ATTENDING TO PICTORIAL DEPTH:
ELECTROPHYSIOLOGICAL AND BEHAVIORAL EVIDENCE OF VISUOSPATIAL ATTENTION IN APPARENT DEPTH

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ATTENDING TO PICTORIAL DEPTH:
ELECTROPHYSIOLOGICAL AND BEHAVIORAL EVIDENCE OF
VISUOSPATIAL ATTENTION IN APPARENT DEPTH

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## GLOSSARY

<table>
<thead>
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<tr>
<td>°</td>
<td>Degrees of visual angle</td>
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<tr>
<td>cm</td>
<td>Centimeters</td>
</tr>
<tr>
<td>CMS</td>
<td>Common Mode Sense</td>
</tr>
<tr>
<td>dB</td>
<td>Decibel</td>
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<tr>
<td>df</td>
<td>Degrees of freedom</td>
</tr>
<tr>
<td>DRL</td>
<td>Driven Right Leg</td>
</tr>
<tr>
<td>EEG</td>
<td>Electroencephalography</td>
</tr>
<tr>
<td>EOG</td>
<td>Electrooculogram</td>
</tr>
<tr>
<td>ERP</td>
<td>Event-Related Potential</td>
</tr>
<tr>
<td>fL</td>
<td>Foot-Lamberts</td>
</tr>
<tr>
<td>Hz</td>
<td>Hertz</td>
</tr>
<tr>
<td>ms</td>
<td>Milliseconds</td>
</tr>
<tr>
<td>LED</td>
<td>Light-Emitting Diode</td>
</tr>
<tr>
<td>oct</td>
<td>octave</td>
</tr>
<tr>
<td>RT</td>
<td>Reaction Time</td>
</tr>
<tr>
<td>SE</td>
<td>Standard Error</td>
</tr>
<tr>
<td>VEP</td>
<td>Visual-Evoked Potential</td>
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<td>μV</td>
<td>Microvolt</td>
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SUMMARY

Visual attention has long been described in terms of the spotlight metaphor, which assumes that two-dimensional regions of the visual field are selectively processed. However, evidence suggests that attention can be distributed to depth in addition to two-dimensional space (Andersen & Kramer, 1993; Gawryszewski, Riggio, Rizzolatti, & Umiltà, 1987). Research supporting this idea has induced depth through binocular disparity. Thus, the results of previous research may be specific to stereoscopic stimuli and not apply generally to the perception of depth. Three experiments were conducted in order to determine if visual attention could be distributed to a non-stereoscopic apparent depth. In these experiments, the perceptual experience of depth was induced in a visual scene using only pictorial depth cues. Subjects were required to attend either a near or far depth in this scene. Experiments 1 and 2 employed electrophysiological recordings and found a reliable modulation in the amplitude of the attention sensitive visual component, P1, when subjects directed attention to far depths. Behavioral measurements in Experiment 3 supported this result, finding speeded reaction time to attended far depth stimuli. No P1 modulation or reaction time facilitation was found when the pictorial depth cues of the visual scene were attenuated. These results suggest that visual attention may be distributed to pictorial depth and are further consistent with a viewer-centered asymmetry in attending to depth.
CHAPTER 1
INTRODUCTION

Traditional theories of visual attention (i.e., spotlight theories) hold that selective processing of the visual field is based on two-dimensional regions of space (Posner, 1980; Posner, Snyder, & Davidson, 1980). This conclusion is not unfounded since the retina can be considered a two-dimensional structure, and the cortical representation of space is retinotopic at least through intermediate stages of visual processing. The problem with such theories is that they cast aside the importance of depth information. That is, spotlight theories assume that selection occurs only in two-dimensional space, and cannot be allocated differentially to depth.

When one looks at a painting, photograph, or even line drawing, the impression of depth is inescapable. The visual system evolved in a three-dimensional world and its development occurs in a three-dimensional world. Because of the pervasiveness of depth in our experience of the world, it seems logical that a mechanism as fundamental as visual attention would incorporate depth rather than being strictly limited to two-dimensional selection. A number of studies have provided evidence that visual attention can be distributed in depth (e.g., Andersen & Kramer, 1993; Arnott & Shedden, 2000; Gawryszewski, Riggio, Rizzolatti, & Umiltà, 1987; He & Nakayama, 1995; Marrara & Moore, 2000). These studies indicate that the distribution of visual attention is not limited to two-dimensions. However, the majority of research of attention in depth has been conducted using stimuli cued to be in depth solely or conjointly through binocular disparity. Though the findings of these studies have supported the view that attention can
be distributed in depth, the results obtained may be specific to stereoscopic perception and may not necessarily apply generally to the perception of depth. If attention can truly be distributed to depth then effects of attention should be present in any display in which depth is perceived, not just those in which depth is cued by stereopsis.

In order to determine whether attention may be distributed to a perceived depth, the current investigation required subjects to attend to depths defined solely by pictorial cues. Such displays remove all stereoscopic depth information. Three experiments were conducted to test the idea that attention may be distributed to a pictorial depth. Experiments 1 and 2 examined effects on the attention sensitive components P1 and N1 of the visual evoked potential (VEP). Experiment 3 employed a similar paradigm to that of Experiments 1 and 2 but assessed attentional effects through the behavioral measure of reaction time (RT). All three experiments relied on sets of planned comparisons to assess electrophysiological and behavioral effects of attending to pictorial depth. Planned comparisons in Experiments 1 and 2 evaluated attended and unattended amplitudes of the P1 and N1 components of the VEP. Planned comparisons in Experiment 3 tested differences in attended and unattended RT.

Prior to the presentation of experimental results, a brief review will be given to the following topics: theories of visual attention, attentional effects of event-related potentials, and visual attention in depth.

1.1 Theories of Visual Attention

Among the most influential works in visual attention research was a study conducted by Posner, Snyder, and Davidson (1980). In their study subjects maintained
central fixation and were required to respond to the presentation of a target appearing in
either the left visual field (LVF) or right visual field (RVF). Before presentation of the
target, one visual field was cued by a brief flash which was either predictive (.8
probability) or nonpredictive (.5 probability) as to the upcoming location of the target.
Reaction times (RTs) were found to be faster when a visual field was validly cued as
opposed to when the cue was invalid or all locations were equally probable (i.e.,
nonpredictive). Since subjects were required to maintain central fixation, RT differences
were not attributable to saccades to validly cued locations. Posner, Snyder, and Davidson
theorized that this speeded RT was due to the allocation of attention to the cued location.
They further proposed that the movement of attention to the validly cued location
assumed a form analogous to that of a spotlight. Specifically, this “spotlight” assumed
some geometric configuration and was capable of moving about the visual field.
Furthermore, visual processing was assumed to be most efficient within the limits of this
spotlight.

Other researchers have since expanded on this spotlight metaphor and suggested
somewhat more complex configurations of the region of attentional enhancement.
Downing and Pinker (1985) proposed that the spotlight of visual attention has a gradient
such that processing at the central focus of attention is most efficient and this degrades
with eccentricity from the focus of attention. Eriksen and Yeh (1985) theorized that the
focus of visuospatial attention may vary in size. Their “zoom-lens” model of attention
suggests that the focus of visuospatial attention may be adjusted to encompass the entire
visual field (in which case processing is less efficient) or constricted to smaller areas of
more detailed processing. Rather than a single spotlight, others have argued for the
existence of multiple spotlights that may simultaneously select different regions of the visual field (Awh & Pashler, 2000).

The spotlight models of attention discussed above all succumb to a common limitation: two-dimensional selection. Visual information is transduced into neural activity by a two-dimensional retinal input, and spotlight models assume that directing attention to space is accomplished by selecting some two-dimensional region of the visual field for enhanced processing. Such low-level models of selection ignore the elaborate perceptual experience that arises from visual input. In contrast to spotlight theories, object-based theories of visual attention propose that mechanisms of selection operate at a higher level of processing, where representations of objects have already been formed.

Duncan (1984) showed that performance in identifying features of objects was better if identification of these features occurred within the same objects, and performance decreased significantly if feature identification had to be spread between two objects. This occurred even though the two objects occupied a small region of space (1°) – an area deemed too small to be accounted for by a spotlight model. From this finding Duncan proposed that attention is capable of acting upon object representations rather than simply regions of the visual field. Vecera and Farrah (1994) supported this object-based account, though they further proposed the possibility that object-based attention may not necessarily act on an object representation per se, but instead this selection may occur by means of a flexible spotlight exactly outlining an object (a grouped array representation).
An important aspect of the environment which is overlooked by both spotlight and object-based theories of attention is that of depth information. The visual system evolved in a three-dimensional world as a means to provide organisms with the ability to efficiently navigate through the environment. However, spotlight theories cast aside depth information by assuming two-dimensional selection of visual field regions. Object-based theories assume depth information has been processed but make no direct claim regarding how attention is distributed to depth. It is necessary to understand how attention interacts with depth for a complete and ecologically valid theory of visual attention to be developed.

### 3.2 Attention and the Visual Evoked Potential (VEP)

Electroencephalography (EEG) is a non-invasive method of recording the electrical potentials generated by ongoing neural activity of the brain. Time-locking and averaging EEG to the onset of some stimulus results in what is termed the event-related potential (ERP). Through direct measure of neuroelectric potentials, ERPs provide a method of assessing neural activity with high temporal fidelity (millisecond resolution). Furthermore, by time-locking ongoing EEG, the ERP reveals neural processes directly associated with a particular stimulus or psychological event (see Regan, 1989). Neural activity within an ERP waveform is evaluated through analysis of positive and negative voltage fluctuations (components) across time. Nomenclature of these components often follows a convention in which each component is labeled according to its polarity and serial position within the ERP waveform. For example, the first positive component in an
ERP is termed the ‘P1’ component, whereas the first negative component would be called ‘N1’.

When an ERP is elicited by a visual stimulus it is termed a visual-evoked potential (VEP). The components present in a VEP vary depending on stimulus and task parameters, but the obligatory (and most well-described) VEP components include the C1 (50-90 ms), P1 (80-130 ms), and N1 (140-200 ms) components. The C1 component does not follow typical naming convention since its polarity reverses between upper and lower visual field stimuli – a result of its generator being located along the walls of the calcarine fissure (Jeffreys and Axford, 1972a,b). The C1 is thought to reflect early visual processing within the striate cortex (Jeffreys and Axford, 1972a,b). The P1 component arises from a later stage of visual processing and its generator has been localized to dorsal and ventral extrastriate cortex (Di Russo, Martinez, Sereno, Pitzalis, & Hillyard, 2001). Neural generators of the N1 component are less well defined but contributions appear to arise from frontal, parietal, and extrastriate occipital regions (Clark & Hillyard, 1996; Di Russo, Martinez, Sereno, Pitzalis, & Hillyard, 2001).

The C1 component is unaffected by visuospatial attention (Clark & Hillyard, 1996). However, the P1 and N1 components have been shown to modulate reliably under attentive conditions. That is, P1 and N1 amplitudes increase when a stimulus is attended as compared to that same stimulus when it is ignored. Eason (1969, 1981) was the first to describe attentional effects of the P1 and N1 components. In Eason’s paradigm, subjects responded to stimuli presented in one visual field (relevant) while ignoring those presented in the other visual field (irrelevant). Eason’s results showed P1 and N1 amplitudes for relevant stimuli to be significantly greater than P1 and N1 amplitudes in
response to the identical stimuli when they were irrelevant. The amplitude enhancement of P1 and N1 is most prominent over posterior electrodes on the side of the head contralateral to the stimulus and has little effect on the latencies or scalp distributions of the two components. This amplification of P1 and N1 components has been shown to be consistent under a variety of spatial attention tasks (for review see Luck, Woodman, & Vogel, 2000; Mangun, 1995).

Effects of attention on P1 and N1 amplitudes have been proposed as evidence for an attentional mechanism of sensory gain control (Hillyard, Vogel, & Luck, 1998; Posner & Dehaene, 1994). Gain control refers to an amplification of neural activity in sensory areas under attentive conditions (Hillyard, Vogel, & Luck, 1998). Furthermore, since the C1 component reflects early visual processing within area V1 and shows no effects of attention, the modulation of P1 and N1 indicate that attentional selection occurs later in the stream of visual processing, beginning in extrastriate regions.

Effects of attention on the VEP are not strictly limited to that of the P1 and N1 components, but may also arise in a number of other components depending on task and stimulus parameters. Non-spatial attention tasks elicit entirely different electrophysiological effects from the P1 and N1 effects present in spatial attention tasks. When attention is directed to a feature (e.g., color or spatial frequency) rather than a region of space, a broad negative component emerges over occipital-temporal electrode sites. This component has been termed selection negativity (SN) and arises between 150 and 300 ms post-stimulus (Harter & Aine, 1984). SN has been taken as evidence for late selection of non-spatial features. The importance of the distinction between spatial and
nonspatial feature effects on the VEP will become apparent in the experimental design of the studies presented here.

3.3 Attending to Depth

The majority of visual attention research has concentrated on describing the properties of visuospatial attention in two-dimensional space. However, a small number of studies have found evidence suggesting that visuospatial attention does not simply involve selection of two-dimensional space, but rather interacts to a high degree with depth information. The following sections review those studies which have examined the role of visuospatial attention in depth through binocular and monocular depth cues.

3.3.1 Attending to Binocular Depth

Gawryszewski et al. (1987) were among the first to examine whether visual attention could be directed to depth. In their paradigm, subjects were situated in front of a platform upon which light-emitting diodes (LEDs) were positioned at three depths from the observer (19, 38, and 57 cm). The LED at the middle depth (39 cm) served as a fixation point and was continuously visible. This fixation point further served as a cue as to the upcoming location of a target at the far (57 cm) or near (19 cm) depths. An arrow appearing at the fixation LED cued with high probability (.8) the depth at which the target would appear. Another fixation cue (cross) indicated that both depths were equally likely. Subjects were tasked responding to the illumination of a near or far LED. The results of Gawryszewski et al. showed that a valid cuing of depth resulted in significantly faster RTs than either invalid or neutral cues, suggesting that attention is capable of being
allocated differentially to depth. Gawryszewski et al. further found that attentional cost (invalid RT - neutral RT) was greater when attention had to be switched from a near depth to far depth as opposed to switching from far to near. This result was interpreted as the existence of an asymmetry in the distribution of visual attention to depth. Specifically, it was suggested that this asymmetry was viewer-centered such that attentional resources are greatest between the observer and focus of attention, and are lessened beyond the focus of attention. Although this experiment provides great insight into the distribution of visual attention to depth, it should be noted that the design is such that depth and retinal location are confounded. A spotlight model may still be able to account for these data since targets are always presented at different regions of the visual field.

A number of researchers since Gawryszewski et al. (1987) have found evidence that visuospatial attention may be allocated to depth. Unlike Gawryszewski et al. (who used real depth), most of these researchers have induced depth relationships between stimuli using solely stereoscopic displays. Andersen and Kramer (1993) found such evidence using a stereoscopic flanker task. In their task the subject was to respond to the presentation of a central target (X or O) flanked by either consistent or inconsistent distractors. Consistent distractors were the same letter as the target whereas inconsistent distractors were the opposite letter. These distractors were presented such that they appeared at one of four stereoscopic depths: no depth, near depth, intermediate depth, or far depth. RT to the central target was found to be speeded when the flanking distractors were separated in depth from the target. Furthermore, attentional cost was found to be significantly greater when distractors were at a depth beyond the target compared to
when the distractors were in depth between the target and the observer. In accordance with Gawryszewski et al. (1987), these results suggested an asymmetry in the gradient of attention such that the attentional gradient is steeper past the focus of attention and less steep between the viewer and the focus of attention (viewer-centered).

Arnott and Shedden (2000) confirmed findings of a viewer-centered attentional asymmetry to depth but further proposed that this asymmetry was dependent on the observer’s attentional load. In their paradigm (Experiment 3) subjects were presented with a stimulus of depth in an autostereogram under low or high attentional load conditions. In the high load condition, the autostereogram was constructed such that fusion would result in the perception of a circle stimulus with a gap in its side. For two seconds the subject would be presented with one such circle stimulus. Directly after the first circle, a second circle was presented for 200 ms, having a gap orientation the same or different from the first circle. These two circle stimuli were presented at one of five depths such that it was either required to switch attention from a far stimulus to a near stimulus, from a near stimulus to a far stimulus, or not to switch between depths at all. The task of the subject was to detect whether the gap orientation was the same or different between the two circle stimuli. The low load condition was very similar to the high load condition but required subjects to differentiate highly discriminable horizontal or vertical rectangles. Under the high load condition, Arnott and Shedden found speeded RTs when attention was switched from a far to near depth compared to a near to far depth. This indicated the same viewer-centered asymmetry in the attentional gradient to depth described in previous research (Andersen & Kramer, 1993; Gawryszewski et al. 1987). However, in the low perceptual load condition no such asymmetry was
discovered. In line with previous ideas of the dependence of perceptual load on selective attention (Lavie, 1995), Arnott and Shedden (2000) showed that visual attention to depth may also be dependent on perceptual load.

He and Nakayama (1995) took a different approach to the allocation of visual attention to depth (see also Nakayama, Shimojo, & Silverman, 1989). They suggested that attention is applied to surfaces of particular depth plane as opposed to a gradient which extends to a depth. In a visual search paradigm, observers were tasked with finding the odd element at the middle depth among a three-dimensional search matrix consisting of three depths each with 4×3 elements. In order to find a distinction between attentional allocation to depth and that to a surface, the elements of the three-dimensional search array were slanted in depth such that they retained the same average disparity value but no longer were perceived to form a surface. When these elements were oriented in this way such that surface perception is lost, the RTs to find the odd element significantly increased compared to when the elements formed a perceivable surface. This result is obtained even though the elements fall at the same disparities. This suggested that depth alone is not sufficient for attentional allocation, but in addition there must be the presence of some well-formed surface (however, see Marrara & Moore, 2000). This idea is of interest to the current investigation since it may suggest an incorporation of pictorial depth information (relationships between objects) into the distribution of attention to depth.

Little research of attending to depth has been conducted using electrophysiological measures. However, Kasai, Morotomi, Katayama, and Kumada (2003) found evidence of modulation of the early sensory components P1 and N1 when
examining the interaction of visual attention with 2-D location and stereoscopic depth. While maintaining central fixation, subjects were given a stereoscopic display containing targets which varied by 2-D location (left or right of fixation), depth (near or far), and shape (triangle, oval, diamond, or square). For a given block subjects were assigned to pay attention to one combination of these features (e.g., far right triangle). Throughout the block, stimuli of all combinations were presented, but appeared in the assigned combination of features with higher probability that the other stimuli. EEG was recorded throughout the presentation of these stimuli and ERPs were calculated for each stimulus type. Results revealed that P1 and N1 components were enhanced when attending to a two-dimensional location (the typical finding). Furthermore, P1 enhancement was found to be greater when stimuli were presented in depth such that they appeared closer to the observer. Interestingly, N1 amplitude modulations were found to be greatest for stimuli farther from the observer’s fixation point (the antithesis of the P1 effect). These findings suggest that the type of amplitude amplification seen in early sensory components (P1 and N1) when attending to a two-dimensional location may also be found when attention is directed to depth. The findings of Kasai et al. may also point toward a neural correlate of the viewer-centered asymmetry described by Gawryszewski et al. (1987).

The research reviewed above investigated the distribution of attention to depth through the use of stereoscopic stimuli. Many of these studies reported a viewer-centered asymmetry in the distribution of attention to depth (Andersen & Kramer, 1993; Arnott & Shedden, 2000; Gawryszewski et al., 1987). However, since stimuli were always presented in disparity, the described asymmetries may only be found in stereoscopic depth. Specifically, these results may be attributable to a difference in crossed versus
uncrossed disparity rather than an effect due to depth in general. For this reason it is important to explore attention in non-stereoscopic depth.

### 3.3.2 Attending to Monocular Depth

Most research of attention in depth has been conducted using stereoscopic stimuli to give the impression of depth. This approach has provided insight into the properties of attention in depth, but does not tell a complete story since findings may be specific to stereoscopic stimuli and are often plagued with confounds of oculomotor depth cues (e.g., convergence and accommodation). Binocular disparity is an important depth cue, but depth information is not conveyed solely in this manner. Rather, pictorial depth cues provide additional depth information which is sufficient for the perception of depth even in the absence of stereopsis. To date, little research has been conducted to examine the behavior of attention in pictorial depth (i.e., depth induced by pictorial cues). Some visual search results have shown the pop-out of a target to be influenced by the presence of pictorial depth cues (Aks & Enns, 1996) and pictorially-defined surfaces (Morita & Kumada, 2003). However, a study conducted by Downing and Pinker (1985) is of most relevance to the current investigation.

Downing and Pinker (1985) examined the possibility that attention may be distributed to monocular depth by having observers respond to LEDs viewed through a single eye. An array of four LEDs formed the possible target locations and a fifth LED served as fixation. The four target LEDs were at two possible depths: near (101 cm) or far (171 cm). Between sessions these target LEDs were positioned such that half of them were at each depth, or all of them fell at the near depth. The fixation LED was always
located at the same position (127 cm from the subject). At the beginning of a trial, the fixation LED would display a number from 1 to 4 which indicated the target position with high probability (.8). Alternatively, the LED would display a ‘0’, which indicated that all targets were equally probable. The attentional cost was found to be greater if attention had to be switched between depths. That is, when attention was directed to one depth, it required the subject longer to respond if the target were to occur at the other depth. The data of Downing and Pinker also suggested the existence of an asymmetry in the distribution of attention to monocular depth. Although not significant, the pattern of this asymmetry was similar to that described by Gawryszewski et al. (1987). That is, the cost of switching attention from a far depth to a near depth was less that switching attention from a near depth to a far depth. Thus, under cyclopean conditions, it appears that attention may be distributed to depth, and this distribution appears to be asymmetric in the same viewer-centered nature as discovered under stereoscopic conditions (Andersen & Kramer, 1993; Gawryszewski et al., 1987). It should be noted that although subjects from Downing and Pinker (1985) only viewed stimuli with a single eye, the oculomotor depth cue of accommodation could still have played a role in their results.

Although the examination of attention to monocular depth is quite under-developed, results indicate that it is indeed possible to distribute attention to depth in the absence of binocular depth information (Downing & Pinker, 1985). Furthermore, these results hint at the existence of an attentional depth asymmetry similar to that observed with stereoscopic stimuli. The investigation presented here conducted three experiments to examine whether attention may be distributed to pictorially defined depth. Such a finding would indicate that visuospatial attention to depth occurs relatively late in the
stream of visual processing, after depth information based on object relationships has been integrated. Experiments 1 and 2 employed an electrophysiological technique in which attentional enhancement was indexed by modulation of P1 and N1 components of the visual evoked potential. Experiment 3 investigated the aforementioned hypothesis through the behavioral measure of reaction time.
CHAPTER 2
EXPERIMENT 1

Behavioral and electrophysiological evidence have shown that visual attention may be distributed in binocular depth (Andersen & Kramer, 1993; Gawryszewski et al., 1987; He & Nakayama, 1995; Kasai et al., 2003). Some evidence further suggests that this may also exist in monocular depth (Downing & Pinker, 1985). Experiment 1 was designed to determine whether attending to pictorial depth could be indexed by modulation of the P1 and N1 components of the VEP. Subjects performed a sustained attention task in which they were required to attend and respond to targets presented on surfaces at different apparent depths. Attentional modulation of P1 and N1 components was assessed through a set of planned contrasts, comparing P1 and N1 amplitudes between attended and unattended conditions.

2.1 Method

2.1.1 Subjects

Sixteen undergraduate students (4 females, ages 18-25) were recruited from the Georgia Institute of Technology undergraduate psychology pool and received $10/hr compensation for their participation in the study. All subjects had normal or corrected-to-normal vision. Two subjects (both males) were subsequently dropped due to poor task performance (overall accuracy below two standard deviations from the mean).

2.1.2 Stimuli
The stimuli consisted of a background designed to induce depth through a combination of pictorial cues (linear perspective, occlusion, transparency, relative size, and compression). The perceptual experience of this background was such that it appeared as a long “hallway” extending in depth away from the observer. Overlaid on this background were two semitransparent rectangular surfaces (Figure 1).

![Figure 1. Example of the depth-inducing stimuli used in Experiment 1. Alternatively, the Near surface could be red.](image)

One surface subtended 23.0° of visual angle across and 4.3° in height. Centered within the area of this surface was a second, smaller surface measuring 11.5° by 2.2° of visual angle. The semitransparent nature of these two surfaces was such that when presented in the context of the depth-inducing background, the larger surface appeared to be closer in depth to the observer and the smaller surface farther away. These surfaces will be termed Near and Far, respectively. Each surface was colored either green or red but both surfaces
were never the same color\textsuperscript{1}. For example, if the Near surface were green then the Far surface would be red (Figure 2). Surface color was counterbalanced across blocks of trials. Additionally, a fixation point (cross) measuring $0.5^\circ \times 0.5^\circ$ was centered on the display. See Figure 2 for luminance values of the display.

![Figure 2. Luminance and visual angle values for the background and surface stimuli of Experiment 1. Luminance values are given in foot-lamberts (fL).](image)

Both the Near and Far surfaces had a pair of tick marks to the left and right of fixation. Between these tick marks, vertically or horizontally oriented targets were

\textsuperscript{1} It should be noted that the Far surface was never purely red or green. Due to the semitransparency of the Near surface, the Far surface was always a red/green mixture. Rather, the Far surface appeared to be red or green.
flashed for 100 ms. These targets appeared at one of two apparent depths (Far or Near) and in either left or right visual field. The size, luminance, and color of these targets varied depending on condition (Figure 3). Physical properties of targets varied in order to induce the experience of targets appearing on either the Far or Near surface. That is, Far targets were smaller and dimmer in luminance to appear as if they were being flashed on the Far surface. An important aspect of the Far and Near surfaces was their semitransparency. This allowed Near and Far targets to be presented such that they overlapped in two-dimensional space, thus removing confounds of attending to a two-dimensional location. Physical differences between Far and Near targets are detailed in Figure 3.

<table>
<thead>
<tr>
<th></th>
<th>Near</th>
<th>Far</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>1.4°×1.4°</td>
<td>0.8°×0.8°</td>
</tr>
<tr>
<td>Luminance (fL)</td>
<td>9.0</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Figure 3. Far and Near targets differed in their physical properties in order to induce the perception of targets appearing at Far or Near depths. There were two types of Far targets because the Near surface could be either red or green. Luminance values are given in foot-lamberts (fL).
2.1.3 Procedure

In a sound attenuating and electrically shielded room, subjects were positioned in a chinrest situated 57 cm from a 21-inch computer monitor. The subject’s task was to direct attention to a single depth (i.e., Far or Near) and perform a simple orientation discrimination on targets appearing at that depth. Thus, one depth was attended while the other was ignored. At the beginning of each block of trials, subjects were assigned a depth to attend through written instructions and visual aids. The fixation point served as a further cue which was continuously available to the subject. If Near was to be attended, the fixation point was bright and appeared as if on the Near surface. If the Far was to be attended, the fixation point was dimmer and appeared to fall on the Far surface.

The orientation discrimination task was performed by pressing an appropriate key on a keyboard number pad. The subject pressed ‘1’ if the target was of vertical orientation and ‘2’ if the target was of horizontal orientation. No response was to be given for targets which appeared at the unattended depth.

Individual trials consisted of a random delay of between 400 and 550 ms after which time a target flashed at either the attended or unattended depth for 100 ms. Targets were presented at the attended depth with a probability of .7 and at the unattended depth with a probability of .3. A period of 1000 ms then elapsed, during which time responses occurred. See Figure 4 for an illustration of the trial sequence.

Subjects were given four practice blocks of 100 trials during which they received feedback on their performance. These practice sessions were followed by eight blocks of 200 experimental trials. In four of these blocks subjects were assigned to attend Far and in four they were assigned to attend Near. The order of these blocks was randomly
determined. Subjects were instructed to look directly at the central fixation cross throughout testing. Furthermore, they were told to blink only when necessary in order to reduce the degree of ocular artifact in the electrophysiological data. Data recorded during practice sessions was excluded from electrophysiological analyses.

2.1.4 Electrophysiological Recording and Analyses

Electrophysiological data were recorded using a BIOSEMI Active-Two amplifier system. Scalp potentials were recorded from 32 electrode sites according to a modified 10-20 system. Standard 10-20 locations were electrodes FP1, FP2, F7, F3, Fz, F4, F8,
C3, Cz, C4, P7, P3, Pz, P4, P8, T7, T8, O1, Oz, and O2 (Jasper, 1958). Additional 10-10 electrode sites were AF3, AF4, FC1, FC2, CP1, CP2, PO3, PO4, FC5, FC6, CP5, and CP6 (Nuwer et al., 1998). In accordance with convention, odd numbered electrode locations refer to left-hemisphere sites, even numbered locations refer to right hemisphere sites. Vertical electrooculogram (EOG) was calculated offline as the difference between electrodes positioned above and below the left eye. Horizontal EOG was calculated offline as the difference between electrodes positioned on the outer canthi of the left and right eyes. Two additional electrodes served as reference and ground electrodes. These electrodes were the common mode sense (CMS) and driven right leg (DRL), respectively. EEG was digitized at 512 samples per second and band-pass filtered online .16-100 Hz. Additional digital filtering was done offline using a low pass 30 Hz zero phase shift Butterworth filter (12 dB/oct) and a 60 Hz notch filter (12 dB/oct). Continuous EEG was epoched into 1000 ms segments beginning 200 ms prestimulus and persisting 800 ms poststimulus. Horizontal and vertical ocular artifacts were corrected in each segment according to the Gratton and Coles (1983) ocular correction procedure. Additional artifact correction was conducted by rejecting segments from all channels containing activity greater than 100 µV and less than -100 µV. Segments were baseline corrected by setting the average of the 200 ms prestimulus baseline to zero. Subject averages for each condition were formed by collapsing ipsilateral electrodes and contralateral electrodes across left and right visual fields. Resulting grand average waveforms at ipsilateral and contralateral posterior electrode sites are displayed in Figure 5 at occipital (O1/2), occipital-temporal (P7/8), and parietal-occipital (PO3/4) electrode sites. All component measures and statistical analyses were performed on collapsed waveforms at electrode
P7/8. This electrode was chosen as the focus of analyses since previous research has found attentional effects of the P1 and N1 components to be most apparent at occipital-temporal electrode sites (Heinze et al., 1994; Hillyard et al., 1998).

At ipsilateral and contralateral P7/8, the P1 and N1 components were defined as the average of eleven data points (approximately 22 ms) centered at the largest voltage of appropriate valence within a particular time window (P1: 100-160 ms, N1:160-220 ms). P1 and N1 time windows were chosen according to their respective time course in the grand average waveform of all conditions. Planned contrasts were employed to assess attentional differences in the P1 and N1 components. Paired-samples t-tests compared attended and unattended amplitudes separately for P1 and N1 components and Far and Near targets. This was carried out for ipsilateral and contralateral P7/8. For all contrasts, an alpha value of p < .05 was used to determine significance. Table 1 details the planned contrasts performed on the P1 and N1 components in Experiment 1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Contralateral P7/8</th>
<th>Ipsilateral P7/8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Attended</td>
<td>Unattended</td>
</tr>
<tr>
<td>Far</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>I1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Near</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>I2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note. The planned contrasts listed above were conducted for both P1 and N1 components. The letter ‘C’ in the contrast name denotes contralateral electrode P7/8 whereas ‘I’ denotes ipsilateral electrode P7/8. ‘1’ and ‘2’ in the contrast name refer to Far and Near targets, respectively.
Figure 5. Grand average waveforms elicited by Far and Near targets of Experiment 1. Waveforms are displayed for ipsilateral and contralateral hemispheres at three posterior electrode sites (O1/2, P7/8, PO3/4). Components P1, N1, P2, and P3b of the visual-evoked potential are identified at prominent locations. Note the P1 amplification visible at ipsilateral P7/8 for attended Far targets.
2.2 Results

Grand average plots of attentional effects for Far and Near targets are displayed in Figure 5. Results from planned comparisons for P1 and N1 components elicited by Far and Near targets are detailed in Table 2. Significant effects of attention were found in both P1 and N1 components, but differed depending on target depth.

2.2.1 Far

Planned contrasts on the P1 component showed a significant effect of attention on the P1 at ipsilateral electrode site P7/8 (t(13)=3.78, p<.01). This effect was such that ipsilateral P1 amplitude was greater under attentive conditions, supporting the hypothesis that attention may be distributed to pictorial depth (Table 2; Figure 6).

Planned contrasts on the N1 component showed no significant effects of attention at ipsilateral or contralateral P7/8 (Table 2; Figure 6).

Table 2. Experiment 1 Results From Planned Contrasts on P1 and N1 Components at Electrode P7/8

<table>
<thead>
<tr>
<th>Contrast</th>
<th>P1</th>
<th>N1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t-value</td>
<td>alpha</td>
</tr>
<tr>
<td>Far</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>+1.04</td>
<td>n.s.</td>
</tr>
<tr>
<td>I1</td>
<td>+3.80</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Near</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>-1.41</td>
<td>n.s.</td>
</tr>
<tr>
<td>I2</td>
<td>+1.08</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Note. The + and – signs of the t-value indicate the direction of the attentional effect. For P1, ‘+’ indicates amplitude was greater in the attended condition. For N1, ‘+’ indicates amplitude was greater in the unattended condition. ‘n.s.’ denotes the contrast was non-significant. All contrasts used a p-value of <.05 to determine significance. For all contrasts, df = 13.
Figure 6. Attended and unattended P1 and N1 amplitudes at contralateral and ipsilateral electrode P7/8. P1 and N1 amplitudes are shown for both Far and Near targets. A red asterisk denotes a significant difference at the .05 level. All error bars depict 1 SE.
2.2.2 Near

Planned comparisons found no significant differences in the P1 component for Near targets (Table 2; Figure 6).

A surprising effect of attention was present for the N1 component. Grand average plots and planned comparisons revealed N1 to be of greater amplitude when Near was unattended (Table 2; Figures 5 & 6). This effect was significant at ipsilateral P7/8 (t(13)=2.71, p<.05).

2.2.3 Unanalyzed Components

It is obvious in the grand average waveform plots that effects exist in two later positive components – the P2 and P3b components (Figure 5). These effects are further present in all conditions of Experiment 2. Since the focus of the current investigation is on the effects of the P1 and N1 components, no statistical treatment was given to the P2 or P3b. However, from visual inspection of grand average waveforms it is apparent that the P2 component increased in amplitude when the target depth was unattended (at least for Near) and the P3b component showed increased positivity under attentive conditions. This effect in the P2 component was unexpected and cannot be explained by the current investigation. The effect on the P3b component arises from the task demands of the experiment. The P3b is a well studied component which has been shown to increase in amplitude when detecting a task-relevant stimulus (Donchin & Coles, 1988; Duncan-Johnson & Donchin, 1984). The current experiment required subjects to detect targets appearing at a particular apparent depth, which undoubtedly resulted in such a P3b effect. Since these P2 and P3b effects do not bear critically on the current hypotheses, they will
not be examined further. However, the surprising P2 modulation may warrant further investigation.

2.3 Experiment 1 Discussion

Electrophysiological effects of attending to pictorial depth were present in P1 and N1 components, but differed depending on the perceived depth of targets. Of particular interest to the current investigation was the presence of an increased ipsilateral P1 amplitude when the Far depth was attended. This finding indicates that attention may be allocated to pictorial depth (as indexed by P1 amplification). However, the absence of this effect from Near targets further suggests that the distribution of attentional resources in depth is not uniform. Specifically, the lack of P1 modulation in Near stimuli is consistent with an attentional depth asymmetry (Andersen & Kramer, 1993; Gawryszewski et al., 1987). That is, distributing attention to a far depth may also enhance depths between the observer and attended depth.

Since the physical parameters of Far and Near targets differ, an alternative interpretation of the P1 effect is that it arises due to feature selection rather than attending to pictorial depth. This possibility was explored in Experiment 2, but is unlikely since electrophysiological investigations of feature selection report no P1 effects but rather are associated with a later negative component termed selection negativity (Hillyard, Teder-Sälejärvi, & Münte, 1998).

No N1 effects were present for Far stimuli. However, significant N1 differences were present for Near stimuli such that unattended Near targets were found to have greater N1 amplitude in both contralateral and ipsilateral electrodes. The cause of this
effect is unknown, but may relate to a mechanism of attentional capture. The relation of 
this effect to depth was explored further in Experiment 2.

A result deserving further investigation relates to the ipsilateral nature of the P1 
component. Typically, a P1 elicited by a visual stimulus shows a large amplitude in 
contralateral posterior electrodes followed by a smaller and later latency ipsilateral P1. 
Furthermore, attentional effects on the P1 component are typically greatest in 
contralateral electrodes. In the current experiment, the later ipsilateral P1 was of greater 
amplitude than the earlier contralateral P1. This was the case for both Far and Near 
targets (Figure 5). Also, the attentional P1 effect found for Far depth targets was present 
only for ipsilateral P1. The reason for this is unknown, but an attempt to further 
investigate this finding was made in Experiment 2.
CHAPTER 3
EXPERIMENT 2

The results of Experiment 1 revealed effects of attention in both the P1 and N1 components. P1 enhancement was found in response to Far stimuli whereas the N1 component increased in amplitude for unattended Near stimuli. Experiment 2 was designed to control for a feature selection account of the P1 effect found in Experiment 1 as well as provide further insight into the N1 effect present for Near targets. This was accomplished by comparing effects across two conditions: one condition of many depth cues (identical to Experiment 1), and a second condition in which depth cues were greatly reduced. Comparing attentional effects across these two conditions allows feature selection accounts of attention to be controlled for. An additional test was conducted on subjects from Experiment 2 in order to provide further insight into the larger ipsilateral P1 amplitudes found in Experiment 1.

3.1 Method

3.1.1 Subjects

Sixteen subjects (8 females, 18-29 years of age) participated in this experiment. Subjects were recruited from the Georgia Institute of Technology undergraduate psychology pool and were paid $10/hr for their participation. All subjects had normal or corrected-to-normal vision. Three subjects (all females) were subsequently dropped from analysis. One subject was dropped due to poor task performance (overall accuracy below
two standard deviations from the mean). Two additional subjects were dropped due to poor signal in their electrophysiological data. All subjects participated in two experimental sessions conducted within two weeks of each other.

3.1.2 Stimuli

Stimuli of Experiment 2 fell into two conditions: Depth or No-Depth. The stimuli of the Depth condition were identical to that described in Experiment 1.

![Figure 7. Example of the stimuli used in the No-Depth condition of Experiment 2. Depth information in this display is substantially reduced compared to that of the Depth conditions (Figure 1).](image)

Stimuli in the No-Depth condition differed from the Depth condition only in that the depth inducing background was changed to consistent square pattern (Figure 7). Thus, the No-Depth condition reduces pictorial depth information by removal of the cues of linear perspective, compression, and apparent size. The perceptual experience of this No-Depth condition was such that the two semitransparent surfaces appeared to directly
overlay each other on top of a “floor”. It should be noted that the No-Depth condition does not completely remove pictorial depth information. Rather, depth information (and perception of depth) was greatly attenuated. Luminance values of the No-Depth condition adhere to those listed in Figure 2. Target stimuli were also identical across Depth and No-Depth conditions. Although depth information was reduced in the No-Depth condition, target stimuli will still be referred to as Far and Near.

3.1.3 Procedure

Subjects participated in two sessions on two different days. On each day, participants received both the Depth and No-Depth conditions, the order of which was counterbalanced within a subject across experimental sessions. Initial ordering was further counterbalanced between subjects.

The procedure for both Depth and No-Depth conditions was identical. Each began with four blocks of 50 practice trials (200 trials total). These practice trials were followed by four blocks of 200 experimental trials (70% attended, 30% unattended). The task, timing, and target stimuli for both Depth and No-Depth conditions were the same as that from Experiment 1.

3.1.4 Electrophysiological Recording and Analyses

EEG acquisition and data reduction were performed according to the specifications described in Experiment 1.

Measures of the P1 and N1 components at electrode P7/8 followed the procedures outlined in Experiment 1. Just as in Experiment 1, the statistical analyses conducted in
Experiment 2 relied on a set of planned contrasts. These contrasts separately assessed attended and unattended P1 and N1 amplitudes for Far and Near targets. These comparisons were also carried out separately for Depth and No-Depth conditions. Table 3 details the set of planned comparisons performed in Experiment 2.

### 3.2 Results

Grand average waveforms from electrode P7/8 for both Depth and No-Depth conditions are displayed in Figure 8. Results from planned contrasts of the Depth and No-Depth conditions are reported in Table 4 and Figure 9.

![Figure 8. Grand average waveforms at electrode P7/8 from the Depth and No-Depth conditions of Experiment 2. Note the presence of ipsilateral P1 modulation for Far targets of the Depth condition, but the absence of this effect in the No-Depth condition.](image-url)
Table 3. Planned Comparisons for Experiment 2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Depth</th>
<th>Contra P7/8</th>
<th>Ipsi P7/8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Attended</td>
<td>Unattended</td>
</tr>
<tr>
<td>Far</td>
<td></td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Near</td>
<td></td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>No-Depth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Far</td>
<td></td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Near</td>
<td></td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note. The planned contrasts listed above were conducted for both P1 and N1 components. Letters ‘D’ and ‘N’ in the contrast name indicate the contrast is for the Depth or No-Depth condition, respectively. The letter ‘C’ in the contrast name denotes contralateral electrode P7/8 whereas ‘I’ denotes ipsilateral electrode P7/8. ‘1’ and ‘2’ in the contrast name refer to Far and Near targets, respectively.
3.2.1 Far

Planned comparisons on the P1 component found significantly larger ipsilateral P1 amplitudes for attended Far targets in the Depth condition (P7/8: t(12)=3.28, p<.01). No significant P1 differences were found for Far targets in the No-Depth condition (Table 4; Figure 9).

No Significant N1 differences were found for Far targets in either the Depth or No-Depth conditions (Table 4; Figure 9).

<table>
<thead>
<tr>
<th>Table 4. Experiment 2 Results From Planned Contrasts on P1 and N1 Components at Electrode P7/8.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contrast</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Far</td>
</tr>
<tr>
<td>DC1</td>
</tr>
<tr>
<td>DI1</td>
</tr>
<tr>
<td>NC1</td>
</tr>
<tr>
<td>NI1</td>
</tr>
<tr>
<td>Near</td>
</tr>
<tr>
<td>DC2</td>
</tr>
<tr>
<td>DI2</td>
</tr>
<tr>
<td>NC2</td>
</tr>
<tr>
<td>NI2</td>
</tr>
</tbody>
</table>

Note. The + and – signs of the t-value indicate the direction of the attentional effect. For P1, ‘+’ indicates amplitude was greater in the attended condition. For N1, ‘+’ indicates amplitude was greater in the unattended condition. ‘n.s.’ denotes the contrast was non-significant. All contrasts used a p-value of <.05 to determine significance. For all contrasts, df = 12.

3.2.2 Near

Planned comparisons for the P1 component found no significant amplitude differences in either the Depth or No-Depth condition (Table 4; Figure 9).
Figure 9. Amplitudes of the P1 and N1 components for Depth and No-Depth conditions of Experiment 2. Attended and unattended amplitudes are shown for Far and Near targets at contralateral and ipsilateral P7/8. One red asterisk indicates a significant difference at the .05 level. Two red asterisks indicate a significant difference at the .01 level. Error bars represent 1 SE.
Planned comparisons for the N1 component revealed significant differences. N1 amplitudes were found to be of greater amplitude at both contralateral and ipsilateral electrodes when unattended. This was the case for both Depth and No-Depth conditions. T-values and mean amplitudes of the N1 comparisons are given in Table 4 and Figure 9, respectively.

3.3 Experiment 2 Discussion

Just as in Experiment 1, P1 amplitude was found to increase when the Far surface in the Depth condition was attended. No such result was found in the No-Depth condition. This demonstrates that in the presence of ample depth information, attention can be allotted differentially to a far depth, but in the absence of sufficient depth information attention cannot be distributed in this manner. Furthermore, this P1 effect cannot arise as a result of feature selection, since this would predict modulation in both Depth and No-Depth conditions. The finding of this P1 modulation in both Experiment 1 and Experiment 2 indicates a robust effect of attending to a distant depth in a pictorially-defined scene.

P1 effects further support an asymmetry in the distribution of attention to pictorial depth. A viewer-centered asymmetry suggests that attentional resources are extended between an observer and an attended depth, and drop off more steeply past the attended depth (Andersen & Kramer, 1993; Gawryszewski et al., 1987). The P1 effects presented here are consistent with such an asymmetry. In this experiment, the P1 amplitude for far depth targets is smaller when the near depth is attended and larger when the far depth is attended. The P1 amplitude for near targets is the same regardless of whether the near or
far depth is attended. This is the pattern a viewer-centered asymmetry would predict. That is, P1 modulation is present for the far depth because attentional resources taper off when the near depth is attended, and no P1 modulation is present for the near depth because attentional resources between the observer and attended depth are equivalent of that at the attended depth. Applying this same logic to the No-Depth condition would predict no P1 modulation for either the far depth or near depth since their apparent depth separation is very small, and attentional resources would spread across both depths regardless of which is attended.

As in Experiment 1, N1 amplitudes for Near targets were larger when unattended (i.e., Far was attended). This was the case for both Depth and No-Depth conditions, suggesting that this N1 effect is not related to the apparent depth induced by the background of the Depth condition. This increase in N1 amplitude when unattended is unexpected since the N1 has been shown to increase in amplitude under attentive conditions (Mangun, Hillyard, & Luck, 1993). The exact cause of this effect cannot be known without further investigation. However, it is possible that this enlarged N1 to unattended targets relates in some manner to attentional capture. That is, as subjects are attending to smaller, less salient stimuli (i.e., Far targets), the presentation of a large, salient stimulus (i.e., Near targets) captures attention, and this may be reflected in the amplitude increase seen for unattended Near targets.

The larger ipsilateral P1 found in Experiment 1 was also found to be present in Experiment 2. It was thought that this may arise due to object or texture information present in the backgrounds used in these Experiments. In order to further investigate this ipsilateral P1, subjects from Experiment 2 were run in a short test to obtain a baseline
VEP to target stimuli. This test was administered before each session and consisted simply of flashing Near and Far targets every 500-800 ms on a uniform colored background (matching the color of surfaces used in Experiments 1 and 2). Contrasts compared ipsilateral and contralateral P1 amplitudes at three electrode sites (O1/2, PO3/4, and P7/8) using data from twelve of the thirteen subjects from Experiment 2 (one additional subject was dropped from these analyses due to excessive artifact). P1 amplitudes were found to be significantly larger at ipsilateral electrode sites for both Far (PO3/4: t(11)=-2.31, p<.05) and Near (O1/2: t(11)=-2.73, p<.05; PO3/4: t(11)=-2.98, p<.05) targets. This finding suggests that the ipsilateral P1 present in both Experiments 1 and 2 does not arise specifically due to object or texture information within the display. My current speculation is that the effect arises due to inferred depth of targets. Since the Far and Near targets differ in luminance, size, color, and spatial frequency, the random appearance of these targets convey enough depth information to induce the perception of depth between targets. Thus, the ipsilateral P1 may be related in some way to this perceived depth separation of these targets. Further investigation of this effect is necessary in order to be certain of its cause.
Experiments 1 and 2 both found electrophysiological effects suggesting that visual attention may be allocated to pictorial depth. Experiment 3 was designed to provide behavioral evidence in favor of this idea. Subjects were presented with stimuli identical to those of the Depth and No-Depth conditions of Experiment 2 and tasked with responding as quickly and accurately as possible to both Far and Near targets. Reaction-time was measured and assessed for behavioral effects of attending to pictorial depth.

4.1 Method

4.1.1 Subjects

Seventeen individuals (10 females, ages 18-23) were recruited from the Georgia Institute of Technology undergraduate psychology pool. Participants received course credit for their participation in this experiment. All subjects had normal or corrected to normal vision. One female subject was dropped due to poor task performance.

4.1.2 Stimuli

The stimuli of this experiment were identical to the Depth and No-Depth conditions of Experiment 2.

4.1.3 Procedure
Timing and stimulus parameters of Experiment 3 were identical to that of Experiment 2. The task of Experiment 3 differed only from that of Experiment 2 in that the subject was required to respond to targets appearing at both attended and unattended depths. The procedure for both Depth and No-Depth conditions was the same. In each, subjects first completed four blocks of practice trials (104 trials total). Following practice, 640 experimental trials were given over 4 blocks. The order in which Depth and No-Depth conditions were received was counterbalanced across subjects. RT data was collapsed across visual field and analyzed for effects of attending to pictorial depth.

4.1.4 Analyses

Effects of attending to Near and Far depths were assessed through a set of planned comparisons. Paired-samples t-tests compared reaction time differences between attended and unattended targets for Far and Near targets. Table 5 details the planned comparisons used in Experiment 3.

<table>
<thead>
<tr>
<th>Table 5. Planned Comparisons for Experiment 3.</th>
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<td>Contrast</td>
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<tr>
<td><strong>Far</strong></td>
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<td>D1</td>
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<td><strong>Near</strong></td>
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<td>D2</td>
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<td>N2</td>
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*Note.* The planned contrasts listed above were conducted for both P1 and N1 components. Letters ‘D’ and ‘N’ in the contrast name indicate the contrast is for the Depth or No-Depth condition, respectively. ‘1’ and ‘2’ in the contrast name refer to Far and Near targets, respectively.
4.2 Results

Planned comparisons revealed attentional differences in the presence of depth cues. That is, RT to attended Far targets was significantly faster in the Depth condition \((t(15)=-2.90, p<.05)\), but not in the No-Depth condition \((t(15)=-.99, p>.3)\). Thus, the presence of depth cues appears to facilitate RT.

For Near targets, planned comparisons found no significant attentional differences in either the Depth or No-Depth conditions.

Figure 10 shows the mean RT for Far and Near targets in both the Depth and No-Depth conditions. Plots of attentional facilitation for each condition are also shown in Figure 10. These plots were calculated by subtracting attended RT from unattended RT, and summarize how the effects of attending to Far or Near change depending on the depth information present in the display.

<table>
<thead>
<tr>
<th>Table 6. Results From Planned Contrasts on RT Data From Experiment 3</th>
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<tr>
<td><strong>Contrast</strong></td>
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*Note.* The + and – signs of the t-value indicate the direction of the attentional effect. A ‘-’ indicates reaction time was speeded under attentive conditions. ‘n.s.’ denotes the contrast was non-significant. All contrasts used a p-value of <.05 to determine significance. For all contrasts, df = 15.
Figure 10. Reaction time differences for attended and unattended targets of Experiment 3. Panel (a) displays the mean RT for Far and Near targets in both the Depth and No-Depth conditions. Panel (b) plots reaction time facilitation (unattended RT – attended RT) as a function of Depth cues. In the Depth condition, RT was speeded for attended Far targets. Error bars depict 1 SE.
4.3 Experiment 3 Discussion

Experiment 3 provides behavioral evidence that visual attention may be distributed to pictorial depth. Contrasts showed that RT to attended Far stimuli was speeded in the Depth condition but not in the No-Depth condition (Figure 10). This indicates that the additional depth information present in the Depth condition increased the efficiency of attending to Far depth stimuli. Such a finding is consistent with the attentional effect indexed by P1 modulation in Experiments 1 and 2. No effects of attention were found for Near targets in the Depth condition. This is also consistent with electrophysiological results from Experiments 1 and 2. The results from Experiment 3 are also consistent with a viewer-centered asymmetry of attending to depth. That is, RT to far-depths is facilitated as attention is allocated to that depth, but no RT facilitation is found for depths between the observer and attended depth.

No significant effects of attention were found in the No-Depth condition for either Far or Near surfaces. This indicates that the attentional effects in the Depth condition are not related to feature selection, nor are they related to stimulus saliency. However, a trend in RTs (where attended targets are faster) in the No-Depth condition may suggest a slight advantage in attending to either Far or Near targets.
CHAPTER 5
GENERAL DISCUSSION

The present investigation was primarily concerned with whether
electrophysiological and behavioral effects of attention could be found when the task
involves distributing attention to depths defined by pictorial cues. Findings indicated
that when pictorial cues induced a depth relationship between stimuli, attentional
differences arose between attended and unattended stimuli at far depths. These effects
were apparent in the P1 component, which showed significant amplitude differences in
depth inducing conditions. These results cannot be accounted for by a simple two-
dimensional spotlight model since Far and Near surfaces overlapped in two-dimensional
space. Furthermore, the results described here cannot be attributed to selective attention
to feature differences between Far and Near stimuli because no significant P1 amplitude
differences were present when pictorial cues were greatly reduced (No-Depth). Thus, as
indexed by P1 modulation, attention may be distributed efficiently to far depths when
sufficient pictorial cues are available, but in the absence of this depth information
attention may not be differentially distributed. Behavioral results (Experiment 3) further
support the idea that visual attention may be allocated to pictorial depth. In the presence
of ample depth information, reaction times were facilitated to attended stimuli at far
depths. However, with reduced depth information, no significant RT differences were
present.

Results of the experiments conducted here further support the theory that the
allocation of attention to depth is viewer-centered (Andersen & Kramer, 1993;
Gawryszewski et al., 1987). A viewer-centered asymmetry proposes that when a depth is attended, the distribution of attention extends between the observer and the attended depth but falls off rapidly beyond the attended depth. Electrophysiological and behavioral results were consistent with such an asymmetry. In the presence of ample depth information, the P1 component was found to modulate with attention for far depth stimuli, but no attentional modulation was found for near depth stimuli. In a similar manner, RT to far depth targets was facilitated under attentive conditions, but no differences were found in RT for near depth targets. Such results would be expected if a viewer-centered asymmetry existed. That is, effects of attention are seen for far depth stimuli because attention does not extend to the far depth when the near depth is attended, but no effects of attention are present for near depth stimuli since attention is allocated equivalently when attending to the near depth or attending to the far depth.

Results from reduced pictorial depth cue conditions (i.e., No-Depth) are also consistent with an attentional asymmetry. In the No-Depth condition, the perceptual experience of the two surfaces is such that they are very close to each other in depth. In this condition, no P1 differences were found for either far or near depth targets. Additionally, no significant reaction time differences were found for either far or near targets. This result is also predicted by a viewer-centered asymmetry. Since far and near surfaces appear close in depth, distributing attention to one surface also encompasses the other surface. Figure 11 depicts a model of viewer-centered asymmetry and how it applies to the results of the experiments presented here. It should be noted that although the aforementioned results are consistent with a viewer-centered asymmetry, the existence of such an asymmetry cannot be explicitly proven without additional testing.
The depth relationships between the two surface stimuli of this experiment are induced entirely by pictorial cues. Thus, no true depth separates the two surfaces. The experiments presented here have shown that visual attention is capable of operating within depth even if this depth is inferred solely from pictorial cues. Such a finding demonstrates that attending to depth is not a phenomenon specific to stereoscopic depth. Rather, it has been shown that visual attention may be distributed to an apparent depth, computed only from pictorial cues. This suggests that attending to depth occurs at a high level representation of space. If attending to depth was specific to stereoscopic depth then a low level account may be sufficient since binocular disparity arises early in the stream of visual processing. However, since attention can be distributed to pictorial depth, it must operate at a higher level of visual processing where depth relationships between objects have already been processed.

Two unexpected electrophysiological results were uncovered in the analysis of P1 and N1 components of the VEP. The first such result was that of the enlarged ipsilateral P1. This was surprising since the P1 component is typically found to have a larger amplitude at contralateral electrodes followed by a later and smaller ipsilateral positivity. A short test conducted on subjects of Experiment 2 suggested this effect did not arise due to background or object information in the displays. My current speculation of this result is that it relates to depth inferred between the target stimuli due to differences in their physical properties (i.e., size, luminance, color, and spatial frequency). If this idea is correct, it may suggest a special role of the ipsilateral hemisphere in the processing of stimulus depth. Further experimentation is required in order to draw any definitive conclusions.
A second unanticipated electrophysiological result was that of the increased N1 negativity to unattended near depth targets. Attentional effects of the N1 component have shown its amplitude increase under attentive conditions (Mangun, Hillyard, & Luck, 1993). The fact that N1 to near targets displays such an opposite effect is quite puzzling. One explanation of this effect may be that it relates to a mechanism of attentional capture.

In the sustained attention task used in Experiments 1 and 2, attending to the far depth required subjects to detect the presentation of the dim, colored targets at that depth. The onset of a large bright stimulus (Near target) may engage some mechanism of attentional capture which is reflected in the modulation of the N1 component. However, such an interpretation is speculative and further investigation of this result is required for a complete account to be made.

In summary, electrophysiological and behavioral results allow us to conclude with confidence that visual attention may be allocated differentially to a distant depth if sufficient pictorial cues are available to induce the perception of a depth separation. Furthermore, results suggest that attentional resources cannot be selectively allocated to depths which fall between the observer and an attended depth. These results are consistent with a viewer-centered asymmetry in the distribution of attention to depth. The current investigation has demonstrated that attending to depth is not limited strictly to depths induced by binocular disparity. Rather, attention may be distributed differentially to depth solely on the basis of pictorial depth information. This suggests that visual attention to depth operates at a higher-level representation where depth information has been computed from stimulus relationships in the visual field.
Figure 11. A depiction of a viewer-centered asymmetry as applies to the stimuli of this investigation. The left panel shows the manner in which attention is distributed to depth in the presence of ample depth information (i.e., Depth condition). Such a distribution would explain why P1 and RT differences were found for the Far depth but not the Near depth. The right panel depicts the way in which attention is distributed when pictorial depth cues are greatly reduced (i.e., No-Depth condition). This distribution would explain why no P1 or RT differences were present for either Far or Near targets in the No-Depth condition.
REFERENCES


