

University of Nevada, Reno

**Simultaneous Recording Reveals Attentional Modulation of Chromatic Visual Evoked Potentials**

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in Psychology

By

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## Abstract

Prior research has shown that the chromatic pattern-onset VEP is robust to attentional manipulations when test and distracter stimuli are either superimposed or spatially separated. These results suggest that the chromatic VEP response is occurring early (V1) and may not be sensitive to feedback from attentional mechanisms. We report here studies of chromatic and achromatic VEP responses recorded in the presence of attentional modulation using stimulus parameters designed to reduce variability and favor detection of small attentional effects. VEPs were recorded to attended and unattended stimuli simultaneously in separate hemifields using a frequency-tagged averaging technique and task relevant distracters. Additionally, stimuli were perceptually equated and presented close to the fovea. Under these conditions, small but significant attentional modulations of the chromatic waveform amplitudes are revealed. In addition, we explore effects of attentional modulation across both chromatic LM and S, and the achromatic visual pathways. These results showed adaptation effects that were independent of distracter pathway. A Further exploration is required however, since the results from a control experiment to rule out a fixation bias towards the attended stimuli failed to eliminate shifts in fixation as the cause for the observed attentional effects.

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## 1. Introduction

Many behaviors require a degree of attentional focus that taxes the neural resources of attentional mechanisms. This same focus may lead to the potential for one environmental cue or stimuli to preferentially activate the neural networks relevant to the attended stimulus, while at the same time reducing processing capacities for aspects of the environment outside the individual's focus of attention. An excellent example of this is the phenomenon of change blindness (Levin et al., 1997; Rensink et al., 1997; McConkie et al., 1996; Pashler, 1988). Change blindness is a phenomenon in which an individual fails to notice sometimes large changes in the stimulus scene, particularly when given a distracting task. Hobbies are also an excellent real-life example, often requiring intense attention. Fly fishing for example requires patience, focus, and accuracy. The rhythmic presentation of a fly and the controlled retrieval often leave the individual unaware of other abundant stimuli in the environment. Sometimes the attentional focus can be independent of visual fixation as when attending to something in the periphery. This ability to shift attention within the visual field has been termed "the spotlight of attention" (Posner, 1980) and has been shown to be limited by neural resources. A biased competition model of attention (Desimone et al., 1990; Lavie, 1995; Desimone, 1998) suggests that only those items which capture attentional resources will influence memory and motor systems. A question then arises as to what happens to the information from unattended stimuli and to what extent might it

influence perception and behavior. For an extensive review of some of the issues in the area see Pashler (1998).

Posner (1980) makes several insightful distinctions between behaviors associated with attention. Covert attention is an internal shift of mental focus to an external location outside the foveal region, while overt visual attention relies on the movement of the orbits of the eyes, the head or the body itself. It is the internal locus of control which allows the individual to orient not only to discernable aspects of the environment but more generally to areas in space without definitive form. It is this locus of control which provides enhanced detection of cued stimuli. This experimental paradigm has been used extensively psychophysically and physiologically to test the effects of attention.

Behavioral studies have shown attentional effects in the discrimination domain (Lee et. al, 1999; Muller & Findlay, 1987; Nakayama & Mackeben, 1989), in visual processing (Carrasco & McElree, 2001) and in the reaction time of motor responses (Eason, Harter & White, 1968; Posner et al., 1980). Attention has been shown to modulate neural activity in the absence of a stimulus using functional magnetic resonance imaging (fMRI) (Kastner & Ungerleider, 2001; Rees, Backus & Heeger, 2000) and in single cell recordings (Luck et al., 1997) resulting in a sustained increase in baseline activity. A study conducted by Heravian-Shandiz, Douthwaite, and Jenkins (1992) examined the effects of attention using binocular and monocular viewing as variables. The authors found that when gratings were viewed monocularly the increase

in VEP amplitude due to spatially directed attention was not present, suggesting that binocular summation may play an important role in the attentional network. This finding also suggests that any attentional affect would have to occur after the lateral geniculate nucleus (LGN) since primary visual cortex is the first visual area to receive binocular input.

Kastner and Ungerleider (2001) propose that the competition for representation in the visual cortex is likely resolved in distributed networks located in frontal or parietal cortex. They make the distinction that these processes may not be seen directly in the visual evoked responses revealed in spatial attention paradigms; rather they may be the locus of attention facilitating the function of the initial stages of visual representation driven by attention. Separation of these distributed networks from the initial stages of perceptual processing has been given some attention but more work needs to be done to define the degree to which attention may modulate early stages of visual processing and to determine the general time course of these events. fMRI results indicate that multiple objects presented simultaneously suppress activity but not in an additive manner, rather there is biased competition such that the same stimuli presented serially produce a greater activation predominantly in later visual areas V4, lateral occipital area, and area TEO (Kastner & Ungerleider, 2000). Nosselt et al. (2002) combined event related potentials (ERP), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI) in an attempt to separate the effects of spatial attention. They found that changes in cortical activity from spatially directed attention in V1

reflected feedback activity occurring in the 140-250ms time frame. The authors indicate that initial cortical activity at the calcarine fissure typically reflected in the C1 component occurs between 60-90ms. Some single cell recordings in the macaque have shown increased activation during covert spatial attention in striate cortex (V1) (Motter, 1993; Roelfsema et al., 1998) and extrastriate areas (Luck et al., 1997; Treue & Maunsell, 1996; Connor et al., 1997). Other research, however has failed to find activation in V1 when stimuli compete for neural resources associated with spatial attention within the receptive field of the cells being measured (Luck et al., 1997).

Studies of steady state visual evoked potentials (SSVEP) have shown attentional modulations resulting in increased amplitudes to achromatic stimuli (Di Russo, Spinelli, & Morrone, 2001; Di Russo & Spinelli, 1999a, 1999b, 2002; Morgan, Hansen, & Hillyard, 1996; Muller et al., 1998; Muller & Hillyard, 2000; Wang & Wade, 2011). However, Ding, Sperling and Srinivasan (2006) showed that the cortical locus of SSVEP amplification for achromatic stimuli is dependent on the reversal frequency. One study found that the phase advance noted while measuring SSVEP reversals was more pronounced than the latency decrement that was revealed during transient VEP achromatic reversal recordings under conditions of covert spatial attention (Di Russo & Spinelli 1999a). Only a handful of studies have looked at the effects of spatial attention on the chromatic visual pathways. In the first studies to look at the effects of spatial attention on the LM pathway, Di Russo and Spinelli (1999b, 2001) found changes in amplitude for both achromatic and LM stimuli and changes in phase for achromatic stimuli, but not for

chromatic LM stimuli. The authors suggest that attention acts on cortical gain control mechanisms resulting in differential activation of the magno- and parvo-cellular systems and suggest that the faster magno-cellular pathway may provide the initial sensory enhancement needed to facilitate attentional modulation of the parvo-cellular system (Di Russo & Spinelli, 1999b).

Highsmith and Crognale (2010) found that for both LM and S cone stimuli attention did not affect the chromatic onset VEP when stimuli were spatially contiguous (superimposed through a beam splitter) or when they were separated by hemifield at 5° eccentricity. In both conditions a letter task was used as the attentional task. This study used transient chromatic pattern-onset visual evoked potentials (VEP) which have been reported to preferentially activate the chromatic pathways (e.g. Murray et al., 1987; Berninger et al., 1989; Rabin et al., 1994). The authors indicate that this may be one reason their results differ from those of Di Russo and Spinelli (1999b, 2000). Similar to prior studies, Highsmith and Crognale (2010) also report that attention modulates both amplitude and latency for achromatic responses. A study conducted by Wang and Wade (2011) looked at spatial attention for both achromatic and S-cone stimuli using SSVEPs. Cortical localization was estimated based on electrical source imaging derived using functional magnetic resonance imaging (fMRI) mapping techniques. They found no evidence for increased amplitude or phase shifts with spatial attention for S-cone stimuli, but did find an increase in amplitude and a phase advance for luminance stimuli in area V1. The authors note that although no statistically significant effects of attention

on S-cone responses were observed, several areas including V4, V3a, and the LOC showed marginal modulation by attention. The authors note that the level of significance in the amplitude domain increased at high contrast levels.

Studies of attentional effects on the visual pathways provide insight into the ways in which clinical applications may be affected. Several studies provide evidence that transient visual evoked potentials may be used in determining the neurological integrity and function of the color vision system which may have clinical applications in the detection of glaucoma and other ocular diseases (e.g. Accornero et al., 2000; Crognale et al., 1992; Crognale et al., 1993a, 1993b; Gerth et al., 2003; Porciatti et al., 1997; Rabin et al., 1992; Schneck et al., 1996; Schneck et al., 1997; Suttle & Lloyd, 2005) and in studies of maturation and development (Boon et al, 2007; Brecelj et al., 2002; Crognale, 2002; Crognale et al., 1997; Crognale et al., 1998; Page & Crognale, 2005; Pompe et al., 2006; Suttle et al., 1997, Tekavčič-Pompe et al., 2011). Attentional effects on the VEP have potential significance for clinical and developmental populations wherein attention may be difficult to control or monitor.

One factor that has been strongly tied to attentional modulation of cortical activity is task difficulty (Lavie, 1995; Reviewed in Pessoa, Kastner & Ungerleider 2003, Pessoa, Mc Kennna, & Ungerleider, 2002). It is possible that with more difficult tasks, attentional effects for the chromatic onset VEP might be revealed.

The current study sought to further test the hypothesis that the chromatic VEP is robust to attentional effects. We reasoned as have others in previous studies, that the optimal conditions to reveal attentional effects would be to utilize task relevant and difficult distracters and to spatially separate the test and distracter into different hemifields. In addition, since variability in response amplitudes and reduced amplitudes from using extra-foveal stimuli may have concealed small effects in prior studies, we made 2 additional modifications: 1) we moved the edge of the test and distracter stimuli to 1 degree from the fovea to increase response amplitudes and 2) instead of recording the responses to attended and unattended conditions in separate test runs, we recorded them simultaneously using a frequency tagging method. In this method the test and distracter responses are recorded from the same electrode site at the same time using slightly different temporal frequencies. The use of this procedure removes sources of variability in response amplitudes incurred between test runs and provides a more precise comparison of attended and unattended responses within each condition. In addition to testing chromatic attentional effects within chromatic channels, we also wished to test how attention might affect responses across the chromatic channels and the achromatic channel (L-M, S, and achromatic). For example, “How do distracters that preferentially modulate the S-cone pathway affect the responses of the L-M cone or achromatic pathways?”

## 2. Methods

### 2.1. Participants

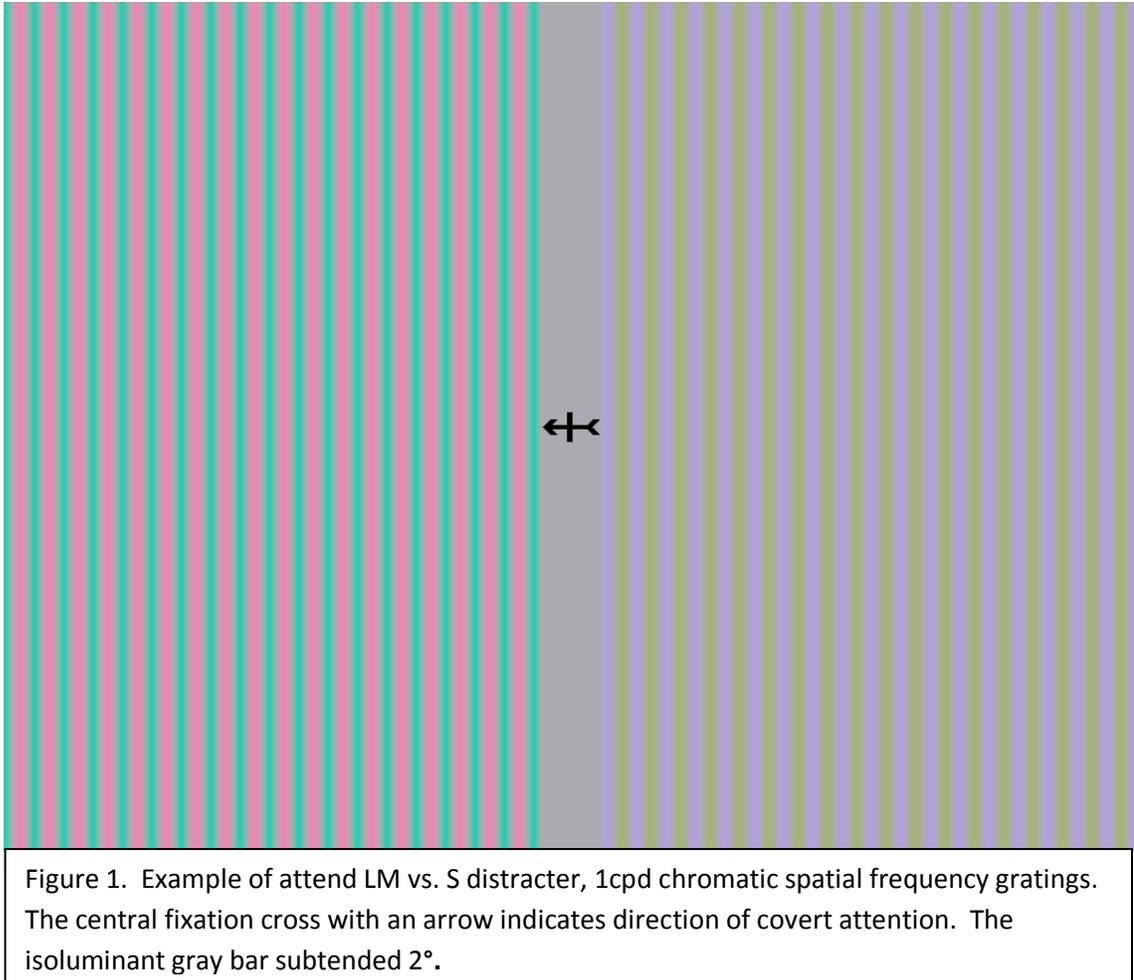
Participants for experiments one and two were adults, aged 20-28, with a mean age of 21.88 years (N=9). Participants provided written informed consent. The research protocol was approved by the University of Nevada, Reno Biomedical Institutional Review Board. Participants were screened for normal color vision using the Neitz pseudo-isochromatic test (Cotter et al., 1999), Ishihara 38 plate test, and an Oculus HMC anomaloscope.

## 2.2 Stimuli

Stimuli consisted of two chromatic patterns (LM and S) each consisting of 1 cpd sinusoidal gratings (see figure 1) and an achromatic pattern consisting of a 4 cpd sinusoidal grating. All stimuli were modulated around 25 cd/m<sup>2</sup> and the chromaticity of Illuminant C (0.6568, 0.1825 in Macleod-Boynton color space). Stimuli were equated for individual isoluminance using a minimum motion paradigm (Anstis & Cavanagh, 1983) with the gratings sinusoidally modulated in space and time. The contrast along the test axes were further scaled to equate for each individual's subjective contrast (Switkes & Crognale, 1999).

The average Macleod-Boynton coordinates for the endpoints of the scaled LM stimuli were  $r = .691$ ,  $b = .0183$  (red) and  $r = .623$ ,  $b = .0183$  (green); those for the endpoints of the scaled S stimuli were  $r = .657$ ,  $b = .0304$  (blue) and  $r = .657$ ,  $b = .006$  (yellow). The averaged Michelson contrast for the scaled achromatic stimulus was 0.62. Individual cone contrasts for LM stimuli were  $L = .0510$ ,  $M = .0975$ ,  $S = .018$  and for S stimuli were  $L = 0$ ,  $M = 0$ ,  $S = .666667$ .

Distracter and test stimuli were separated by an isoluminant gray bar subtending 2 degrees of visual angle in the middle of the monitor (See figure 1). A fixation cross was centered within the gray bar. Stimuli were viewed binocularly at 57 cm and presented on a Trinitron Multiscan 20sc II monitor (Sony Corporation, Tokyo, Japan) running at a refresh rate of 100 Hz. Stimuli were generated using a VSG card (Cambridge Research Systems, Rochester, Kent, UK) and calibrated using a PR-650 Spectrascan spectral radiometer (Photo Research Inc. Chatsworth, CA, USA). Chromatic stimuli were presented using an onset presentation. Achromatic stimuli were presented using a reversal presentation. A frequency tagged averaging technique was used to separate the responses to the stimuli in the two visual fields. Achromatic reversal stimuli were presented at 2.38 Hz except when both the left and right hemifields were achromatic reversing stimuli, in which case one of the stimuli was presented at 2 Hz. Chromatic onset stimuli were presented at one of two possible frequencies 2 Hz or 2.05 Hz. In either case the stimulus onset was held constant at 100 ms while the offset was either 400 ms or 387 ms to accomplish the frequency tagging. Responses during the presentation of an unchanging isoluminant gray field were averaged at both 2 Hz and 2.05 Hz to provide estimates of noise. VEP responses were averaged for 60 presentations for each recording. Each condition was recorded twice and averaged together. The stimuli subtended  $18.5^\circ$  in width ( $(18.5^\circ \text{ stimuli} * 2) + 2^\circ \text{ divider} = 39^\circ$  width) and  $29^\circ$  in height.



### 2.3 VEP recording and analysis

Electrodes were placed according to the international 10-20 system with the active electrode located at Oz, the reference at Fz, and the ground located at Pz. Grass gold electrodes (Grass Technologies, West Warwick, RI, USA) were used to provide signal through a Grass P511 amplifier set at 50k amplification, notch filtered at 60Hz, and digitized with a National Instruments IO Board (National Instruments, Newbury, Berks, UK) in a PC. Impedance on each electrode was held below 5 k $\Omega$  (measured at 30 Hz). Impedance was checked before and after the experiment. Computer software was

used to analyze data and apply digital filtering. A low pass digital filter was set at 100 Hz and a high pass digital filter was set at 1 Hz. . All conditions were run twice and the responses were averaged together for individual participants and saved in a spreadsheet for off-line analysis. Peak-to-trough amplitudes for responses to chromatic stimuli were determined by measuring the voltage difference between the largest negative deflection (CII, occurring between 100-200ms) and the following positive component (CIII). Chromatic response latencies were measured from stimulus onset to the trough of CII. Achromatic trough-to-peak response amplitudes were determined by taking the difference between the large negative deflection around 75ms (N75) and the large positive response around 100ms (P100). Achromatic response latencies were measured from stimulus onset to the largest positive P100 response.

#### 2.4 Attention Task

Participants were instructed to fixate on the cross located in the center of the monitor display which indicated one of three attentional tasks: 1) attend to grating in either the left or right hemifield, 2) attend to the gray field in the left or right hemifield, or 3) attend to fixation cross. The three stimulus conditions were: 1) isoluminant gray in one hemifield and a grating or pattern in the contralateral hemifield 2) within category stimuli in both hemifields 3) across category stimuli, one in each hemifield. This resulted in a total of forty five conditions. Though the combination of 4 test stimuli X 3 attentional conditions X 4 distracter conditions actually yields 48 conditions, we omitted the stimulus/distracter permutation wherein the pattern on the monitor had a uniform gray field on both sides. Presentation frequency and side of presentation were

balanced in the design. In the conditions where the fixation cross contained an arrow, participants were to covertly attend to the stimulus on the side the arrow was pointing (left or right) and press a space bar each time they noticed a reduction in the apparent contrast of the cued grating. Chromatic cue gratings were reduced by 50% contrast and achromatic cue gratings were reduced by 75% contrast. In the fixation-attention condition there was no arrow and participants were to press the space bar each time the vertical axis of the fixation cross changed incrementally (one pixel) in length. In each condition, four presentations of the cue were randomly presented in time. All forty five conditions were randomized for each participant and each participant ran through the series of forty five conditions twice.

### 3. Results

#### 3.1 Behavioral measures and data normalization

Analysis of behavioral data yielded a mean hit rate of 80% correct for the detection of reduced contrast gratings and subjects reported that the task was difficult for all conditions. No significant differences in waveform amplitude or latency were found between the frequencies used to isolate the respective left and right hemifield neural response ( $p > .05$ ). In order to better confine the analysis to the effects of attention we normalized the data using the two control conditions for each stimulus condition (LM, S, and achromatic) in which the participant was attending to the hemifield containing the stimuli while the opposite hemifield was an isoluminant gray background (blank). These two amplitude data points were averaged together and the ratio of the other response amplitudes within that condition to this value was taken as a

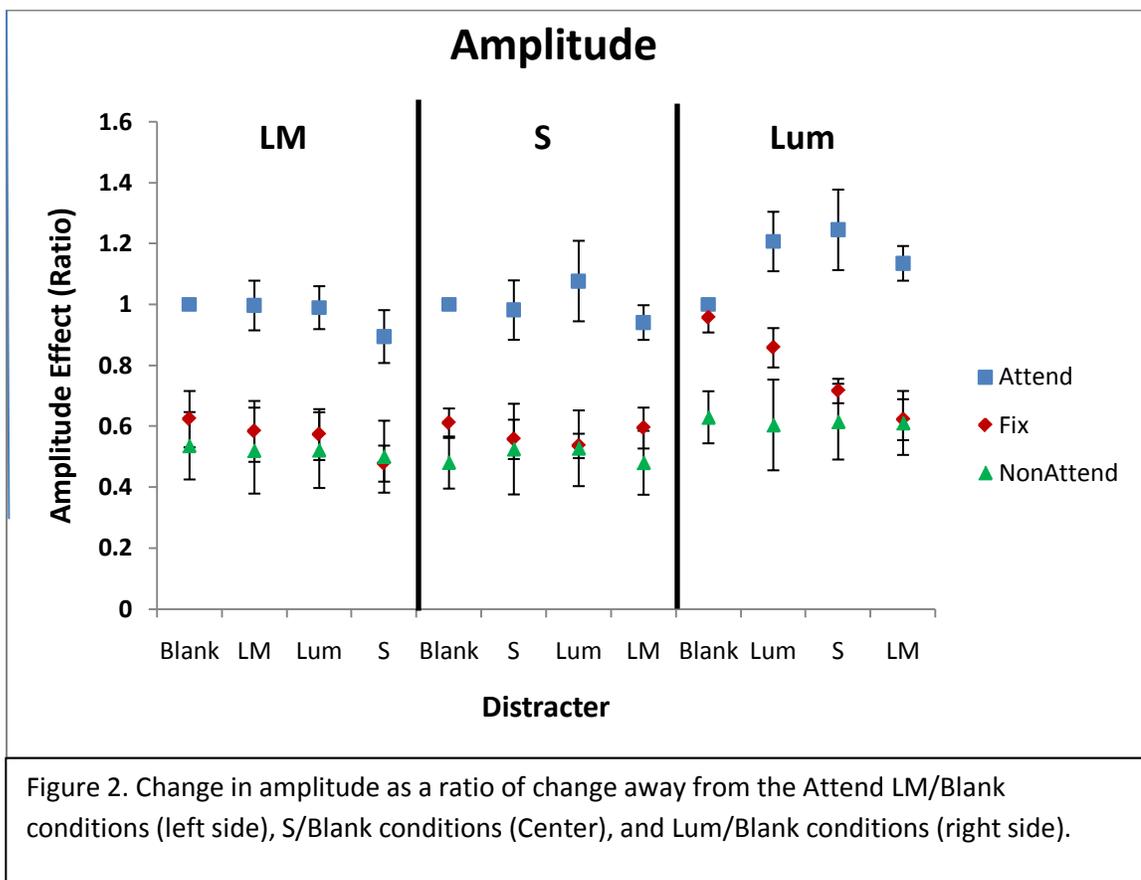
measure of change. Normalization of the latency data was accomplished by taking the difference between each latency data point in LM, S, and achromatic conditions and the average of the two latencies from the control conditions identified above. Note that the normalization was specific for each test stimulus condition (LM, S, achromatic) to discount any systematic differences in response amplitudes between test conditions.

### 3.2 Main Analyses

A total of six 2x3x4 ANOVAs were performed to isolate statistically significant differences within each visual path. These analyses incorporated Side(2) x Attend(3) x Condition(4). The following three analyses are based on the amplitude ratio data for each visual path (See figure 4). Amplitudes in the four LM pathway attend conditions were consistently larger across all distracter types. A main effect of attention for LM stimuli regardless of distracter type is shown in the left side of Figure 2, Attend  $F(2,16)=16.271$ ,  $P < .001$ . Pairwise comparisons reveal significance ( $P < .05$ ) for all LM attend conditions compared to all fixation and non-attend conditions; fixation is not significantly different from any of the four non-attend conditions.

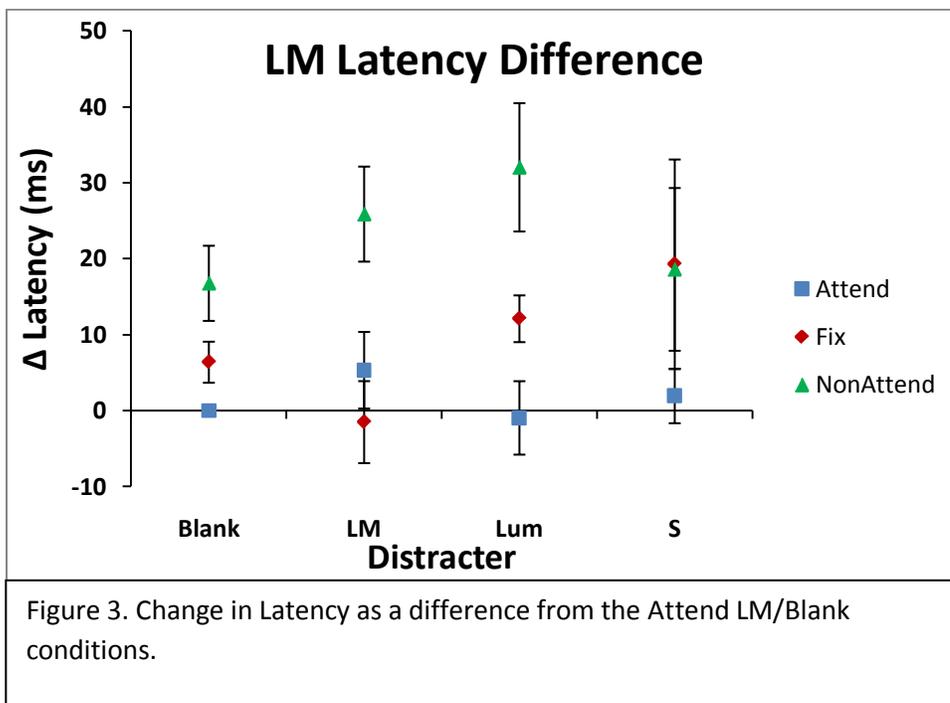
Amplitudes in the four S pathway attend conditions were consistently larger across all distracter types. A main effect of attention for S stimuli regardless of distracter type is shown in the center of figure 2, Attend  $F(2,16)=18.263$ ,  $P < .001$ . Pairwise comparisons reveal significance ( $P < .05$ ) for all S attend conditions compared to all fixation and non-attend conditions; fixation is not significantly different from any of the four non-attend conditions.

A main effect of attention for achromatic (Lum) stimuli, Attend  $F(2,16)=18.263$ ,  $P < .001$  is shown in the right side of figure 2. Pairwise comparisons of the achromatic attend conditions reveals significance ( $P < .05$ ) for all achromatic attend conditions compared to non-attend distracter conditions and for the S and LM distracter fixation conditions. The upward shift in amplitude for central fixation in the blank and achromatic distracter conditions reveals a  $P < .05$  compared to the non-attend blank and achromatic conditions.



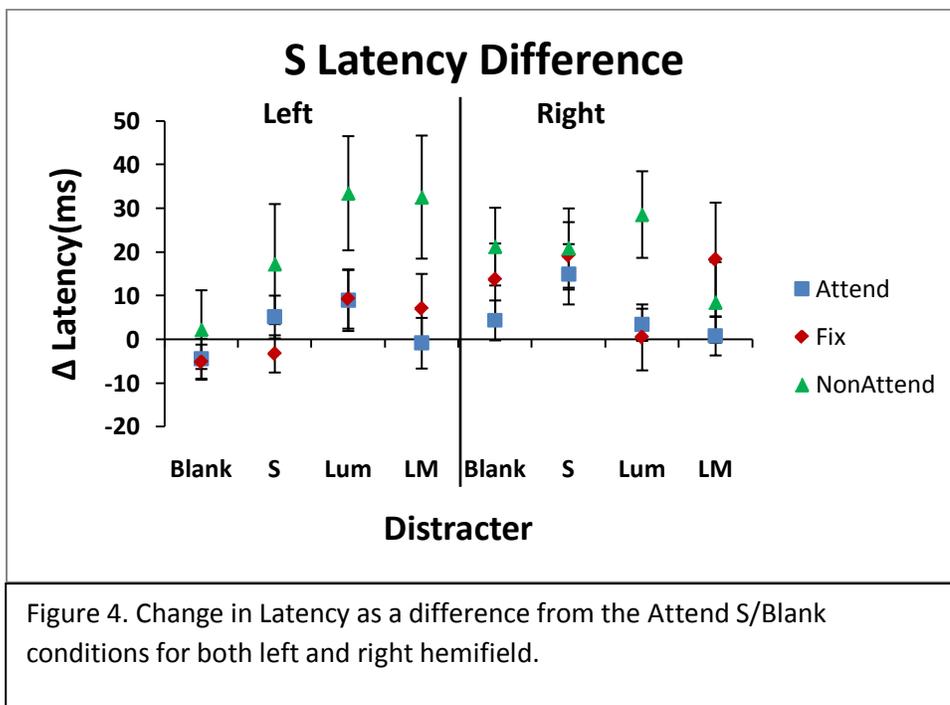
The next three analyses depict the latency differences. A main effect of attention, Attend  $F(2,16)=7.625$ ,  $P = .005$  and an interaction of Attend x Condition  $F(6,48)=2.496$ ,  $P$

= .035 for the LM stimuli is depicted in figure 3. Pairwise comparisons of the LM conditions reveals a significance ( $P < .05$ ) for the LM attend conditions compared to the blank, LM and Lum non-attend distracter conditions and the fixation blank and Lum distracter conditions. The fixation condition reveals significance ( $P < .05$ ) for the LM fix distracter conditions. The fixation condition reveals significance ( $P < .05$ ) for the LM fix distracter condition compared to the Non Attend LM and Lum distracter conditions. Given the variability within participants noted by the error bars, a lack of statistical significance in several conditions exists, however; it does appear that a trend toward an overall attention effect for LM attend may exist compared to both LM fixation and non-attend distracter conditions .

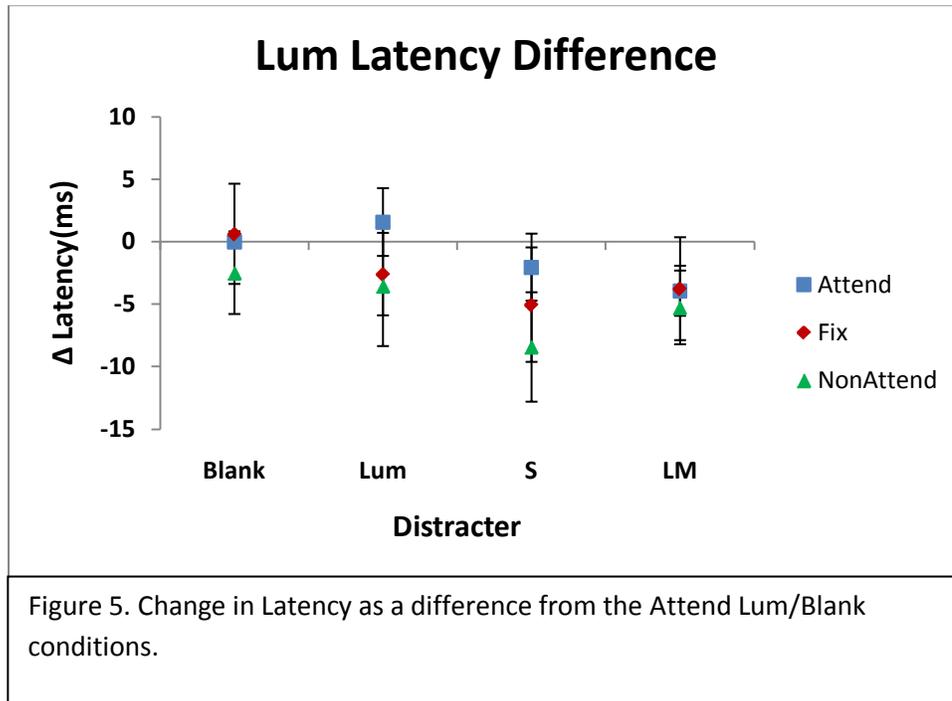


Latencies in attend and fixation conditions for S stimuli appear to follow a similar trend, occurring slightly before the non-attended S stimuli. There is a main effect of attention for S stimuli,  $F(2,16)=4.249$ ,  $P = .033$ , However; an interaction of Side x Condition

$F(3,24)=5.59$ ,  $P=.005$  was also revealed (see figure 4), so it was necessary to separate the hemifield data in order to identify the source of this interaction. Pairwise comparisons within the left hemifield data reveal significance ( $P < .05$ ) for the S attend LM distracter condition compared to the LM Fix and Non Attend LM distracter conditions and a significance ( $P < .05$ ) for the S Fix LM distracter condition compared to the Non Attend LM distracter condition. There was also significance in the right hemifield for the S attend lum distracter condition compared to the non-attend lum distracter condition. When the factor of side is removed from the analysis the significance for attend is also removed.



No statistically significant differences are apparent in the achromatic latency difference analysis. Figure 5 depicts the data for the achromatic analysis.



### 3.3 Experiment 2 Fixation Control

A control experiment was also conducted to determine how much a movement in fixation toward the attended stimulus would affect the responses. This was reasoned to be important since the stimulus edges were close to the fixation cross ( $1^\circ$ ) and the magnitude of the VEP is much larger for foveal stimulation. In this experiment we measured the cpVEP while attending to the left hemifield while displaying the LM attend-left /LM distract-right condition. Participants ( $n = 5$ ) were closely monitored and told to maintain fixation at the center of the original fixation cross ( $1^\circ$  experimental

condition) and on additional fixation points at eccentricities of 0.4°, 0.8°, 2.0° and 10° (foveated VEP) from the fixation point in the direction of the attended stimulus. The results from this analysis indicate that amplitude changes are seen even at the smallest fixation shift (0.4°). These amplitude changes are in fact at least as large as the reported attentional effects, as can be seen in the figure. As expected a much larger increase in amplitude is apparent (See figure 6) at the fixation eccentricity of 10° from the original central fixation, wherein the stimulus completely covers the fovea. These data suggest that even small but consistent shifts in fixation towards the attended stimulus could produce shifts in amplitude that exceed those observed with attentional modulation. It is therefore not possible at this time to rule out small, systematic shifts in fixation towards the attended stimulus as the source of the amplitude effects reported in Experiment 1. A decrease in latency greater than the experimental effect reported in Experiment 1 is observed for only the full foveal VEP at 10° (see figure 7). It is not possible at this time to conclude whether the similarity at .4° and .8° fixation is due to attention or to the shift in fixation in the control experiment because the control data reflect attentional conditions only. Further experiments are needed to rule out fixation shifts as the source of both the amplitude and latency effects reported with attentional modulation in Experiment 1.

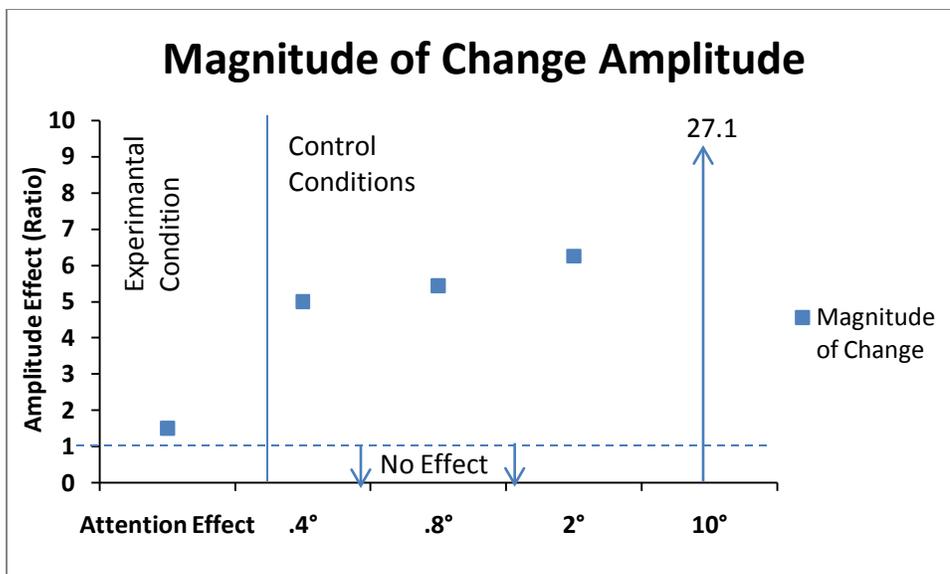


Figure 6. Control for eye movement. Amplitudes reflect a magnitude of change in relation to the central fixation; attend left LM/LM condition. All conditions were for attend left.

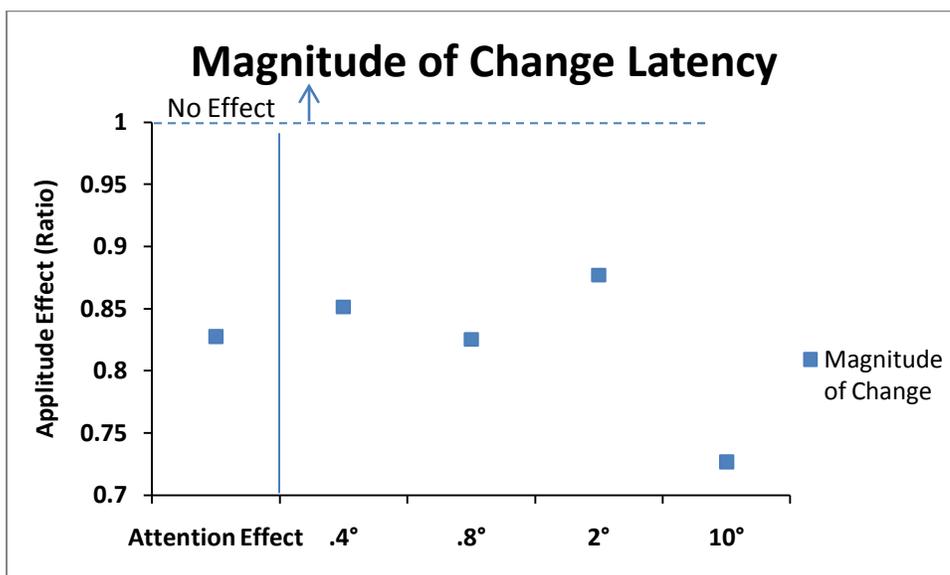


Figure 7. Control for fixation shift. Latencies reflect a magnitude of change in relation to the central fixation; attend left LM/LM condition. All conditions were for attend left.

#### 4. Discussion

Our results indicate that the pcVEP may be modulated by attention in the near periphery for both LM and S cone isolating stimuli. The paVEP also appears to be susceptible to attentional modulation under these conditions. These findings were consistent across stimulus types designed to stimulate the LM, S, and achromatic visual pathways regardless of distracter type. One of the most prominent but unsurprising features of the present results is the reduced amplitudes found for all of the stimuli. This of course results from the lack of foveation of the stimulus pattern and suggests that the subjects were not shifting their fixation to the center of the attended stimulus. The latency data also appear more variable than most previously reported VEP data. This is also not surprising since the peaks and troughs become less well defined as amplitudes decrease. Nonetheless, an attenuation of the CII component in the LM latency domain and to a lesser extent in the S latency domain for attended vs. non-attended stimuli was observed. The present results can be contrasted with prior research (Highsmith & Crognale, 2010) that failed to reveal any effects of attention on the chromatic VEP. Differences in the methodology, however may account for this discrepancy. Experiment two of the previous study displayed stimuli as close as 5° eccentricity as opposed to the 1° eccentricity reported in this study producing even smaller response amplitudes and greater variability than found in the present study. It is well known that the distribution of cones is greatest at the fovea and decreases with increasing eccentricity (Curcio et al., 1990) and that the foveal region dominates the

chromatic VEP and other cortical responses (e.g Rabin et al., 1994). Additionally, the current study utilized frequency tagging to record the attended and unattended conditions simultaneously, further reducing response variability. The amplitude modulations that were found in the LM attend condition are in agreement with the findings of Di Russo and Spinelli (1999b, 2000) using SSVEPs, however; we observed an attenuation of the LM pcVEP which was not apparent in the SSVEP L-M phase data previously reported. Again this discrepancy may arise from many methodological differences.

Results from the S cone stimuli indicate that attention is modulated regardless of distracter type in the amplitude and to a lesser extent the latency domain. These results can be contrasted with previous research measuring transient VEP's (Highsmith & Crognale, 2010) and SSVEP's (Wang & Wade, 2011). Differences in methods and stimuli between the present study and Highsmith and Crognale (2010) are discussed above and may explain the discrepancy. The Wang and Wade's stimuli were not split across hemifields from the distracter. And as reported above our lab has also failed to observe attentional effects under similar conditions.

Several studies provide evidence that feedback processes occurring during spatial attention paradigms produce neural activity in V1 after the initial geniculostriate stimulation occurring in the 80-100ms timeframe after stimulus onset in monkeys (Motter, 1993) and in the 140-250ms timeframe in humans (noesselt, 2002). The onset of the p100 generally occurs around 75ms preceding this reentrant timeframe

suggesting that attentional modulations of neural activity should occur for stimuli that produce later components reflected in event related potentials (ERP's). While these studies did not specifically look at stimuli designed to target the chromatic and achromatic visual pathways simultaneously they are an indicator of the potential for a distributed feedback network to act on these neural systems.

Another study that combined fMRI and ERP (Matinez et al., 1999) found the earliest facilitation occurred outside striate cortex around 70-75ms located in area V3 and more anterior regions of the middle occipital gyrus. Given this second possibility, if the VEP is reflective of neural activity occurring in later extrastriate locations the resultant neural response may reflect this activity. The koniocellular visual pathway (layer 2/3) is separated from the magno and parvocellular visual pathways (layer 4C) as they enter striate cortex. Studies in the macaque provide evidence that the innervation of parvocellular synaptic connections in layer 4C $\beta$  onto spiny stellate cells, which in turn have synaptic connections in layers 4C $\alpha$  (magno) and 4A (Konio) may result in the mixing of the three distinct pathways before projections to V2 have even occurred (Callaway & Wiser, 1996; Yabuta & Callaway, 1998; but see Sincich & Horton, 2005). Given this relationship it is possible that the results of this study are reflective of early connections between the chromatic pathways.

The current study supports the conclusion that attention has different effects on the chromatic and achromatic visual pathways, but differs from previous research (Di Russo & Spinelli, 1999; Highsmith & Crognale, 2010; and Wade & Wang, 2011). The decrease in latency with achromatic stimuli that has been reported in the past was not

apparent in the current study, however; the increase in amplitude that has been reported was consistent with previous research using SSVEP (Di Russo and Spinelli, 1999a, 2000) and transient VEP (Highsmith & Crognale, 2010).

Because the stimuli used in the present study were close to the fovea and the VEP responses increase greatly in the fovea, a potential confound exists. If subjects shifted fixation slightly towards the attended stimulus this could increase amplitudes and decrease latencies and be erroneously attributed to cortical attentional effects. A control experiment was therefore conducted to check for the effects of shifts in fixation. The data showed that even small shifts such as from the center of the fixation cross to the tip of the arrow used to cue attention caused an increase in amplitude. These increases in amplitude were considerably larger than the amplitude changes reported for attentional shifts. The latency changes with a shift in fixation were not significantly different than the effect reported in Experiment 1 until the stimulus pattern covered the fovea which would require a large and obvious shift in gaze that was not observed in the subjects' behavior during the experiments. However, the results of the control experiment fail to rule out a bias in fixation towards the attended stimulus as the cause of the changes observed with shifts of attention. Further experiments using eye-tracking to monitor fixation are planned to examine this issue more thoroughly.

The results of the current study provide insight into the ways in which the transient visual evoked potential may be affected under very stringent conditions. It is important to realize that the amplitude and latency modulations are small and well

within the variability of the population (see figure 6 and 7) and could possibly be caused by fixation bias as discussed above. As a result, attentional effects alone would be unlikely to result in a classification as “abnormal” in the clinic. Most importantly, results from prior studies have shown that for clinically and experimentally relevant conditions, i.e. when the test stimuli are viewed foveally, there is no measurable effect for peripheral or parafoveal distracters. Thus, the previous conclusion that monitoring fixation and not attention per se is sufficient for the chromatic onset VEP, remains intact.

## 5. References

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