	124.0	0.05
5	5.6	4.1	0.27	5	97.0	99.0	0.02
6	2.6	1.8	0.28	6	90.0	94.0	0.04
7	3.2	1.9	0.42	7	96.0	117.0	0.22
8	4.3	2.2	0.50	8	126.0	128.0	0.02
Average	4.5	2.7	0.39	Average	98.8	103.0	0.04
SEM	0.9	0.5	0.04	SEM	3.5	3.9	0.01

Table 5. Achromatic Pattern-reversal Amplitude. This table shows amplitudes and latencies for all participants in each condition (experiment 3). The ratio change between the two conditions is also shown. This was calculated by taking the absolute difference between the two conditions and dividing it by the VEP attention condition. The average amplitude and latency with standard error are also shown.

3.7. Figures

Figure 1
a.



b.

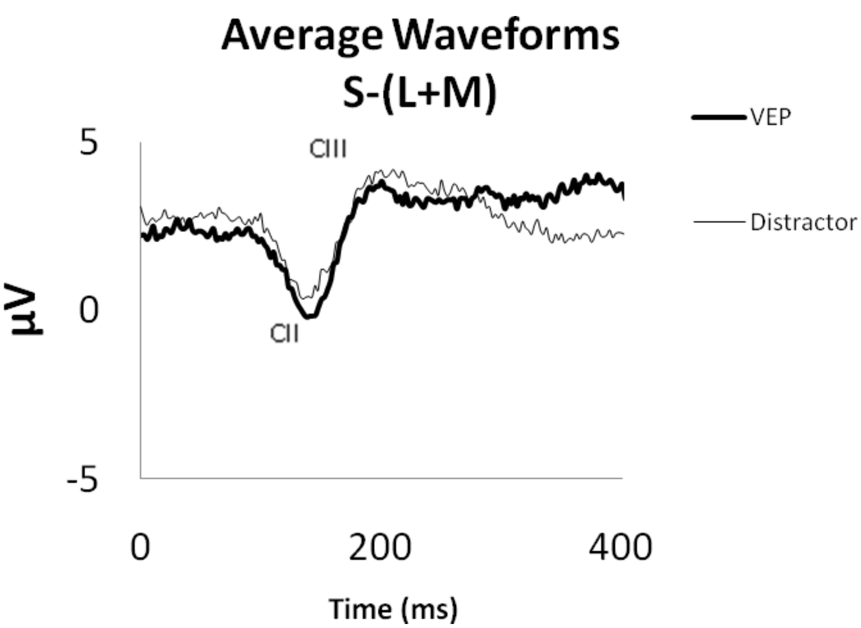
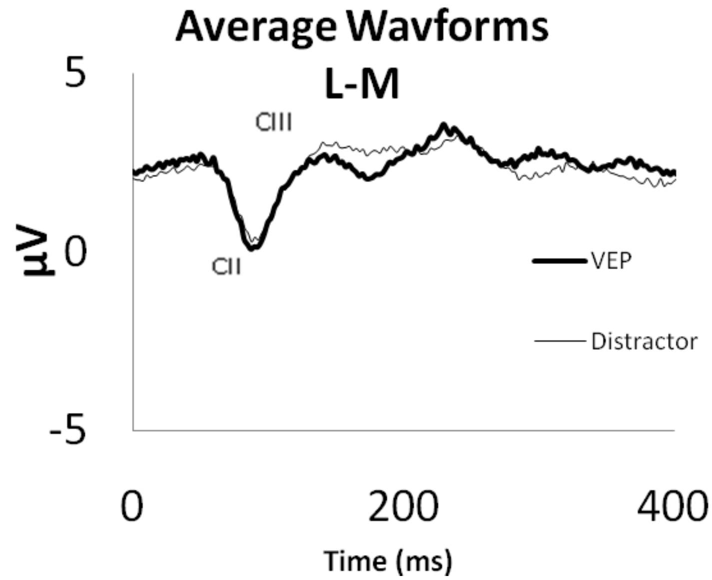


Figure 1. Average Waveforms. Average chromatic pattern-onset responses for both attentional conditions are shown for both the L-M (1a) and S-(L+M) (1b) visual pathways with spatially contiguous stimuli (experiment 1). The thick black line represents the VEP attention condition and the thin black line, the distractor attention condition.

Components of interest are labeled. Amplitude is reported in microvolts (μV), and latency (time) is reported in milliseconds (ms).

Figure 2
a.



b.

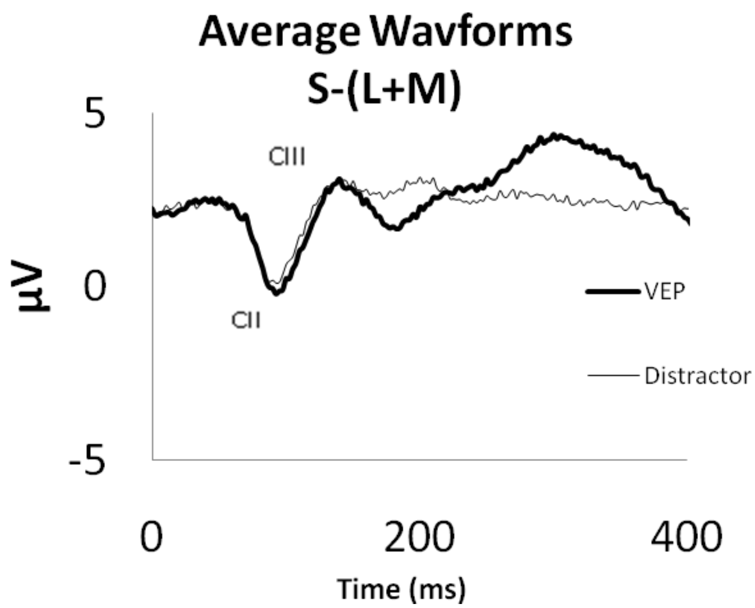


Figure 2. Average Waveforms. Average chromatic pattern-onset responses for both attentional conditions shown for the L-M (2a) and S-(L+M) (2b) visual pathways with spatially separated stimuli (experiment 2). The thick black line represents the VEP

attention condition and the thin black line, the distractor attention condition. Components of interest are labeled. Amplitude is reported in microvolts (µV), and latency (time) is reported in milliseconds (ms).

Figure 3

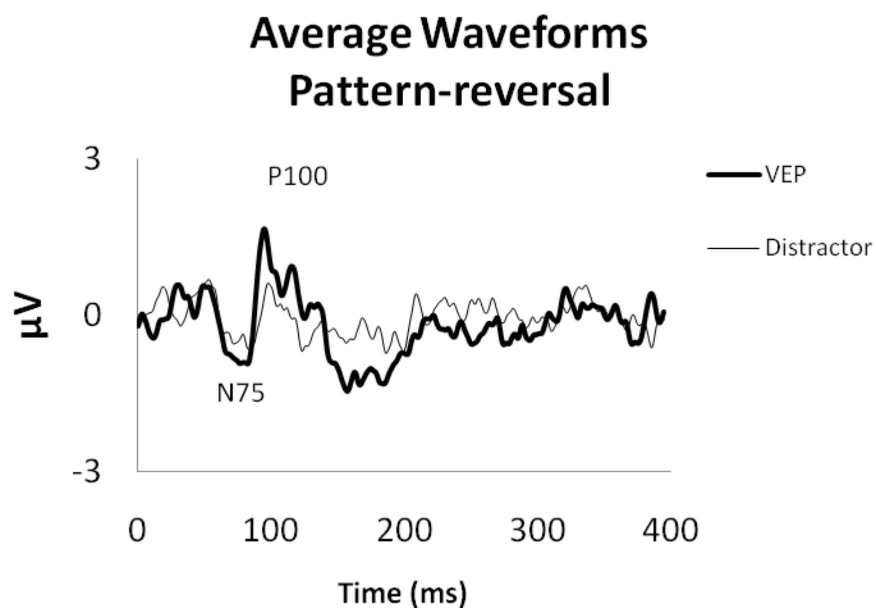


Figure 3. Average Waveforms. Average pattern-reversal responses to achromatic checkerboard stimuli for both attentional conditions (experiment 3). The thick black line represents the VEP attention condition and the thin black line, the distractor attention condition. Components of interest are labeled. Amplitude is reported in microvolts (µV), and latency (time) is reported in milliseconds (ms).

3.8. References

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4. Results Experiment 4

In experiment four no significant changes in waveform amplitude or latency were found between conditions for the L-M and S-(L+M) pathways (Figure 4). The L-M pathway (Figure 4a) showed an insignificant decrease in amplitude in the VEP attention condition as compared to the baseline condition of 0.1 μV (SEM = 0.8), and insignificant increase of 0.4 μV (SEM = 0.9) for the VEP attention condition as compared to the distractor condition, and an insignificant increase of 0.4 μV (SEM = 0.4) in the baseline condition as compared to the distractor condition, ($p > .05$ for all comparisons). Amplitude changes for the S-(L+M) pathway (Figure 4b) were also insignificant with a decrease in latency in the VEP attention condition as compared to the baseline condition of 0.5 μV (SEM = 0.4), an insignificant decrease of 0.1 μV (SEM = 0.3) for the VEP attention condition as compared to the distractor condition, and an insignificant increase of 0.5 μV (SEM = 0.5) in the baseline condition as compared to the distractor condition, ($p > .05$ for all comparisons). The average amplitude for each subject in all conditions is reported in table 6. As shown, subjects showed no consistent increase in amplitude in the VEP attention condition as compared to the baseline or distractor attention condition. Latency measurements between conditions also showed no significant change with attentional manipulations (Figure 4). Latency changes for the L-M pathway (Figure 4a) were insignificant with an increase in latency in the VEP attention condition as compared to the baseline condition, an insignificant increase for the VEP attention condition as compared to the distractor condition, and an insignificant increase in the baseline condition as compared to the distractor condition, ($p > .05$ for all comparisons). Averaged changes in latency were less than 1.0 ms, which was below the sampling resolution of 2.5 ms. The S-(L+M) pathway (Figure 4b) showed an insignificant decrease in latency in the VEP attention condition as compared to the baseline condition of 2.0 (SEM = 1.2), an insignificant increase (< 1.0 ms) for the VEP attention condition as compared to the distractor, and an insignificant decrease of 1.8ms (SEM = 1.2) in the baseline condition as compared to the distractor condition, p > .05 for all comparisons. The average latency for each subject in all conditions is reported in table 7. Participants showed no consistent change in response latency between conditions.

4.1. Tables

Table 6

Amplitude CIII-CII (μV) L-M	Attentional Condition			S-(L+M)	Attentional Condition		
Participant	Baseline	VEP	Distractor	Participant	Baseline	VEP	Distractor
1	4.6	4.7	6.2	1	9.3	10.5	11.0
2	5.3	5.3	5.6	2	3.3	3.2	2.7
3	9.2	7.8	7.1	3	4.6	2.1	2.5
4	6.8	3.9	7.2	4	8.4	8.9	9.4
5	9.0	6.0	7.2	5	8.9	7.1	8.5
6	10.9	14.2	11.1	6	4.1	3.2	2.7
7	14.0	16.3	12.5	7	3.3	1.9	2.0
8	9.3	9.8	7.8	8	6.3	6.9	6.0
Average	8.6	8.5	8.1	Average	6.0	5.5	5.6
SEM	1.1	1.6	0.9	SEM	0.9	1.2	1.3

Table 6. Amplitudes. Amplitudes are shown for all participants in each condition (experiment 4). The average amplitude and standard error are also shown. Amplitudes were calculated by subtracting CII from CIII. There was no significant change between conditions.

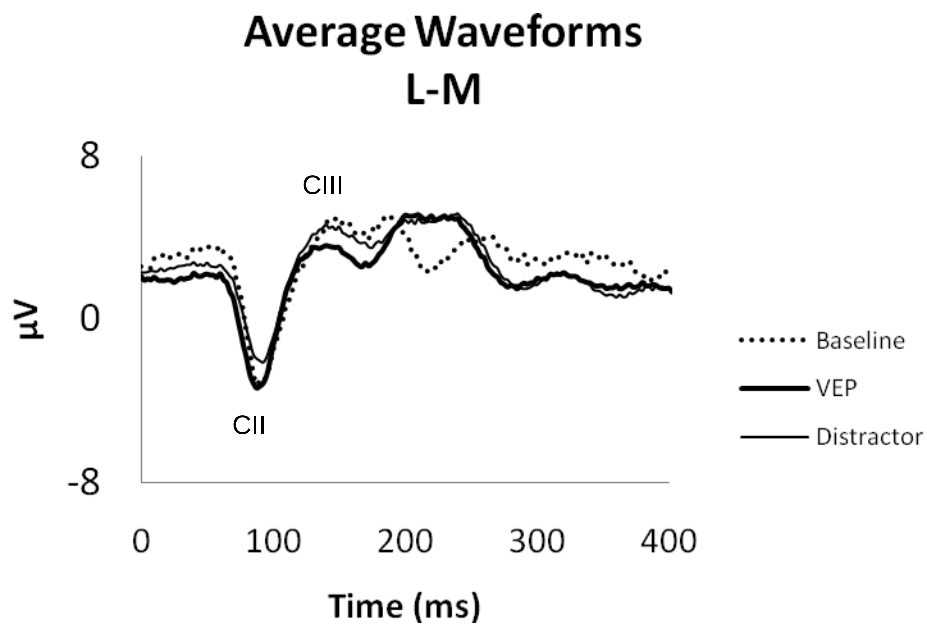
Table 7

Latency to CII (ms)				S-(L+M)			
L-M	Attentional Condition				Attentional Condition		
Participant	Baseline	VEP	Distractor	Participant	Baseline	VEP	Distractor
1	103	103	105	1	101	105	104
2	98	96	93	2	103	105	103
3	88	87	85	3	88	94	93
4	101	101	94	4	100	98	98
5	90	88	90	5	101	103	98
6	85	84	88	6	98	97	102
7	84	84	88	7	90	96	96
8	95	69	94	8	98	95	97
Average	93	92	92	Average	97	99	99
SEM	2.5	2.7	2.2	SEM	1.9	1.6	1.3

Table 7. Latency. Latencies are shown for all participants in each condition (experiment 4). The average latency and standard error are also shown. Latencies were measured to CII. There was no significant change between conditions.

4.2. Figures

Figure 4
a.



b.

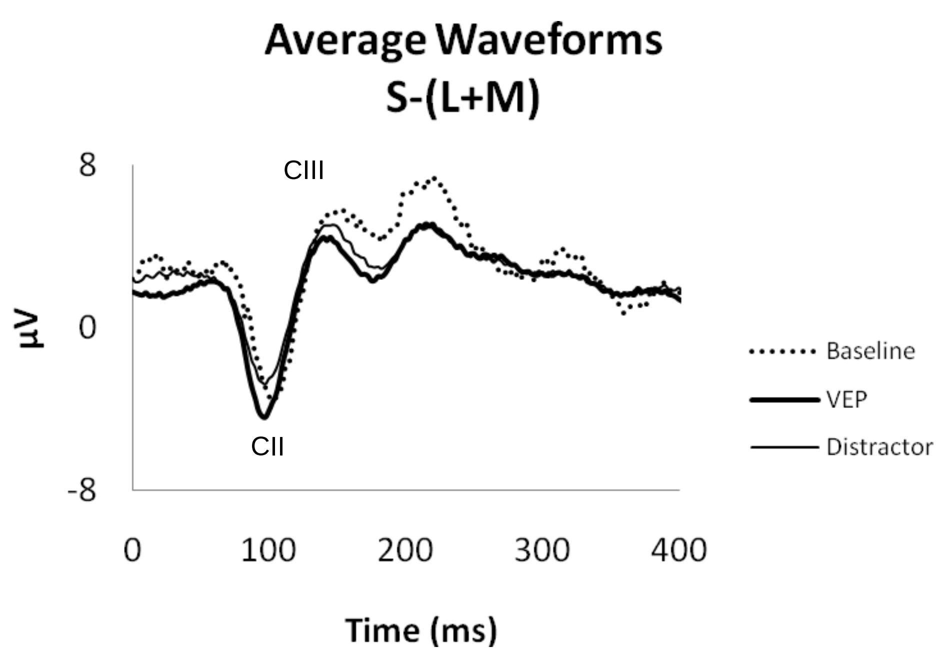


Figure 4. Average Waveforms. Average waveforms for chromatic pattern-onset responses for baseline, VEP attentional, and distractor attentional conditions are shown for the L-M (4a) and S-(L+M) (4b) visual pathways with spatially contiguous stimuli (experiment 4). The thick black line represents the VEP attention condition, the thin black line the distractor attention condition, and the dotted line represents the baseline condition. Components of interest are labeled. Amplitude is reported in microvolts (μV), and latency (time) is reported in milliseconds (ms).

5. Results Experiment 5

Experiment five did show a marginally significant increase in amplitude for the VEP attention condition as compared to the baseline condition and distractor attention condition for the S-(L+M) pathway (Figure 6). There was a significant increase in amplitude of 1.1 μV (SEM = 0.2) for the VEP attention condition as compared to the distractor attention condition ($p = 0.001$), and a significant increase of 0.8 μV (SEM = 0.3) in the VEP attention condition as compared to the baseline condition ($p = 0.027$). There were no significant changes in amplitude for the L-M pathway. There was an insignificant increase of 0.3 μV (SEM = 0.4) in the VEP attention condition as compared to the baseline condition, an insignificant increase of 0.5 μV (SEM = 0.4) in the VEP attention condition compared to the distractor attention conditions, and an insignificant increase of 0.2 μV (SEM = 0.6) in the baseline compared to the distractor attention condition, ($p > .05$ for all). The average amplitude for each subject in all conditions is reported in table 8. As shown, the only significant increase in amplitude was found in the VEP attention condition as compared to the distractor attention and baseline condition for the S-(L+M) pathway. Latency showed no significant change between conditions for either pathway (Figure 5). For the L-M pathway (Figure 5b) there was an insignificant decrease in latency in the VEP attention condition as compared to the baseline condition, an insignificant increase for the VEP attention condition as compared to the distractor condition, and an insignificant increase in the baseline condition as compared to the distractor condition ($p > .05$ for all comparisons). Latency changes between all conditions were less than 1.0 ms, which is below the sampling resolution of 2.5 ms. The

S-(L+M) pathway (Figure 5b) showed an insignificant decrease in latency in the VEP attention condition as compared to the baseline condition, an insignificant increase for the VEP attention condition as compared to the distractor condition, and an insignificant increase in the baseline condition as compared to the distractor condition, ($p > .05$ for all comparisons). Latency changes between all conditions were less than 1.0ms. The average latency for each subject in both attentional conditions is reported in table 9. Subjects showed no consistent change in response latency between the two conditions.

5.1. Tables

Table 8

Amplitude CII-CII (μV)

L-M	Attention Condition			S-(L+M)	Attention Condition		
Participant	Baseline	VEP	Distractor	Participant	Baseline	VEP	Distractor
1	2.2	3.4	3.8	1	4.0	4.6	3.7
2	2.7	2.7	3.8	2	4.5	5.1	3.9
3	4.9	6.1	6.8	3	6.1	6.1	5.9
4	3.4	4.8	3.1	4	4.4	4.8	3.7
5	4.8	4.9	3.8	5	4.8	6.3	4.3
6	4.0	4.3	3.7	6	4.3	4.8	4.0
7	7.1	7.0	5.2	7	5.8	8.3	6.8
8	4.9	3.1	2.6	8	3.5	3.8	3.2
Average	4.3	4.6	4.1	Average	4.7	*5.5	4.4
SEM	0.5	0.5	0.5	SEM	0.3	0.5	0.4

Table 8. Amplitudes. Amplitudes for all participants in each condition (experiment 5). The average amplitude and standard error are also shown. The asterisk (*) notes a significant increase of 1.1 μV (SEM = 0.2) in the VEP attention condition as compared to the baseline and distractor attention conditions for the S-(L+M) pathway only. Amplitudes were calculated by subtracting CII from CIII.

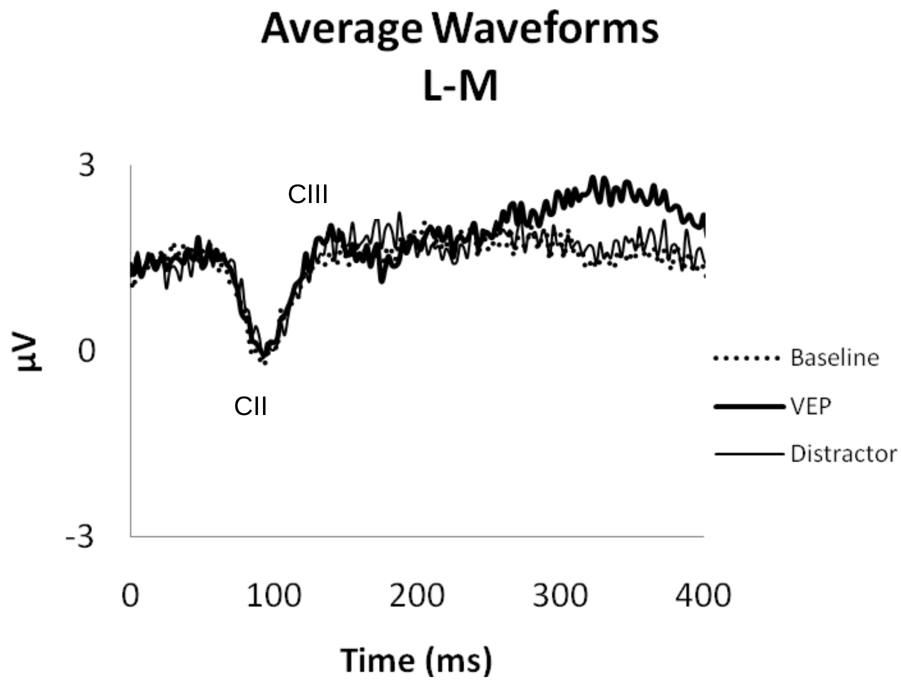
Table 9

Latency (ms) L-M	Attention Condition			S-(L+M)	Attention Condition		
Participant	Baseline	VEP	Distractor	Participant	Baseline	VEP	Distractor
1	100	98	98	1	96	98	97
2	110	107	111	2	103	93	106
3	96	96	95	3	95	94	93
4	88	88	86	4	94	94	91
5	103	116	106	5	106	101	103
6	103	103	103	6	101	101	100
7	116	103	105	7	91	96	93
8	91	91	94	8	92	92	91
Average	101	100	100	Average	97	96	97
SE	3.3	3.2	2.9	SE	1.9	1.3	2.0

Table 9. Latency. Latencies for all participants in each condition (experiment 5). The average latency and standard error are also shown. Latencies were measured to CII. There was no significant change between conditions.

5.2. Figures

Figure 5
a.



b.

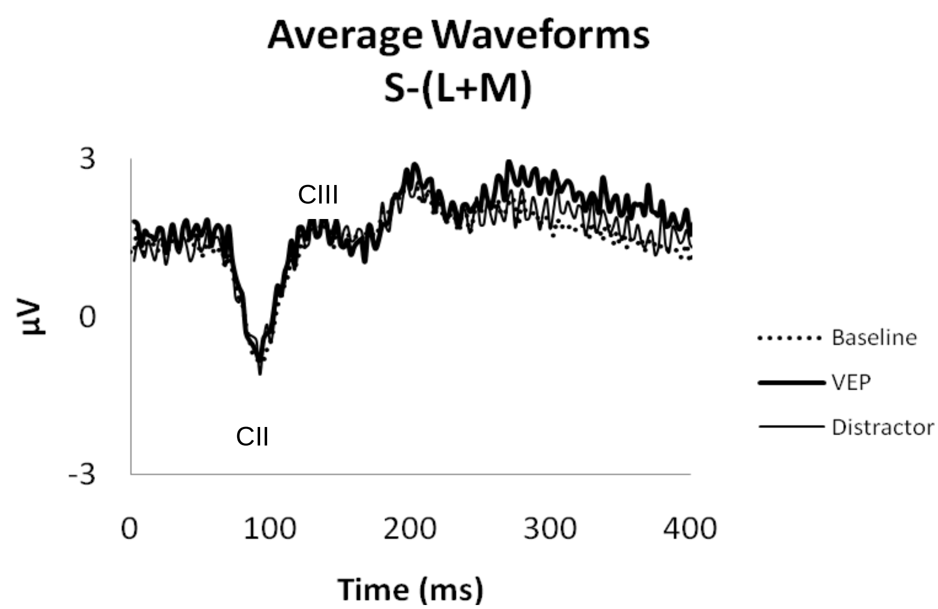


Figure 5. Average Waveforms. Average chromatic pattern-onset responses for baseline, VEP attentional, and distractor attentional conditions are shown for the L-M (5a) and S-(L+M) (5b) visual pathways with spatially separate stimuli and a difficult, task-relevant distractor (experiment 5). The thick black line represents the VEP attention condition, the thin black line the distractor attention condition, and the dotted line represents the baseline condition. Components of interest are labeled. Amplitude is reported in microvolts (μV), and latency (time) is reported in milliseconds (ms).

Figure 6

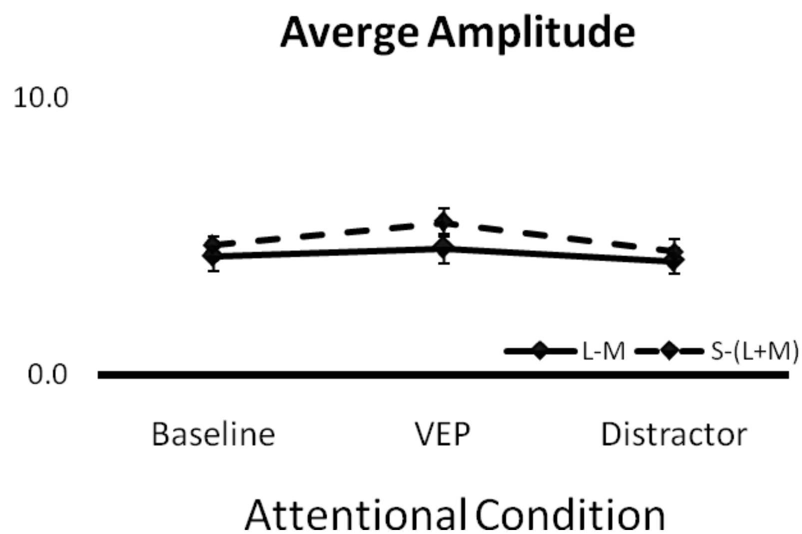


Figure 6. Average Amplitude Changes. The average change in amplitude (μV) in each condition for the L-M and S-(L+M) pathways is shown. The increase in amplitude shown is significant compared to the baseline condition (p= .027) and compared to the distractor condition (p = .001). Amplitude was measured by subtracting the CII from CIII. No significant changes in latency were found for the s-(L+M) pathway. The L-M pathway did not show a significant change in amplitude or latency.

6. Behavioral Results

For all experiments behavioral performance was above chance for both the VEP attention condition and the distractor attention condition. Results for accuracy (% correct) are shown in table 10 and results for reaction time in milliseconds are shown in table 11. A between subjects ANOVA was done to compare conditions in all experiments. In experiment one accuracy performance averaged 82% correct (SD 0.07) for the VEP attention condition and 97% correct (SD = 0.02) for the distractor attention condition. This was a small but significant difference ($p = 0.024$). A small but significant difference was also found for reaction time in experiment one. The average reaction time for the VEP attention condition was 357 ms (SD = 1.99) and 328 ms (SD = 13.71) for the distractor attention condition ($p = 0.043$). In experiment two accuracy performance averaged 73% (SD 0.03) for the VEP attention condition and 96% (SD = 0.02) for the distractor attention condition. This was significant at 0.001. The average reaction time for the VEP attention condition was 360 ms (SD = 1.28) and 360 ms (SD = 5.13) for the distractor attention condition. This was not significant ($p > 0.05$). In experiment three accuracy performance averaged 100% (SD = 0.00) for the VEP attention condition and 98% (SD = 0.03) for the distractor attention condition. No significant difference was found. The average reaction time for the VEP attention condition was 346 ms (SD = 6.82) and 357 ms (SD = 2.13) for the distractor attention condition. No significant difference was found ($p < 0.05$). In experiment four accuracy performance averaged 76% (SD = 0.01) for the VEP attention condition and 97% (SD = 0.01) for the distractor attention condition ($p < 0.001$). A significant difference in reaction time was also found. The average reaction time for the VEP attention condition was 348 ms (SD = 10.47) and 402 ms (SD = 19.9) for the distractor attention condition ($p = 0.028$). In experiment five a significant difference was found for accuracy performance between conditions. Participants averaged 75% (SD 0.01) for the VEP attention condition and 66% (SD = 0.03) for the distractor attention condition ($p = 0.018$). The average reaction time for the VEP attention condition was 354 ms (SD = 1.59) and 443 ms (SD = 5.10) for the distractor attention condition ($p < 0.001$). A between subjects ANOVA was done on behavioral performance collapsing across the letter distractor stimuli (exp one-four) comparing it to the more difficult task-relevant distractor stimuli (exp five). This showed a significant decrease in performance when the task-relevant VEP stimulus was used as a distractor compared to the less demanding letter stimuli. For the letter stimuli participants were correct 96% of the time as compared to only 66% of the time when the more difficult task-relevant distractor ($p <0 .001$). The average reaction time was 348 ms (SD = 17.84) when the letters were used as distractor stimuli and 443 ms (SD = 6.08) when the task-relevant stimuli were used as a distractor ($p < 0.001$). Subjects performed with 100% accuracy for the VEP attention task in experiment three which was significantly better than accuracy performance in the VEP attention condition for experiments one, two, four, and five, with an average of 76% correct (SD = 0.05) ($p < .001$). No significant difference was found for reaction time when comparing experiment three to the other experiments for either the VEP or the distractor attention conditions. Performance measures were also compared for VEP attention tasks for experiments with central fixation (one and four) and peripheral fixation (two, three, and five), and no significant difference was found. An ANOVA was done to compare the reaction time performance on the distractor task in experiment four against reaction time for the letter distractor task in experiments one, two, and three. A significant increase in average reaction time of 402 ms (SE = 19.9) for the distractor attention condition in experiment four as compared to the letter distractor attention conditions with average reaction time of 348 ms (SD = 17.84) in experiment one, two, and three (p = 0.002). Reaction times for the distractor task in experiment one were also compared to reaction times for distractor tasks in experiments two, three, and four. A small but significant decrease in reaction time of 328 ms (SD = 13.71) was found for distractor task performance as compared to an average reaction time of 373 ms (SD = 25.15), (p =0.017). No other significant differences were found for accuracy performance or reaction time when comparing VEP or distractor attention conditions between any other experiments.

6.1. Tables

Table 10

Average % Correct (SD)	Attentional Condition	
Experiment	VEP	Distractor
1	82 (0.07)	97 (0.02)
2	73 (0.03)	96 (0.02)
3	***100 (0)	98 (0.03)
4	76 (0.01)	97 (0.01)
5	75 (0.01)	**66 (0.03)

Table 10. Average Accuracy Performance. Average accuracy performance (% correct) is shown for each experiment for in both the VEP attention condition and the distractor attention condition. Standard deviation is shown in parenthesis. Accuracy was significantly worse for the distractor condition in experiment five as compared to distractor task accuracy performance in all other experiments (** means significant at 0.001).

Table 11

Average Reaction Time in milliseconds (SD)	Attentional Condition	
Experiment	VEP	Distractor
1	357 1.99)	*328 (13.71)
2	360 (1.28)	360 (5.13)
3	346 (6.82)	357 (2.13)
4	348 (10.47)	**402 (19.9)
5	354 (1.59)	***443 (5.10)

Table 10. Average Reaction Time. Average reaction time (milliseconds) is shown for each experiment for the VEP attention condition and the distractor attention condition. Standard deviation is shown in parenthesis. Reaction times were significantly longer for the distractor condition in experiment five compared to the distractor task reaction times in all other experiments. Reaction times were significantly lower for distractor tasks in experiment one compared to other experiments with letter distractors. Reaction times were significantly higher for the distractor task experiment four as compared to the other experiments with letter distractors (***means significant at 0.001, **means significant at 0.01, and * means significant at 0.05).

7. General Discussion

Components of interest (CII) for the chromatic pattern-onset VEPs are typically thought to be responses from lower levels of the visual system i.e. primary visual cortex (V1) when recorded over the occipital region (Oz). Previous research using pattern-reversal VEP stimuli recorded at Oz has revealed changes in waveform amplitudes with attentional shifts (Clark & Hillyard, 1996; Muller, et al., 1998; Muller & Hillyard, 2000; Di Russo & Spinelli, 2002, Di Russo et al., 2001; Di Russo, & Spinelli, D, 1999). However, in some studies attentional modulations have not been seen when recording from lower visual areas (e.g. Kastner & Ungerleider, 2001; Geng et al., 2006). The present study aimed to measure chromatic pattern-onset responses under conditions of selective attention using spatial and difficulty manipulations. Chromatic responses have not been extensively tested using selective attention paradigms and it is important to understand attentional effects on this response as it can be used as a clinical measure of the functioning of the chromatic visual pathways. The present study also focused on shifts in latency as well as amplitude. Most studies of selective attention on VEP responses focus on amplitude however, amplitudes for chromatic response are often highly variable across and within subjects, making them more problematic as a measure of changes in neural functioning (Murray et al., 1987; Rabin et al., 1993; Switkes et al., 1996). Latency tends to be a more consistent and less variable measure of chromatic pattern-onset response.

In experiment one, when comparing the baseline condition to experimental conditions where VEP stimuli and distracter stimuli are spatially contiguous no change in waveform characteristics were found (see Appendix A: Figure A-2). This is not surprising as a previous VEP study using spatially contiguous stimuli also did not find significant effects with selective attention (Heravian-Shandiz et al., 1992). These results also support the idea that the chromatic pattern-onset response is low-level. If it was a higher level response, some changes may have been found because of biased competition in neurons with the same visual field (Desimone, 1998). Additionally, effects due to top-down activation or inhibition or feedback from higher levels in the visual system are not evident with the results from this study. Behavioral accuracy was very high for both the VEP attention and the distractor attention conditions. Behavioral performance was significantly better for the distractor attention task as would be expected because the distractor stimuli were presented at a slower rate than the VEP stimuli. Reaction time performance was also short for both tasks, but significantly shorter for the distractor task. Additionally, reaction time performance for the distractor was better for this experiment as compared to the other experiments using letters as distractors. This is because the distractor was at fixation and not in the periphery. The behavioral results for this experiment show that both the VEP attention and distractor attention tasks were relatively simple and easy for participants to complete.

In experiment two VEP and distractor stimuli were spatially separated and displayed in opposite hemifields. No enhanced waveform characteristics were found for the VEP attention condition as compared to baseline, or distractor attention condition (see Appendix A: Figure 3-A). These results further support the idea that chromatic pattern-onset response is a low-level response and not greatly effected by feedback from higher visual areas. These results also support the biased competition theory of neural processing. Low-level neural responses not occupying the same visual field do not compete for representation because neural receptive fields are non-overlapping and consequently may not show effects with attentional manipulations. Previous studies of achromatic VEPs have shown increases in waveform amplitude and in some cases latency when dividing attention spatially across the visual fields (Clark & Hillyard, 1996; Muller, et al., 1998; Muller & Hillyard, 2000; Di Russo & Spinelli, 2002, Di Russo et al., 2001; Di Russo, & Spinelli, D, 1999). These studies claim that attention should be monitored when measuring these responses. The results of the present study show no changes in waveform characteristics with spatially divided stimuli, which suggests that chromatic pattern-onset responses are robust to attentional shifts with simple distractor stimuli. It may not be necessary to monitor attention in clinical or research settings when measuring this response. Results from this experiment may also further support that claim that the attention has different effects on chromatic and achromatic pathways in the visual system (e.g. Di Russo & Spinelli, 1999). That study used pattern-reversal chromatic and achromatic stimuli and found more attentional effects for the achromatic response than the chromatic response. In experiment two accuracy performance was again well above chance and reaction times were short. Performance accuracy was significantly better for the distractor task as compared to the VEP attention task due to the slower presentation of the distractor stimuli.

Experiment three used achromatic pattern-reversal VEPs to measure changes in waveform characteristics with spatially separate VEP and distractor stimuli and a simple distractor task. This experiment had the same manipulation as experiment two. Previous studies with similar manipulations have shown that achromatic pattern-reversal VEP responses are affected by attentional shifts. Changes in amplitude and latency were expected to be seen using these methods, which are similar to methods used by Heravian-Shandiz et al., 1992. Results from the present experiment showed an increase in waveform amplitude and a small but significant decrease in latency during the VEP attention condition as compared to the baseline (see Appendix A: Figure 4-A) and the distractor attention conditions. This experiment shows that the simple distractor task used throughout this study was sufficient to create attentional effects for achromatic responses. Results for this study also support the claim that attention affects the chromatic and achromatic visual pathways differently, as no significant results were found for chromatic stimuli in experiment two using the same attentional manipulation. Accuracy performance again was very high. There was no significant difference in behavioral performance measure between conditions in this experiment. The VEP attention accuracy data was significantly higher in this experiment as compared to all other experiments. This is because the behavior task of counting a predetermined number of stimulus reversals was found to be very easy for participants. No differences in reaction time were found when comparing this experiment to the other experiments.

In experiment four the VEP stimulus was centrally located, however the distractor stimuli were spatially separated from the VEP stimuli. This condition is said to be clinically relevant as this situation could occur in actual test situations with high frequency. Again, no changes were found between conditions in this experiment. This supports the idea that cognitive focus is not necessary for the chromatic pattern-onset response as long as the gaze is appropriate. These results also support the claim that this response is low-level in the visual system and may not receive modulatory feedback from higher visual areas. Higher level responses are thought to be affected with changes in cognitive and visual focus because more resources would be allocated to the neurons and brain areas involved with the task and less on the visual areas responding to the ignored VEP stimuli. Again, in this experiment behavioral performance was high. Performance accuracy was significantly better for the distractor task as compared to the VEP attention task due to the slower presentation of the distractor stimuli. As in experiment two the VEP and distractor stimuli were separated, but subjects were able to complete tasks in both conditions above chance. Reaction times for the distractor task in this experiment were significantly longer than reaction times for the other experiments using letter distractors. This is because the letter stimuli were presented five degrees further out in the periphery than in the other experiments.

The four previous experiments used a relatively simple distractor task to divert attention away from the VEP stimuli and found no changes in waveform characteristics for the chromatic response. It could be that the distractor task used did not tax the visual system enough to create enough neural competition to show changes in waveform characteristics. Experiment five aimed to see if changes in waveform characteristics would occur with a more difficult distractor task. This experiment used spatially divided VEP and a difficult, task-relevant distractor task. According to the biased competition theory of neural processing spatially separating visual inputs between the two hemifields may not always be enough to cause performance decrements if the evoked potentials are being generated and recorded from lower visual areas (e.g. V1). However, in some studies more difficult distractor stimuli have been found to create the competition needed to see changes in waveform characteristics. Additionally task-relevant distractors, which use the exact same neural resources as the VEP stimulus, have also been found to create more competition resulting in attentional effects (e.g. Spitzer & Richmond, 1991; Lichenstein-Vidne, Henik, & Safadi, 2006; Geng et al., 2006; Desimone, 1998). Results for this experiment showed a marginally significant increase in amplitude for the VEP attention condition as compared to the distractor and baseline conditions for the S-(L+M) pathway only, however no change in latency was found. The L-M pathways showed no change for either amplitude or latency. These findings may support previous studies that have found task-relevant and more difficult distractor tasks to create more performance decrements in selective attention tasks. These responses may be affected by top-down processing when using difficult tasks which tax the visual system and create more feedback from higher visual areas, which enhances neural responses at lower visual areas. These results suggest that there may be enough competition between neurons in separate visual fields to create changes in neural responses at this level of the visual system when using task-relevant or difficult distractor tasks. Additionally, it may not be surprising that these changes were found for the S-(L+M) visual pathway only as it has been shown to be more vulnerable than the L-M pathway to pathology and environmental stressors (e.g. Crognale et al, 1993; Tekavcic-Pompe & Tekavcic, 2008). S pathways anomalies could in part be explained by differences in signal strength or gain between the L-M and S-(L+M) pathways. There are less S-cones in the retina as compared to the L and M cones. Consequently, the visual system must increase the gain of the S-(L+M) pathway to match the signal of L-M pathway. Cognitively taxing tasks may create more neural competition, which could be initially seen in this pathway. However, given that neither L-M amplitude nor latency for either pathways changed, overall these results still support the idea that the chromatic pattern-onset VEP may be a low-level response in the visual system. A slight amplitude change within participants is by itself not strong evidence of an effect of attention for this response. Even within one session amplitude measures can be variable, which makes amplitude a less reliable measure when determining the effects of any manipulation on the chromatic pattern-onset response. Additionally the significant increase in amplitude for the VEP attention condition was found only when a within-subjects t-test was used. A between subjects ANOVA revealed no significant change in amplitude for the chromatic response. The behavioral data showed that the more difficult, task-relevant distractor task was more challenging for participants. Accuracy performance was above chance but significantly lower for this distractor task as compared to the simpler distractor task used in the other experiments. Reaction times were also significantly slower for this distractor task as compared to the other experiments. Participants had more difficulty carrying out this distractor task than the distractor task in the other experiments. These behavioral results taken in consideration with the electrophysiological results show that even with cognitively taxing tasks, the chromatic pattern-onset VEP is robust to attentional effects. Overall this evidence suggests that this response may be generated in a lower-level area in the visual system such as V1, and feedback from higher visual areas may not greatly affect this response. This is an interesting finding because no source localization has been done on this response and it is not fully understood where this response arises in the visual system. The findings of this study may have provided some information about the location of this response. Additionally attention may not affect this response in the same manner as has been shown with the achromatic response. This finding supports another study which found different effects of attention on chromatic and achromatic pathways. However, more research is needed to further test this claim. Most importantly, the findings from this study can be practically applied to clinical and research settings. These results show that alert attentiveness to the chromatic pattern-onset VEP does not appear to be necessary for a robust response. This is an important finding for clinical and research purposes as it has been previously believed that attentional focus is need for robust VEP responses. These findings have specific implications when working with infant or other nonverbal populations. There is now evidence to suggest that chromatic VEP responses are not affected by attention, and attention does not need to be strictly monitored in laboratory or clinical settings.

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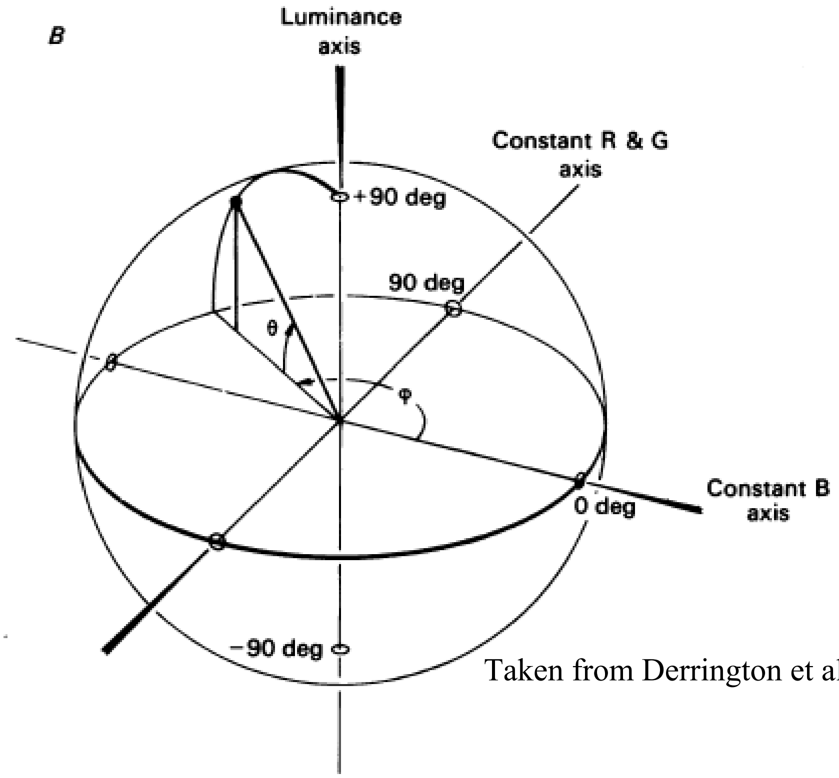
Appendix A

Supplementary Figures

Figure A-1.

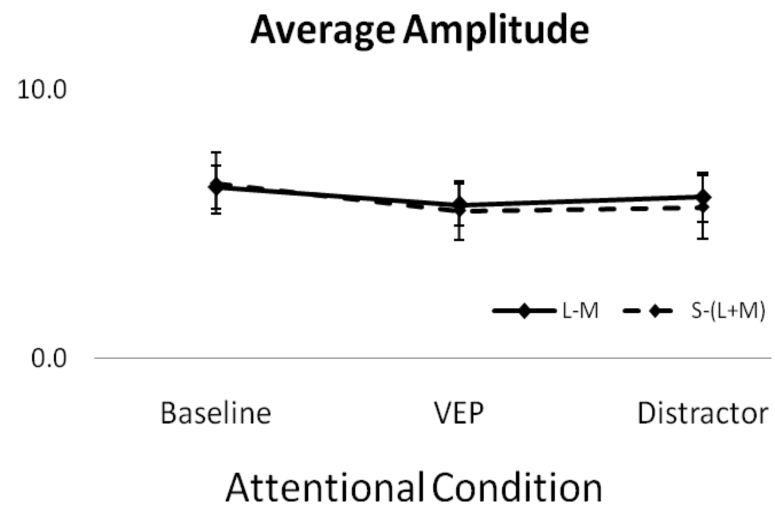


Taken from Derrington et al., 1984

Figure A-1. Cone activation based color space. The horizontal Constant R & G and B axis represent the L-M and the S-(L+M) visual pathways respectively. The luminance pathway is also shown, which takes into account inputs from the L and M cones combined. On each axis chromaticities of equal luminance are represented for the specific visual pathway. The distance between to points on a vector defines contrast. The further the point of the vector from the center of the sphere results in increased contrast. The center most point of the sphere is where the contrasts of all vectors decrease to white. Points in this color space correspond to cone activation. Estimations of the contribution for a given stimulus can be calculated from this color space.

Figure A-2

a.



b.

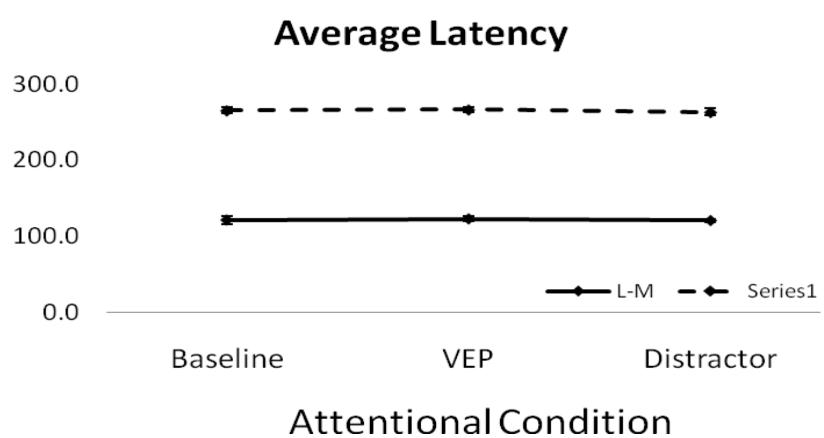
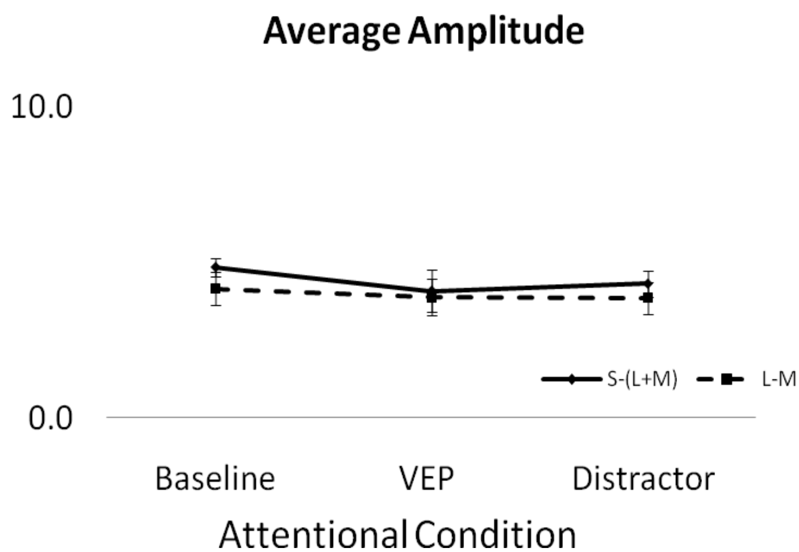


Figure A-2. Average Amplitue Change. Average amplitudes in µV (2a) and latencies reported in milliseconds (2b) for bothe L-M and S-(L+M) pathways for each condition in experiemnt 1. Amplitudes were measured by subtracting CII from CII. Latencies were meaured to CII. As can bee seen, no significant changes in waveform characteristc were found for either pathway (p>.05).

Figure A-3

a.



b.

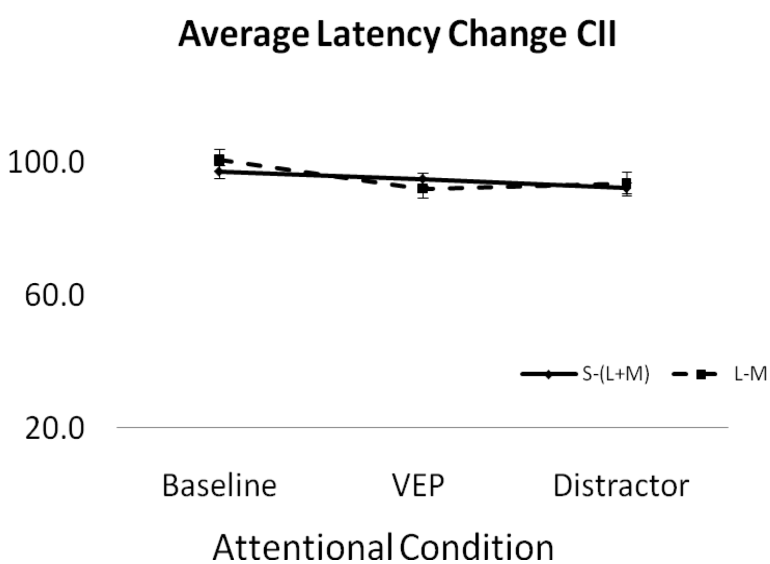
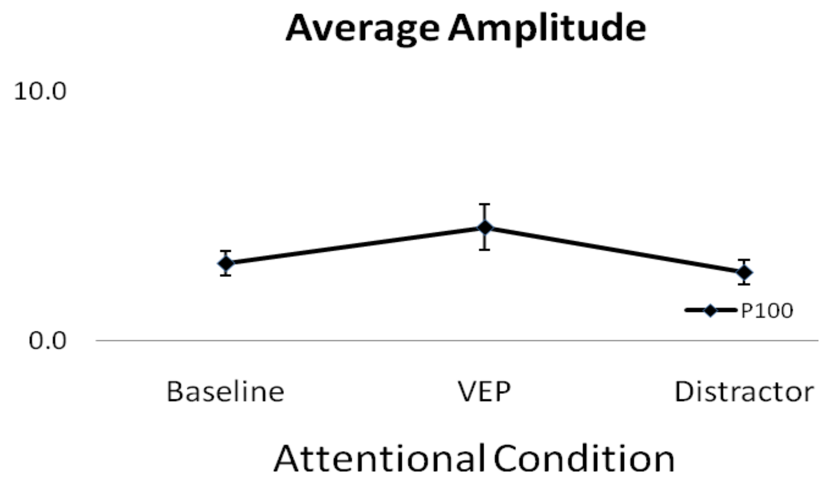


Figure A-3. Average Amplitude Change. Average amplitudes in µV (2a) and latencies reported in milliseconds (2b) for bothe L-M and S-(L+M) pathways for each condition in experiemnt 2. Amplitudes were measured by subtracting CII from CII. Latencies were meaured to CII. As can bee seen, no significant changes in waveform characteristc were found for either pathway ($p>.05$).

Figure A-4

a.



b.

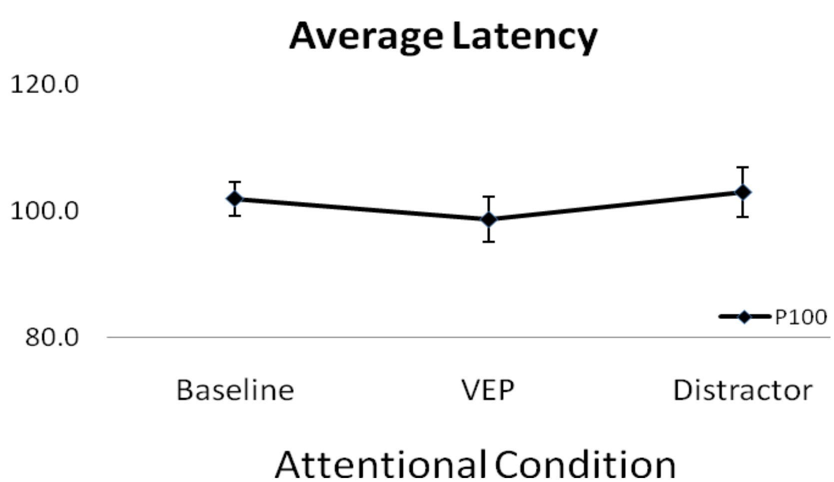


Figure A-4. Average Amplitude Change. Average amplitudes µV (2a) and latencies reported in milliseconds (2b) for achormatic P100 component for each condition in experiemnt 3. Amplitudes were measured by subtracting the N75from the P100. Latencies were meaured to P100. Here significant increases in amplitude were found for the VEP attention conditions as compared to the other conditions (P = 0.003). Significant decreases in latency for the VEP attention condition as compared to the other conditions were also found for the P100 component (P = .034).