University of Nevada, Reno

TOP-DOWN MODULATION OF THE CHROMATIC VEP WITH HYPNOTIC SUGGESTION

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Psychology

by

Chad Steven Duncan

Dr. Michael A. Crognale / Dissertation Advisor

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CHAD S. DUNCAN

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Michael A. Crognale, Ph.D., Advisor

Gideon P. Caplovitz, Ph.D., Committee Member

Michael A. Webster, Ph.D., Committee Member

William Danton, Ph.D., Committee Member

Thomas J. Nickles, Ph.D., Graduate School Representative

Marsha H. Read, Ph. D., Dean, Graduate School

May, 2013

Abstract

Visual perception is composed of both bottom-up (stimulus driven) and top-down (feedback) processes. It has been demonstrated that directed spatial attention enhances processing of attended stimuli, inhibits non-attended stimuli, and increases baseline activity in portions of cortex corresponding to attended areas of the visual scene in the absence of a stimulus. However, mechanisms of attention appear to influence processing of chromatic stimuli differently than that of achromatic stimuli. Visual evoked potentials (VEPs) recorded under such conditions agree with this pattern of activation when elicited by purely achromatic grating stimuli. However, when stimuli were chosen to preferentially activate the S-(L+M) or L-M chromatically opponent pathways, no changes in signal were detected as a function of attention, suggesting different amounts of feedback, or different mechanisms of feedback, reaching the visual cortex where the VEP is thought to originate. Hypnosis is another form of top-down manipulation that can produce significant signal change in the VEP. A set of four experiments were conducted to investigate whether or not feedback extending to lower visual areas is capable of altering processing of incoming information in the presence of hypnotic suggestion. Positive and negative suggestions were used to invoke hallucinations regarding stimulus presence and absence, as well as imagined stimulus occlusions. It was hypothesized that unlike attentional manipulations hypnotic suggestions would affect VEPs elicited by stimuli that were designed to isolate the individual opponent pathways. However, similar to results from attention VEP studies, a significant difference was obtained in the achromatic waveform but not in the chromatic waveform. These data indicate that hypnotic suggestion may feedback to lower visual areas in a manner similar to that of attentional manipulations.

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Introduction

Background

Although visual perception seems like a robust experience of direct translation of our surroundings, it can actually be quite pliable. The world around us simply offers too much information for the visual system to encode. As a result, the retina and the brain utilize several different mechanisms to filter out presumably less important information and allocate resources appropriately (Hupé, James, Girard, & Bullier, 2001; Hupé, James, Girard, Lomber, et al., 2001; Hupé et al., 1998). The visual system then reconstructs the most probable percept using this information combined with prior knowledge. In the brain, this is most likely accomplished through feedback from higher cortical areas to lower areas. This “top-down” processing appears to gate sensory information in such a way that it can greatly influence perception (Boynton, 2011; Kastner & Pinsk, 2004; O'Connor, Fukui, Pinsk, & Kastner, 2002).

Top-Down Processing

Expectations and prior knowledge often impose order and organization on visual scenes as our brain attempts to interpret incoming information. The Necker Cube is an illusion that consists of a series of lines on a two dimensional surface which form two identical and overlapping squares. Corresponding corners of the squares are connected by angled lines that give the impression of depth, representing a hollow cube composed of six transparent walls.

The Necker Cube is essentially the projection of a three dimensional object on a two dimensional surface. In order for the brain to correctly interpret this as a cube, it must choose one of the two overlapping squares to appear as either the front-facing or rear-facing surface. The surface chosen as the front depends on your expectation of the cube (i.e. which way you think it is facing). This perception is bistable, meaning that the viewer can change expectations, and the front and back-facing walls will appear to trade positions (Necker, 1832). Another example is the rotating silhouette figure that can appear to be spinning either clockwise or counterclockwise (Kayahara, 2003). Most participants can change the direction of perceived rotation with concentration. Prior viewing of a similar figure with additional lines that bias the percept towards one interpretation will cause a bias in the perceived direction of rotation of the ambiguous image (Liu, Tzeng, Hung, Tseng, & Juan, 2012).

Prior experience viewing a scene can also influence perception of the scene. Examples of this include illusions such as the low fidelity rendition of images such as a cow. When viewing this image for the first time it can be quite difficult to notice that there is an image of a cow that can be formed by connecting several components together, because the image is disguised by noise. Once the image of the cow is recognized however, it is virtually impossible to view the image again and not see the cow. Once the brain has formed the image of the cow among the noise, it seems reluctant not to impose this structure every time it is viewed in the future. In this way, prior knowledge about the image forms a solid percept that seems robust to intentional manipulation.

In the case of binocular rivalry, each eye views different images, causing a failure of the visual system to achieve stereopsis (Levelt, 1965). As a result, visual signal from one eye is ignored after the brain chooses which image to process further. The viewer typically ends up perceiving only one of the images at a time, and under certain conditions the perception will alternate between both images. In cases such as this there appear to be a combination of top-down and bottom-up mechanisms contributing to suppression of visual processing from one eye or the other. Bottom-up mechanisms appear to be stimulus driven and include elements of attentional capture such as luminance, chromaticity, flicker and motion. Top-down mechanisms such as selective attention allow the viewer some control over which stimulus is perceived (Brascamp & Blake, 2012). By processing input from one eye and not the other, the brain appears to be deciding which eye is relaying the most important information and suppressing input of the opposite eye in order to form a single, coherent image of the world.

Attention

Attention is another mechanism by which the brain filters incoming sensory information. Attention is used to facilitate encoding of important or task-relevant stimuli, while other unattended information may be lost. Changes in brain activity due to overt and covert attention have been identified in retinotopic regions in the brain corresponding to the attended or unattended portion of visual space (Moran & Desimone, 1985). The changes are revealed by increased blood oxygen level-dependent (BOLD) signal amplitude to stimuli presented to the attended region; decreased BOLD signal amplitude to stimuli presented to the unattended region; and increased baseline activity in the attended region in the absence of visual stimulation (Kastner & Pinsk, 2004).

Many areas, from the lateral geniculate nucleus (LGN) of the thalamus (O'Connor et al., 2002) to various regions of extrastriate cortex have shown differential BOLD activation due to attentional manipulation of visual perception (Moran & Desimone, 1985), indicating the possible presence of feedback mechanisms stemming from higher cortical areas. Although less evident (Kastner & Pinsk, 2004; Kastner & Pinsk, 2004; Kastner & Ungerleider, 2001), attentional effects in primary visual cortex (area V1) have been reported (Martinez et al., 2006). These changes in neural activity accompanying attention have been shown to decrease reaction times and improve accuracy of target detection within the attended region (Posner, 1980), as well as increase discrimination (Lu & Dosher, 1998) and contrast sensitivity (Cameron, Tai, & Carrasco, 2002).

Pathological Top-Down Modulation

A recent report (Strasburger et al., 2010; Waldvogel, Ullrich, & Strasburger, 2007) has demonstrated that the visual evoked potential (VEP) and the BOLD signal can be selectively suppressed by feedback mechanisms as early as the LGN. In this case though, the suppression appears to be driven by pathology rather than volitional mechanisms *per se*. Specifically, a patient diagnosed with Dissociative Identity Disorder (Organization, 1990) would rapidly switch between blind and sighted personalities. As she did, visual signals from both the LGN and area V1 were immediately abolished & resurrected accordingly. This was verified via transient and steady state VEPs and functional imaging performed while in both sighted and blind personality states.

Case reports of psychogenic loss of conscious visual perception have been known for many years (Charcot, 1872; Janet, 1911), but most have only reported slight changes of physiological response. Most also report partial to complete sensory loss, sometimes followed by gradual improvement with therapy (Schoenfeld, Hassa, Hopf, Eulitz, & Schmidt, 2011). This particular case stands out because the induced blindness is restricted to certain dissociated personality states, and because of the prompt and all-but-complete changes in visual signal measured both via the BOLD and VEP responses.

These data suggest that manipulation of low-level visual pathway response may be possible via feedback mechanisms that are accessible through non-conscious processing or altered states of consciousness, but not necessarily through volitional means such as attention.

Hypnosis

Hypnosis represents an additional feedback mechanism that appears to alter visual perception, as well as other sensory stimuli such as pain and touch. Hypnosis has been used in place of or in combination with anesthesia in many cases (Kiss & Butler, 2011; Roelants, Georges, Ponchon, Berliere, & Watremez, 2011) to manage pain during surgery and sometimes throughout postoperative recovery (Montgomery, David, Winkel, Silverstein, & Bovbjerg, 2002; Roelants et al., 2011).

Altering the Perception of Pain with Hypnosis

Investigations into the underlying mechanisms of hypnotic suggestibility and their effect on sensory input have revealed several changes within the brain during hypnosis. Rainville, Duncan, Price, Carrier, & Bushnell (1997) used hypnotic suggestions to modulate the unpleasantness of hot water. PET imaging revealed levels of activation within the anterior cingulate cortex (ACC) that were consistent with the perceived unpleasantness, even though the water temperature was held constant. The ACC, (along with the thalamus, insula, and primary (S1) and secondary (S2) somatosensory cortices) is part of the neural matrix that mediates the perception of pain (Apkarian, Bushnell, Treede, & Zubieta, 2005). These results are in accord with a body of pain research regarding hypnosis (Landolt & Milling, 2011; Teeley et al., 2012; Tomé-Pires & Miró, 2012).

Chronic pain resulting from pathologies such as cancer (Tomé-Pires & Miró, 2012), multiple sclerosis (Jensen et al., 2011), and even lower back injury (Tan, Fukui, Jensen, Thornby, & Waldman, 2010) have also been investigated and treated with hypnotic suggestion. Even though the neurophysiological underpinnings of fibromyalgia are not yet well established, Derbyshire, Whalley, & Oakley (2009) used hypnosis to produce changes in pain and in cortical and subcortical BOLD signals in patients diagnosed with fibromyalgia. BOLD activation in several areas of the pain matrix, including the cingulate cortex and thalamus, was correlated with reported changes in the perception of pain.

Altering the Perception of Touch with Hypnosis

Hypnosis has also shown potential to alter other perceptual domains such as tactile sense and vision. Maravita, Cigada, & Posteraro (2012) report a patient who suffered an ischemic stroke that resulted in unilateral spatial neglect (USN) and left spastic hemiparesis. The unilateral right hemisphere damage also caused extinction to double sensory events, in which the patient could detect unilateral tactile stimulation on both sides, but failed to detect stimulation contralateral to the damage when also presented with simultaneous stimulation to the ipsilateral side. With the aid of specific hypnotic suggestions, the patient showed significant improvement in her ability to correctly identify stimulation to the contralateral side. It should be noted that this effect was only achieved after two practice sessions. Participants have been shown to improve their hypnotizability and task performance with repeated hypnotic sessions (Sachs & Anderson, 1967).

Altering Visual Perception with Hypnosis

In an attempt to identify physiological correlates of hypnotic visual illusion, Kosslyn, Thompson, Costantini-Ferrando, Alpert, & Spiegel (2000) used PET to identify regional cerebral blood flow (rCBF) changes when processing color and grayscale images. Participants were given suggestions regarding the presence or absence of color as they viewed patterns that varied only in luminance (achromatic) or chromaticity (chromatic). Following hypnotic induction, researchers found selective rCBF increases in the left fusiform gyrus when participants were told to perceive colored stimuli but were shown achromatic stimuli instead. This increase was not present prior to the suggestion. Likewise, rCBF in the fusiform gyrus was decreased when participants were instructed to perceive achromatic stimuli when viewing colored stimuli. This decrease was also not observed prior to suggestion. The inverse metabolic relationship between responses to chromatic and achromatic stimuli seen in the fusiform gyrus has not been observed in physiological recordings from earlier visual areas such as V1, suggesting either a fundamental difference in attentional effects for these regions, or a difference in attentional effects revealed by the metabolic responses versus electrophysiology.

Collectively, this evidence lends support to the idea that hypnosis is a distinct physiological state (Kihlstrom, 1987) rather than merely an act in which the subject adopts a role to satisfy the hypnotist (Barber, 1961; Spanos, 1982). It also demonstrates that measureable physiological changes accompany altered sensory percepts under hypnotic suggestion.

When discussing hallucinogenic hypnotic suggestions, it is important to account for the difference between suggestion types. Hallucinations can effectively be divided into two major categories; positive and negative. Positive hallucinations typically denote the addition of a stimulus in the environment (i.e. an imagined object); while negative hallucinations typically consist of the absence of a stimulus in the environment (i.e. failure to perceive an object that has been presented). Suggestions of negative hallucinations have been defined by Weitzenhoffer (2000) as invoking anesthesia (or a lack of sensation) by interfering with the processing of incoming sensory stimuli, or possibly as interfering with knowledge of the sensory stimuli entering into conscious awareness. Either way, suggestions of negative hallucinations appear to inhibit conscious perception of the stimulus. Those of a positive nature on the other hand, are thought to be governed by different underlying mechanisms (Weitzenhoffer, 2000). When under the influence of a positive suggestion, participants can often recall very vivid and detailed images from memory, which seem to override incoming sensory information to some extent. Although different, both cases imply top-down feedback stemming from higher cortical areas, and appear to be related to mechanisms of attention. For example, experiences of hallucinogenic inhibition can readily be explained by displaced attention. Reported perception of pain has been shown to decrease with distraction (Van Ryckeghem et al., 2011; Verhoeven et al., 2010), and areas of cortex that correspond to non-attended areas typically show some level of neural inhibition (Kastner & Pinsk, 2004).

The Chromatic Visual Evoked Potential

The crVEP is a gross potential measured over the occipital lobe. Though the exact origins are not yet known, the negative C2 component of the crVEP waveform, which typically appears 100-150ms following stimulus presentation, is believed to be a reflection of low level chromatic processing originating in or near area V1 (Berninger, Arden, Hogg, & Frumkes, 1989; Rabin, Switkes, Crognale, & Schneck, 1994), which receives feed-forward input largely from the LGN. The crVEP has been used as an objective and sensitive measure of color processing as well as overall neural integrity, in developmental and clinical populations (Crognale, 2002; Crognale, Kelly, Weiss, & Teller, 1998; Crognale, Switkes, Rabin, & Schneck, 1993; Madrid & Crognale, 2000; Porciatti, Bartolo, Nardi, & Fiorentini, 1997; Sartucci, Murri, Orsini, & Porciatti, 2001; Suttle & Lloyd, 2005).

Attentional Modulation of the crVEP

Although attention and hypnosis have both been shown to manipulate perception in some way, there appear to be some differences between the amounts of feedback reaching early visual areas that are involved in the processing of chromatic versus achromatic stimuli. Specifically, the chromatic visual evoked potential (crVEP) appears to be less effected by directed spatial attention than VEPs elicited by achromatic stimuli. VEPs elicited by standard achromatic grating stimuli show changes that coincide with those of attention, but those elicited by purely chromatic spatial/temporal modulations, as used to generate the crVEP, appear markedly unchanged by the same manipulations (Highsmith & Crognale, 2010; Highsmith, Duncan, O'neil, Roth, & Crognale, 2008; Highsmith, Santiago, & Crognale, 2007). This appears to hold true for varying levels of difficulty using both similar (task relevant) and non-similar distractor stimuli.

A recent case report by Crognale, Duncan, Shoenhard, Peterson, & Berryhill (2012) supports the suggestion that the crVEP reflects relatively low level chromatic processing, prior to the conscious experience of color. In this study, a subject reported abnormal color perception following an ischemic stroke and displayed abnormal chromatic discrimination when tested, yet her crVEP waveform showed no attenuation of signal or abnormal latency when compared to controls.

Top-Down Modulation of the Chromatic VEP with Hypnosis

Some time ago, Spiegel, Cutcomb, Ren, & Pribram (1985) investigated just such phenomenon by pairing hypnotic suggestion with visual evoked potentials. The stimuli consisted of striped patterns, but spatial frequency, luminance and chromaticites were not reported. The researchers hypothesized that hypnotic hallucination would alter the amplitude of the response. They employed one independent variable, suggestion type, which consisted of three levels; stimulus enhancement (i.e. target stimuli will appear brighter and more vivid than others), stimulus diminution (i.e. the target stimuli will appear dull and drab), and obstructive hallucination (i.e. there is a cardboard box obstructing view of the stimuli). Results indicated that manipulation of the visual evoked potential was achieved at low level recording sites over primary visual cortex. The authors reported significant signal attenuation in the obstructive condition in highly hypnotizable participants. However, within-subject comparisons were made between the various conditions of hypnotic suggestion, but no waveforms were compared to a baseline measure that was free of any hypnotic suggestion. Therefore, although the waveforms elicited were significantly different from each other, there was no evidence of significant change from the normal response.

Furthermore, a distinction between the processing of chromatic and achromatic stimuli suggests varying amounts of feedback reaching the different pathways, which could be the result of separate feedback mechanisms, possibly originating from different cognitive faculties. Although Spiegel et al. (1985) used colored gratings to elicit VEPs, the colors chosen were nonspecific and did not attempt to isolate individual opponent mechanisms. In order to sufficiently isolate the individual mechanisms, it is required that luminance be held constant to avoid contamination of the chromatic signature by magnocellular activation. Consequently, to identify any effects that state of consciousness may have on specific visual pathways, it is important to test the responses of these individual pathways.

Research Questions

The present study aimed to explore the effects that hypnotic suggestion may have on waveform components of the chromatic pattern-onset VEP. Another form of top-down modulation, attention, appears to be capable of altering processing along the magnocellular pathway but not along the chromatic pathways. Mechanisms of attention typically allow increased processing of attended stimuli while inhibiting processing of non-attended stimuli in the visual field. However, this has been shown not to be the case with chromatic stimuli (Highsmith & Crognale, 2010; Roth, Duncan, McDermott, & Crognale, 2011). When presented with individual chromatic stimuli to both hemifields, attending to one or the other does not appear to alter the VEP signal elicited by either. It was hypothesized that hypnotic suggestion may allow greater alterations of processing along the S-(L+M) pathway. Four different experiments were conducted to assess the effects of hypnotic suggestion on the chromatic pattern-onset VEP. Experiments 1-3 explore different types of suggestions and tasks, while Experiment 4 implemented eye tracking to control for eye movements and closures. After controlling for these extraneous variables, Experiment 4 revealed a change in the achromatic waveform but not in the chromatic waveform.

Experiments

Experiment 1: Hypnotic Suggestion and the Chromatic VEP

Participants

85 Participants were recruited via flyers posted around the University of Nevada, Reno campus and from undergraduate psychology classes at UNR. Written informed consent was obtained prior to screening, following the Tenets of Helsinki, and with approval of the Office of Human Research Protection of the University of Nevada, Reno. Participants were offered extra credit in psychology courses in exchange for participation. All participants were initially screened for individual levels of hypnotic susceptibility using the Harvard Group Scale of Hypnotic Susceptibility: Form A (Shor & Orne, 1962) and assigned to 1 of 3 groups based on a scale from 1 to 12; 12 being highly susceptible and 1 being not very susceptible. Participants whose scores were greater than 8 were assigned to the high susceptibility group (High; n=10, 4 males, 6 females, mean age = 21.7 years, mean score = 8.7), and those whose scores were less than 6 were assigned to either the low susceptibility group (Low; n=10, 3 males, 7 females, mean age = 25.6 years, mean score = 4.1) or a third group who were instructed to 'act out' the suggested behaviors whether actually hypnotized or not (Sham; n=9, 4 males, 4 females, mean age = 25 years, mean score = 2.3). All three groups were further screened for normal color discrimination using the Ishihara 38 plate test (Ishihara, 1992).

Stimuli

Stimuli were horizontal sinusoidal gratings generated using a VSG card (Cambridge Research Systems), and presented binocularly on a Sony Trinitron Multiscan 20sc II monitor via custom software written in Microsoft Visual Basic . Stimuli were viewed through an 8 deg. circular mask from a distance of 57 cm. Stimuli were chosen to preferentially isolate the individual S (koniocellular), LM (parvocellular), and achromatic (magnocellular) pathways (Rabin et al., 1994). S and LM stimuli consisted of 1 cpd sine wave gratings that varied only in chromaticity. Gratings were physically isoluminant, and contrast along the LM and S axes of MBDKL color space (Derrington, Krauskopf, & Lennie, 1984; MacLeod & Boynton, 1979) were equated (S=89.2% of max available, LM=86.7%, Achromatic=80%) using lab-averaged supra-threshold contrast matches (Switkes & Crognale, 1999). Colors were modulated around a white point (CIE x-0.31; y-0.31), which resulted in cone contrasts along the S axis of S = 45.0 RMS and along the L-M axis of L = 6% and M = 11%. The achromatic stimuli consisted of 4 cpd sine wave gratings that varied only in luminance.

VEP Recording

VEPs were recorded using gold plated Grass electrodes and Grass amplifiers via a National Instruments IO Board in a PC. Electrodes were held on the scalp with conductive paste and placed according to the International 10-20 system. The active electrode was placed at Oz, the reference at Pz and the ground at Fz. Electrode impedance was kept below 5 kΩ measured at 30 Hz. Gross potentials were sampled at 1000 Hz. Signals were amplified, notch filtered (mains), low-pass filtered (100 Hz), high pass filtered (0.1 Hz) and averaged over 60-70 presentations.

Hypnosis

A clinician trained in hypnotic therapy delivered hypnotic suggestion and administered a modified induction procedure from The Phenomenology of Consciousness Inventory (Pekala, 1982/1991) to each individual participant.

Self-assessments

Before and after VEP recording and induction of any altered state of consciousness, participants were asked to complete Parts 1 and 2 (respectively) of the Phenomenology of Consciousness Inventory: Hypnotic Assessment Procedure (PCI-HAP;(Pekala, 1982/1991). Participants were instructed to answer all questions honestly regardless of their group assignment.

Procedure

Chromatic and achromatic stimuli were presented in an onset/offset timing sequence (100/400ms), and consisted of three separate epochs along all three cardinal axes of MBDKL color space. Blocks of 60-70 LM, S or achromatic grating stimuli were randomly presented twice each (120-140 total presentations per axis). VEPs were first recorded prior to induction (Pre), after induction in the presence of a hallucinogenic suggestion (Hyp), and again after the subject had been awakened from hypnosis (Post). Following induction, participants were given suggestions that they “will not be able to see anything on the monitor in front of them” before presenting blocks of stimuli. A knowledgeable, unbiased confederate was made available during each testing session for participant questions or concerns.

Results

Amplitude of the chromatic response was taken as the difference between the C2 and C3 components of the averaged VEP waveform. The C2 components were identified by the most negative deflection between 100-200ms following stimulus onset, and the C3 components were identified as the largest positive peak immediately following the C2 component and appearing before 300ms. An amplitude index was calculated to compare amplitudes across participants and normalize across different testing sessions. This produced a range wherein the value indicated the degree of attenuation of the signal relative to the Pre-induction condition, unless otherwise noted. The C2 component of the crVEPs elicited by both the LM and S stimuli had smaller amplitudes immediately following the hypnotic suggestion than that of the Pre or Post conditions [LM $t(27)=3.5, p<0.01$; S $t(27)=3.4, p<0.01$], though any changes in VEPs elicited by achromatic grating stimuli did not reach significance [$t(27)=0.88, p>0.05$] (see Figure 1.).

Figure 1. Experiment 1 Mean Amplitude Indices by Color Axis.

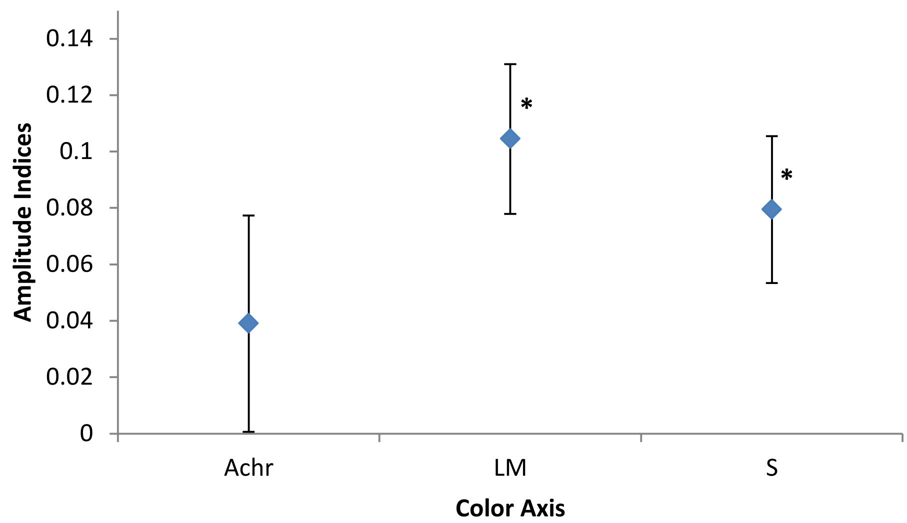

Figure 1. S and LM amplitude indices were significantly greater than zero, indicating that the hypnotic suggestions elicited smaller amplitude than was observed in the baseline conditions. Error bars indicate +/- one SEM. *P<0.05.

T-tests were also performed to compare mean group amplitudes (High, Med, Sham) using the amplitude indices; amplitudes from the High and Low groups were significantly different from each other [t(18)=2.47, p<.01], but those of the High [t(16)=-1.08, p>0.1] and Low [t(16)=1.2, p>0.1] groups were not significantly different than that of the Sham group (see Figures 2 and 3). This indicates that hypnotic susceptibility was not correlated with the changes in signal amplitude.

Figure 2. Experiment 1 Mean Amplitude Indices by Group.

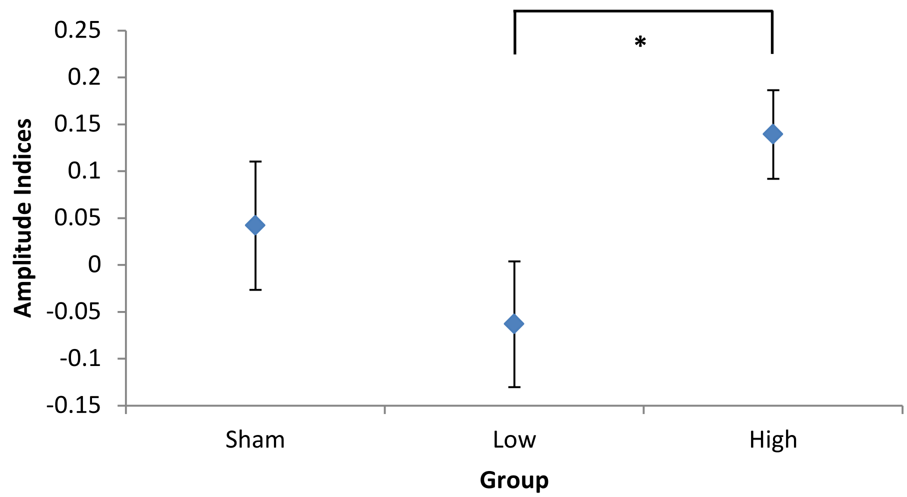

Figure 2. Although the Low and High group indices were significantly different than each other, neither was significantly different than that of the Sham group. Error bars indicate +/- one SEM. *P<0.05.

Figure 3. Experiment 1 Mean Amplitude Indices Expanded.

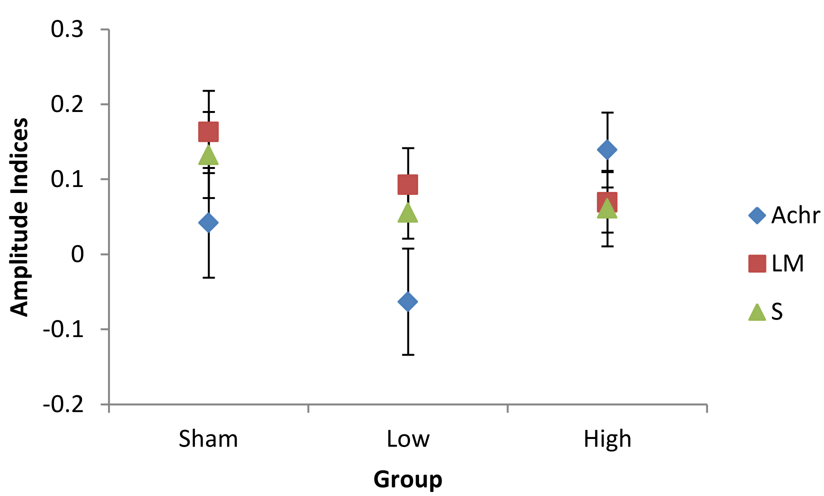

Figure 3. Amplitude indices plotted by color axis. Error bars indicate +/- one SEM.

Experiment 2: Directed Spatial Attention

Experiment 2 investigated the extent to which processing of one stimulus could be altered without effecting that of another stimulus in the visual field. In other words, Experiment 2 was designed to measure the extent to which spatial attention could alter visual processing when paired with hypnotic suggestion. In order to explore any differences between suggestions of positive and negative hallucinations, both were employed in Experiment 2.

Procedure

Two participants who showed significant signal attenuation along at least two of the three tested axes of MBDKL space throughout Experiment 1 were asked to return for participation in Experiments 2 and 3. Suggestions of positive hallucinations were given to induce an experience that an imaginary object was occluding one of the two stimuli being presented (Occluded) while the other was completely visible (Non-occluded). Suggestions of negative hallucinations were given to induce a failure to perceive one of the two stimuli (Non-visible), while the other was visible (Visible).

Stimuli for Experiment 2 consisted of 2 sinusoidal gratings, each presented to opposite hemifields and spatially separated by a 2 deg. wide vertical bar of average luminance and chromaticity (as defined above), which extended throughout the height of the stimuli. Gratings were modulated along the S direction as described above, while luminance was held constant. A frequency-tagging technique was utilized in which each of the 2 gratings was presented in an onset/offset timing sequence at slightly different temporal frequencies (2 Hz; 100/400ms, 2.05 Hz; 100/387ms). This allowed for independent signal averaging. Frequency combinations were counterbalanced. Hypnotic suggestions regarding both positive and negative visual hallucinations were given to all participants. A 4x3 factorial design was used. The first independent variable (IV1) was the suggested visibility of the stimuli (Occluded, Non-occluded, Visible, Non-visible) and IV2 was the state of consciousness; prior to the induction of altered consciousness (Pre) or during the state of hypnosis following suggestion (Hyp).

Results

Results from Experiment 2 indicate that positive hypnotic suggestions (i.e. those pertaining to an imaginary object occluding a portion of the screen) induced changes in the crVEP, but effects of negative hypnotic suggestions were less conclusive (see Figure 4). Amplitudes from both participants were smaller following suggestions of stimulus occlusion than non-occlusion, though more data is required for statistical analysis. Experiment 2 was discontinued due to noticeable eye movement artifacts.

Figure 4. Experiment 2 Raw Amplitudes.

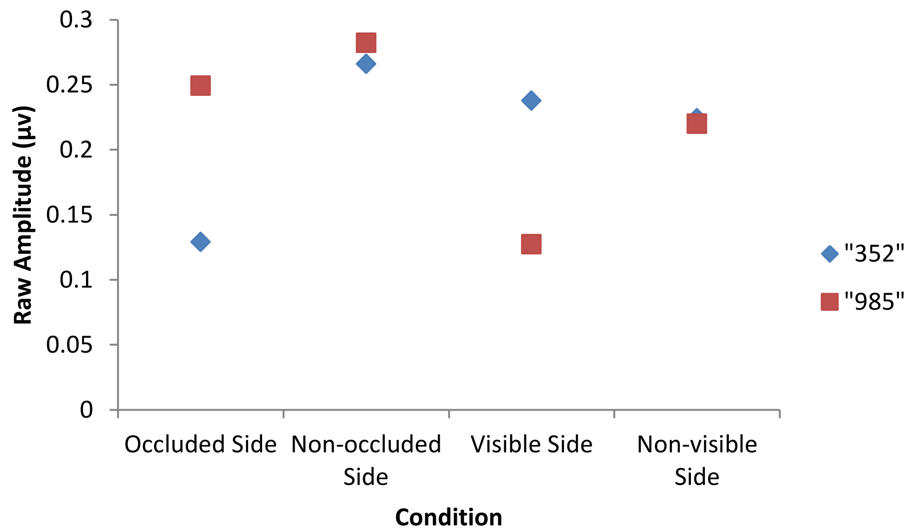

Figure 4. Raw signal amplitudes for 2 participants plotted by condition. Occlusion conditions consisted of positive hallucinations. Visibility conditions consisted of negative suggestions.

Experiment 3: Selectivity of Chromatic and Achromatic Processing

Experiment 3 attempted to examine the differences between feedback mechanisms reaching the various magnocellular and koniocellular pathways that contribute to the VEP. Experiment 3 assessed the ability of participants to selectively alter processing along a single opponent channel without effecting processing along the others.

Procedure

The same 2 participants were used in Experiment 3 as in Experiment 2. Experiment 3 consisted of the same full-field stimuli used in Experiment 1, but presentation blocks consisted of randomly interleaved stimuli from 2 test axes (S and Achr) rather than a single test axis. VEPs were again recorded prior to induction (Pre) and following and hypnotic suggestions (Hyp). The IV used in Experiment 2 was the type of stimulus that was suggested to be perceived. During hypnosis it was suggested to participants that they could only see the S (S-only) or achromatic gratings (Achr-only), at which time a sample stimulus was briefly presented for reference before beginning VEP presentation. Suggestion order was counterbalanced.

Results

It was predicted that negative suggestions regarding the absence of a presented stimulus would cause a reduction in signal amplitude elicited by that stimulus, while that elicited by the other stimulus would be relatively unaffected. For example, when instructed that the achromatic gratings would be the only stimuli presented, it was predicted that amplitude elicited by the S gratings would be significantly attenuated, while that of the achromatic grating would remain unchanged when compared to the baseline condition (Pre). In the Achr-only condition, it appears that one subject (985) showed the expected S signal attenuation from baseline, but the other subject did not. In the S-only condition, P100 amplitude elicited by the achromatic stimuli demonstrated a trend in the expected direction for one subject (352), but trended in the opposite direction for subject 985 (see Figures 5 and 6). Like Experiment 2, Experiment 3 was discontinued due to eye movement artifacts.

Figure 5. Experiment 3 Raw S Amplitude by Subject.

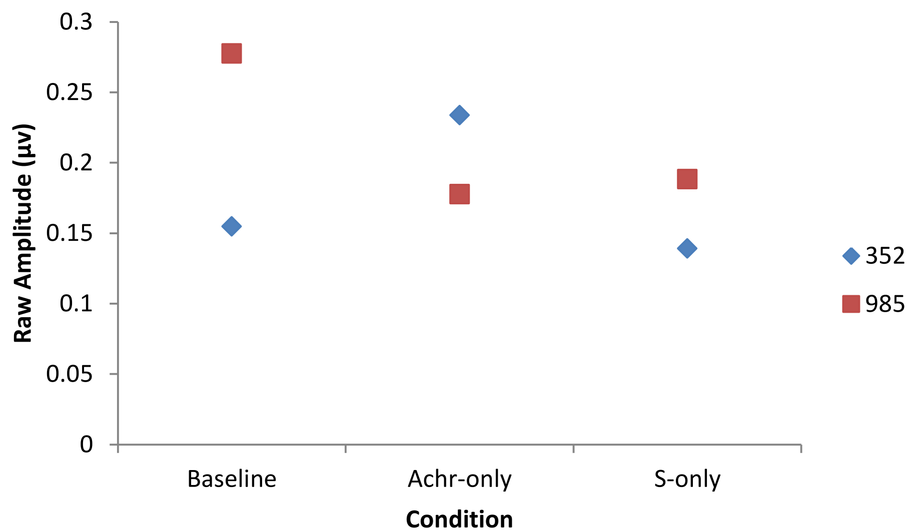

Figure 5. Results from Experiment 3; raw S VEP amplitudes plotted for two participants.

Figure 6. Experiment 3 Raw Achromatic Amplitude by Subject.

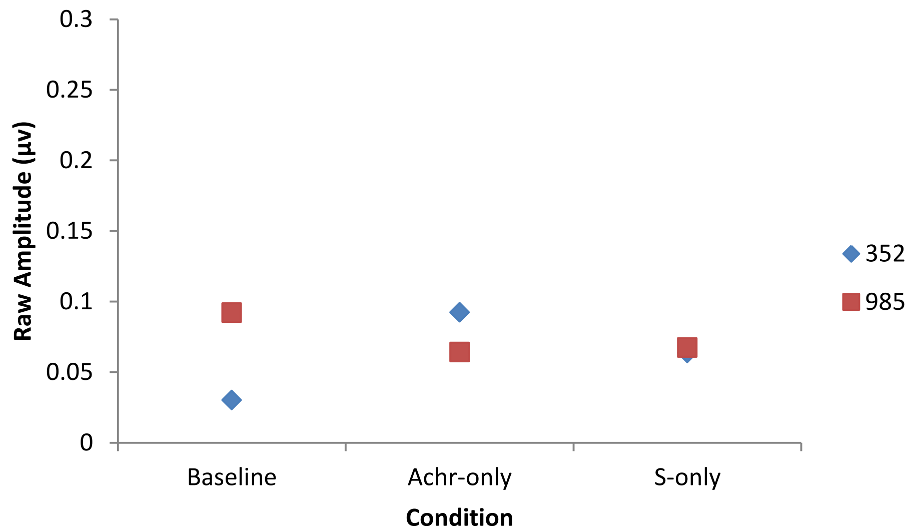

Figure 6. Results from Experiment 3; raw achromatic VEP amplitudes plotted for two participants.

Experiment 4: Hypnotic Suggestion with Eye Tracking

Experiment 4 was conducted in order to verify previous results with the addition of control procedures designed to account for eye movements and closures during hypnosis. Experiment 4 assessed the ability of highly-suggestible participants to alter the chromatic (S) and achromatic VEP signals in the presence of hypnotic suggestions, while keeping their eyes opened and trained on a center fixation.

Procedure

Four participants who demonstrated significant signal attenuation between baseline and experimental conditions in Experiment 1, including subject #985 who also participated in Experiments 2 and 3, were asked to return for further participation in Experiment 4. Eye tracking was used to ensure stable fixation and monitoring of eyelid closure. The stimuli consisted of full field (45 x 35 degrees) grating stimuli modulated along the S or achromatic axes as described above. Stimuli were presented in an onset/offset timing sequence (100/400ms) and were randomly interleaved. Eye closures and movements that shifted the center of gaze more than 15 degrees laterally or 20 degrees horizontally from center fixation were marked as artifacts and rejected during offline analysis. VEP trials lasted 90 seconds, in which participants viewed 180 total presentations. Due to offline artifact rejection based on eye tracking data, VEPs were averaged over 37-90 trials. It appeared that participants experienced difficulty keeping their eyes open and fixated on the center cross during hypnotic sessions. Baseline VEPs were recorded prior to induction, and then experimental conditions were recorded following hypnotic induction and one of two suggestions; participants were either told that they would not see anything on the screen besides the fixation cross (Negative Suggestion type), or that there was a large object occluding their view of the screen (Positive Suggestion type). Eye tracking was monitored during recording sessions and participants were often reminded to fixate on the cross and keep eyes open when the eye tracking signal was lost or deteriorated.

Results

Amplitudes were normalized relative to the baseline conditions (pre-induction). Two amplitude indices were calculated for each color axis (one index per suggestion type), in which zero represented no change, and positivity signified that amplitudes elicited during experimental conditions (hypnotic suggestions) were smaller than those elicited during baseline conditions. One-tailed t-tests were performed on the indices to check for significant deviations from zero. The Achromatic indices revealed one significant change; the Achromatic Positive Suggestion index was significantly different than zero, t(3)=2.4, p= 0.049. The Achromatic Negative Suggestion index was not significantly different than zero however, t(3)=0.9, p=0.22. Neither of the Chromatic indices (Positive or Negative) revealed any significant effect of hypnotic suggestion (Positive: t(3)=0.87, p=0.23; Negative: t(3)=0.67, p=0.28). See Figure 7.

Figure 7. Experiment 4: Effect of Hypnotic Suggestion on VEP Amplitude.

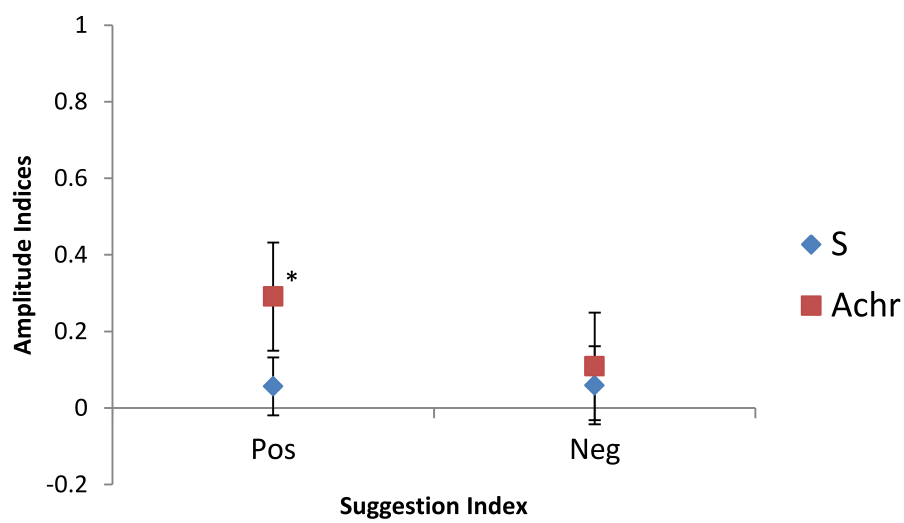

Figure 7. Results from Experiment 4; mean amplitude indices plotted by suggestion index. Diamonds represent C3-C2 amplitudes elicited by S gratings, while squares represent P100-N75 amplitudes elicited by achromatic gratings. The Achromatic Positive index was significantly different than zero, though no other measures reached significance.

The analyses listed above were performed on the first viable data set from each of the 4 participants. Subject #985 was able to return for a total of three hypnotic VEP sessions, though her first session was contaminated by eye-tracking artifacts and was therefore discarded. Even though there are only two complete datasets (t1 and t2), she was actually afforded three separate practice sessions, not including those afforded to her during Experiments 1-3. Though statistical analyses could not be performed on only two viable data sets, there appears to be a strong trend for this subject to demonstrate smaller signal amplitude for both the S and achromatic axes in the presence of hypnotic suggestion. Raw amplitudes obtained from this participant are plotted in Figures 8 and 9.

Figure 8**.** Experiment 4: Raw S VEP Amplitude Recorded from Participant #985.

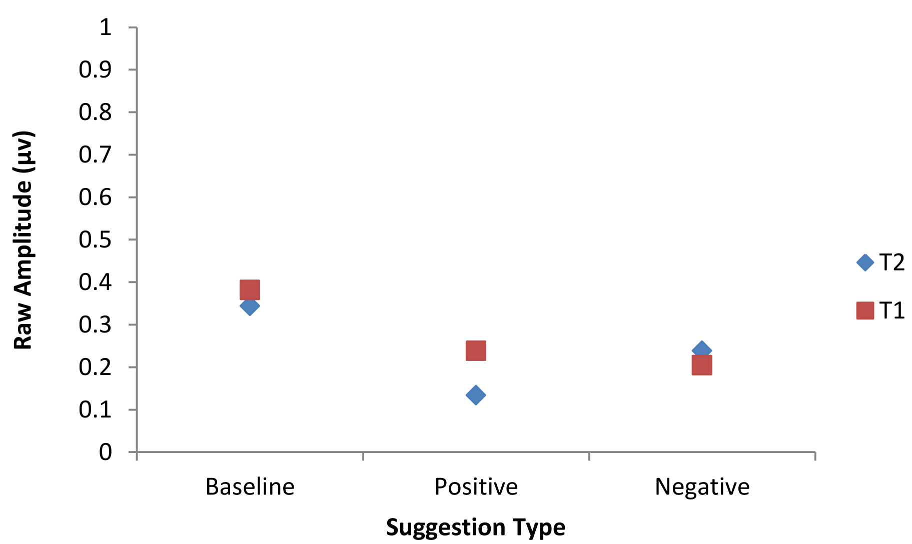

Figure 8. Raw amplitudes elicited by S gratings obtained from participant #985 during Experiment 4. T1 and T2 represent two separate testing sessions in which hypnotic practice was allowed.

Figure 9. Experiment 4: Raw Achromatic VEP Amplitude Recorded from Participant #985.

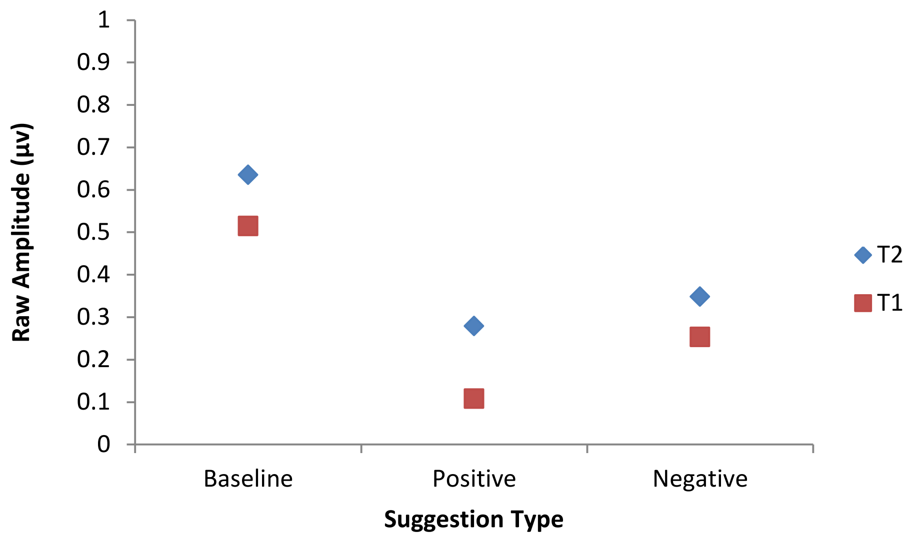

Figure 9. Raw amplitudes elicited by achromatic gratings obtained from participant #985 during Experiment 4. T1 and T2 represent two separate testing sessions in which hypnotic practice was allowed.

Discussion

Components of interest (C2) for the chromatic pattern-onset VEPs are typically thought to represent responses from lower levels of the visual system, i.e. primary visual cortex (V1), when recorded over the occipital cortex from Oz. Attention is one of the most studied forms of top-down modulation affecting visual processing, and results from these studies regarding activity in V1 have been rather inconclusive. Although fMRI literature in humans shows robust attentional modulation in V1 (Brefczynski & DeYoe, 1999; Buracas & Boynton, 2007; Murray, 2008; Silver, Ress, & Heeger, 2007), corresponding electrophysiological changes have proven harder to identify. Various investigations into single-unit activity in visual cortex have found contradictory results (Chen et al., 2008; Luck, Chelazzi, Hillyard, & Desimone, 1997; McAdams & Reid, 2005). Likewise, studies utilizing event related potentials (ERPs) report attentional modulation in extrastriate areas but little to no effect in visual cortex (Clark & Hillyard, 1996; Mangun, Hillyard, & Luck, 1993). The chromatic VEP has also been shown to be robust to such manipulations of attention, even though a significant effect was found on the achromatic VEP (Highsmith & Crognale, 2010). The current study aimed to assess any effect another form of top-down modulation may have on the chromatic VEP. Hypnotic suggestion was employed as an attempt to elicit top-down feedback from higher cortical areas to visual cortex, where the VEP was recorded. Suggestions regarding stimulus visibility were given, and it was predicted that these suggestions would not cause attenuation in the chromatic VEP signal, due to the lack of feedback influencing the chromatic signature, as demonstrated by Highsmith and Crognale (2010).

In Experiment 1 we found that the chromatic VEP was changed as a result of hypnotic induction, though hypnotizability did not appear to be a significantly contributing factor. Contrary to predictions based on manipulations of attention (Highsmith & Crognale, 2010), the achromatic VEP was not significantly changed. Following results from Experiment 1, Experiments 2 and 3 were designed to further expand upon the effects of hypnotic suggestions by utilizing them in different ways. Experiment 2 compared the effects of hypnotic suggestions of both positive and negative hallucinations. Results from Experiment 2 indicated that the positive suggestions may have a larger effect on chromatic VEP amplitude and therefore may be of more use for the current study, however both Experiments 2 and 3 were discontinued due to eye movement and closure artifacts; it appeared that participants became drowsy and experienced difficulty controlling their eye and eyelid movements following hypnotic induction. Experiment 3 was designed to test the selectivity of any feedback reaching early visual areas and contributing to the VEP when hypnotic suggestions only regarded one of two randomly interleaved stimuli. Results indicated that the hypnotic suggestion had no discernible effect on the chromatic or achromatic VEP signal. In Experiment 4 controls were used to account for eye movements and closures. After eye tracking control procedures were applied, it was found that hypnotic suggestion had a significant effect on the achromatic VEP but not the chromatic VEP.

The most valid comparison between conditions with and without eye tracking is that between the subjects of experiment 4 and those of the highly hypnotizable group of experiment 1. When compared to the highly hypnotizable group (High) from Experiment 1, Experiment 4 showed significantly more achromatic signal attenuation, $t(4)=3.3$, $p<0.05$, but differences between the chromatic VEP responses were insignificant, $t(6)=-1.5$, $p=0.1$ (see Figure 10).

Figure 10. Comparison of Results from Experiments 1 and 4.

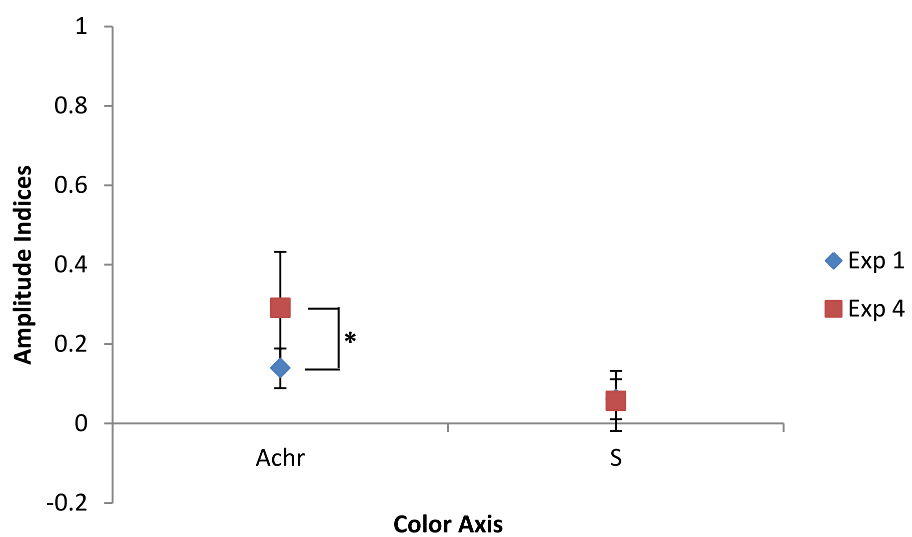

Figure 10. A comparison of the achromatic and S VEP amplitude indices from experiments 1 and 4. Experiment 4 data points represent mean amplitude indices for all 4 participants of Experiment 4. Experiment 1 data points represent mean amplitude indices for the High group of Experiment 1only. Error bars indicate +/- one SEM. *p<0.05.

Since chromatic data are so similar between the two experiments, it is likely that the effect of hypnotic suggestion on the chromatic VEP found in Experiment 1 was due to eye movement artifacts contributed by the Low and Sham groups, though the amount of trials rejected due to eye tracking artifacts in Experiment 4 was also noticeably extensive. Taken together and after accounting for eye movement artifacts, data from these four experiments indicate that any top-down feedback stemming from the presence of hypnotic suggestion seems to have an effect on amplitude of the achromatic VEP but not the chromatic VEP in highly hypnotizable participants.

The purpose of this project was to investigate any top-down feedback elicited by hypnotic suggestion that may have an effect on the VEP. Since the individual magnocellular and koniocellular geniculostriate pathways have been preferentially modulated by the achromatic and S VEP stimuli respectively, attenuation of one signal and not the other indicates that different amounts of feedback are reaching the two pathways in the case of hypnotic suggestion.

Similarities to Attention Data

These results from hypnotic suggestion are similar to those obtained from attentional manipulations (J. Highsmith & Crognale, 2010; Roth et al., 2011), in which the VEP signal elicited by achromatic stimuli was altered by reallocating attentional resources, but that of the signal elicited by chromatic modulations was not. Di Russo, Martinez and Hillyard (2003) reported that early ERP components (50-90ms) elicited by achromatic checkerboard presentations and recorded from v1 were robust to attentional manipulation, but later components (150-220ms) showed activity correlated with attention. Lauritzen, Ales, & Wade (2010) recently used source-imaged EEG to investigate any activity changes in V1 during attentionally demanding tasks. They reported activation stemming from area V1 that appears to be subject to primary response gain changes due to covert spatial attention, indicating that responses to attended stimuli were increased relative to non-attended stimuli. These data are in agreement with the current results and those of Highsmith and Crognale (2010), who found that the achromatic P100 component was significantly affected, as measured from the preceding negative deflection near 75ms (N75). Di Russo, Martinez and Hillyard (2003) theorized that the earlier components are simply too fast to be affected by feedback from higher sources. Together these results point to a potentially common source of feedback in both hypnotic and attentional manipulations, which could quite possibly be the intrapartietal sulcus, as indicated by previous results (Di Russo et al., 2003). These results would also predict that the C2 component of the chromatic VEP would also be affected as much, if not more, since its latency is typically slower than that of the P100 (Rabin et al., 1994), which would allow more time for any would-be feedback to reach V1. The fact that the C2 component is not affected by manipulations of attention or hypnotic suggestion even though it is later than the P100, supports the hypothesis that regardless of origin, different amounts of feedback appear to reach the independent chromatic and achromatic pathways within V1.

One possible explanation for this difference in feedback reaching early visual pathways is that the activity of color-responsive cells represented by the chromatic VEP may be stemming from a processing stage that is prior to the conscious perception of color. A recent case study reported a stroke patient who had significant damage to her primary visual cortex and surrounding areas (Crognale et al., 2012). FMRI scans indicated large amounts of damage surrounding the calcarine fissure, with enough remaining cortex to support foveal sparing but yielding a profound quadrantanopia. As a result the patient reported complete loss of color perception that gradually improved to partial loss. She reported seeing abnormal colors that were "tinted" brownish and her performance on color discrimination tasks was extremely poor. Yet when tested with the chromatic VEP along the S and LM directions, her waveforms indicated a healthy visual system with relatively no pathology. This lends support to the notion that the chromatic VEP is representative of activity taking place prior to conscious perception, and the visual system therefore may require less feedback to these cells than others that may contribute to perception more directly.

Identifying the Outlier

Data from one participant, #985, appears to show a trend that none of the other subjects have shown after accounting for eye closures and movements. It appears that hypnotic suggestion had an effect on both the achromatic and chromatic waveforms. This effect also appears to be consistent; since both hypnotic VEP sessions recorded for #985 (t1 and t2) demonstrated similar changes, and similar trends were observed in Experiments 1-3. This change most likely means one of two things; either participant #985 was able to improve her performance on the task with practice, or she was innately better at performing the task than others tested. It seems more likely that #985's performance was improved by practice given that improved task performance with practice is a common effect of hypnotic suggestion in clinical settings and has also been demonstrated experimentally (Bates, Miller, Cross, & Brigham, 1988; Sachs & Anderson, 1967). However, if this were the case, then it would be expected that amplitude would be more changed in t2 than in t1, but this does not appear to be true. Furthermore, there is no effect of practice needed or demonstrated in the MR imaging literature when testing mechanisms of attention. These observations are also inconsistent with the interpretation that attention and hypnotic induction affect sensory input in a similar manner or by a common mechanism. The alternative explanation is that Participant #985 possesses a heightened ability to perform the task. This could be due to a multitude of factors including but not limited to an increased ability to imagine the suggested scenario, or perhaps increased control over mechanisms of attention that may be underlying any effects of suggestion.

Either way, it appears that performance during Experiments 1-4 may be idiosyncratic. Although this is not in agreement with results from attentional VEP experiments (Highsmith & Crognale, 2010; Roth et al., 2011), it is not very surprising given the fact that hypnotism itself is quite idiosyncratic; some people are much more susceptible to hypnotism and hypnotic suggestion than others (Weitzenhoffer, 2000). It is quite possible that tasks requiring attentional manipulation are idiosyncratic to some degree as well. Before conducting the present study participants were screened for hypnotic susceptibility and only those that demonstrated superior performance (i.e. significant signal change) were asked to return for the succeeding experiments. If this type of screening were done before attention experiments, perhaps a few attentional “virtuosos” would outperform their counterparts as well.

Summary

Overall this evidence suggests that the chromatic VEP response may be generated in a lower-level area in the visual system such as V1, and feedback from higher visual areas do not appear to affect this response. Since the achromatic response presumably arises from the same location and shows effects of modulatory feedback, this suggests different amounts of feedback reaching the chromatic and achromatic pathways. This is an interesting finding since source localization has yet to be applied to this response and it is not fully understood which cells are contributing. These findings may provide some information about the source of this response, as well as mechanisms of top-down modulation that appear to reach some portions of V1 but not others. Furthermore, the mechanisms underlying top-down modulation from hypnotic suggestion and attention appear to have similar effects on the chromatic and achromatic VEP signatures, suggesting that these two forms of modulation may rely on the same or overlapping mechanisms.

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