DO NEGATIVE EMOTIONAL PICTURES

AUTOMATICALLY CAPTURE ATTENTION?

by

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TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

Emotion-induced blindness (EIB) refers to impaired awareness for items that appear soon after an *irrelevant*, *emotionally arousing* stimulus. Previous research (Kennedy et al., 2012) that used event-related brain potentials (ERPs) to study the mechanisms responsible for EIB found that emotional distractor pictures elicited two ERP components that were related to the magnitude of EIB: the EPN, which is thought to reflect attentional *engagement*, and the Pd, which appears to index attentional *disengagement*. The current research investigates whether these components are automatic or require attention. Previous research has produced mixed results on the question of whether the EPN component elicited by negative pictures is affected by attention while the Pd component has not been examined. We addressed the automaticity of these components by requiring participants to perform a multiple object tracking (MOT) task on objects moving in front of a stream of rapidly presented pictures (outdoor scenes and cityscapes). Earlier research showed that MOT abolished awareness for scene pictures appearing in a stream of distractors pictures (Cohen, Alvarez, & Nakayama, 2011). The current experiment uses a similar paradigm to study the impact of emotional "distractor" pictures that could be negative (dangerous animals, mutilated bodies, etc.) or neutral (people and animals in non-emotional settings). When observers attended to the picture stream, distractors produced robust EPN and Pd components. In contrast, when observers performed the MOT task and attempted to ignore the pictures, the EPN associated with distractors was diminished while the Pd components *increased* in amplitude. These results show that the EPN

component elicited by distractor pictures is sensitive to attention and is reduced when attention is occupied by another task. In contrast, the Pd component is enhanced when salient distractors are ignored which is consistent with the claim that this component reflects a process responsible for preventing or terminating attentional engagement.

Chapter 1

INTRODUCTION

1.1 Attentional Capture

A debated issue in the field of attention research revolves around whether attentional capture is a consciously controlled or an automatic process. Two distinct modes of visual processing have been accepted as mechanisms of attentional capture. Some researchers focus on the intrinsic features of objects and images that automatically capture attention, while others concentrate on the deliberately directed attention that is required for stimulus perception. Furthermore, stimuli may trigger shifts in spatial attention in a bottom-up (stimulus driven) fashion or capture attention using top-down mechanisms for goal-directed behavior (see Theeuwes, 2010 for a review).

Based on the bottom-up theory of attention capture, task-irrelevant "distractors" automatically capture attention if the stimuli are significantly different in shape or color from the remaining stimuli in an array (Hickey, McDonald, & Theeuwes, 2006). This effect is known as "distractor interference" and is attributed to differences in the physical salience of the stimuli. Distractor interference is thought to occur using a preattentive mode, which does not require directed attention, and processes information using a spatially parallel mechanism. According to this theory, top-down control cannot override the preattentional processes that capture a distractor.

An altenative theory, known as the contingent capture hypothesis, asserts that the attention capture is never completely automatic and is subject to "attentional control settings" (Folk & Remington, 2006). This theory suggests that the capture of attention by a stimulus is contingent on the stimulus containing a feature consistent with the current attentional set. For example, Folk, Remington, and Johnston (1992) found that red distractors captured attention when paired with red targets, but the red items were not captured when paired with a green target set. Thus, the stimulus properties associated with the demands of the current task initiated involuntary attentional shifts. Some researchers assert that this involuntary attentional capture occurs effortlessly for stimuli that we see everyday.

1.2 Scene Perception and Attention

Attentional researchers debate whether certain types of stimuli are "special" in their ability to involuntarily capture attention. For example, Mack and Rock (1998) conducted several experiments on a phenomenon they called "Inattentional blindness." In this procedure, participants are given four trials in which they are shown a plus sign and asked to determine whether the vertical or horizontal component of a plus sign is longer. On the fifth trial they are unexpectedly shown an additional, irrelevant stimulus along with the plus sign. After this "critical trial," participants are asked whether they noticed anything unusual. If they answer in the negative, the experimenter asks several, more pointed, follow-up questions designed to reveal whether they have any knowledge of the unexpected stimulus. The general finding is that the majority of participants are completely unaware of the presence of the unexpected stimulus, suggesting that attention is necessary for awareness. The exception they noted was perception of scenes where they found that subjects were able to describe the gist of a scene when it was presented as the unexpected stimulus in the inattentional blindness paradigm.

Previous research suggests that subjects perceive the 'gist,' or general meaning of scenes in the "near absence of attention" (Koch & Tsuchiya, 2007). Other studies also indicate that in the presence of a primary demanding task, scene perception and categorization can occur preattentively and are not impaired by dual-task conditions (Li, VanRullen, Koch & Perona, 2002; Rousselet, Fabre-Thorpe, & Thorpe, 2002). Li and colleagues showed that subjects rapidly detected the presence of an animal or vehicle in a briefly presented natural scene, despite concurrent completion of an attentionally demanding letter discrimination task. This letter discrimination task required participants to indicate the presence of an "L" or a "T" in an array of five rotated letters. Subjects were able to perform both tasks simultaneously, without detracting from the accuracy of either task. These results reveal that natural scenes may be categorized in conditions of inattention.

Cohen, Alvarez, and Nakayama (2011) refuted this claim and suggested that the primary tasks used in previous studies were not sufficiently demanding to prevent allocation of excess attentional resources to scene perception. Cohen and colleagues increased the attentional demand of their primary task by using multiple-object tracking (MOT).

Pylyshyn & Storm (1988) developed the MOT task, which required subjects to simultaneously track several target objects moving in an array of identical, moving distractors. At the start of each trial, all of the objects remained stationary, and a subset flashed to mark their status as targets. The objects then returned to their original color and begin to move on independent, random trajectories. Participants were asked to maintain attention on the targets and "mentally track" the objects as they move around the screen. At the end of each trial, objects became stationary and subjects were instructed to select each target object with a mouse-click.

Throughout the duration of each trial, subjects are asked to track these objects without moving their eyes and to maintain visual fixation on a cross that is located at the center of the screen. Research has shown that subjects can effectively keep track of these targets using their peripheral vision (Posner, 1980). Maintaining tracking in the MOT task depends upon subjects allocating sustained attention throughout the tracking period, which would deplete resources required for other high-level attentional processes (Scholl, 2001). The MOT task requires a significant allocation of the limited-resources of selective attention to maintain accurate responses and avoid losing track of some of the objects (Cavanagh and Alvarez, 2005).

Cohen et al. used MOT in conjunction with natural scene detection during a rapid serial visual presentation (RSVP) of images. The use of both MOT and RSVP tasks in this paradigm substantially increased the attentional demands of the experiment since both tasks required continuous, sustained visual attention. On each of the first four trials, participants tracked a set of 4 target disks moving among 4 identical distractors. The moving objects appeared in front of an irrelevant, rapidly presented series (one every 67 msec) of random checkerboard patterns. At the end of each trial, subjects were asked to click on the targets. Importantly, there were not asked about the content of the RSVP stream. On the fifth, “critical trial,” one of the checkerboard images was unexpectedly replaced with a scene from one of five categories (beach, building, highway, indoor, or mountain). Immediately after the critical trial, subjects were asked if they noticed anything different on this trial.

In contrast to previous results (Li et al. (2002); Rousselet et al. (2002), Cohen and colleagues found that natural-scene perception was significantly impaired during the attentionally demanding MOT task. In fact, the majority of participants (64%) displayed full inattentional blindness meaning that they did not detect any difference at all on the critical trial. Only a small number of participants (18%) were able to classify the scene. These results suggest that subjects can be rendered blind to the presentation of a natural scene if they are sufficiently engaged in a simultaneous, attentionally demanding task.

1.3 Emotional Stimuli

The preceding studies suggest that scenes may require directed attention for perception, and that when attention is occupied with other visual tasks, the presentation of a scene may go unnoticed. However, this effect may not occur for scenes containing potentially threatening, biologically salient information, which may capture attention automatically.

People are predisposed to attend to fearful or emotional information in the surrounding environment (Ohmn, Flykt, & Esteves, 2001) and consequently, threatening emotional stimuli captures attention even when they are irrelevant to the observer's task (Vuilleumier, Armony, Driver, & Dolan, 2001) This explains why drivers slow down to view an accident on the opposite side of the highway.

Stimuli, such as words and images, with emotional content have been shown to capture attention, even when these stimuli are presented for brief durations. Investigators designed an experimental paradigm known as rapid serial visual presentation (RSVP) to investigate the attentional capture by fleeting emotional stimuli in a laboratory setting. In the RSVP paradigm, observers view a sequence of scene images (architectural and landscape photographs) presented at a rate of 10 images per second in the same spatial location. The observer's task is to find a target image, which is a scene picture that has been rotated 90 deg. to the left or right. An irrelevant emotional "distractor" picture sometimes precedes the target. Even though this image is irrelevant to the observer's task, it severely disrupts awareness of the target, a phenomenon known as emotion-induced blindness or EIB (Most, Chun, Widdler, & Zald, 2005). The robust blink produced by the EIB, despite the task irrelevance of the emotional picture, has caused researchers to question whether directed spatial attention is required to perceive these intense emotional images.

1.4 Spatial Attention and Emotional Image Perception

If perception of emotional stimuli is automatic, attentional capture will occur based on the emotional salience of the stimulus, even when attention is engaged at another location. A neuroimaging study by Vuilleumier, et al. (2001) supports the claim that emotional processing of stimuli in certain brain regions is not dependent on spatial attention. In this experiment, participants were shown images of faces and houses at two of four unpredictable locations lateral to fixation. Some of these locations were predefined as being "task relevant," while other images were presented in locations that were to be ignored. A neuroimaging technique, known as functional magnetic resonance imaging (fMRI), recorded activation in brain areas during performance of this task. Results of this study indicated that the amygdala, a brain area that has been shown to respond to fearful and emotional stimuli, was activated in response to the presentation of the fearful emotional faces, regardless of the task relevance of their locations. This activation was significantly larger for fearful faces in comparison to neutral faces. Therefore, these findings suggest that even when participants were not attending to the location of the fearful stimuli, the emotional nature of the stimuli was represented in the amygdala.

Another study used the same task as Vuilleumier et al. (2001) and recorded the electrical activity in the brain using event-related brain potentials (ERP) to investigate the role of attention in emotional stimuli processing (Holmes, Vuilleumier, & Eimer, 2003). The findings of Holmes et al. (2003) for attended locations were consistent with the fMRI study and indicated that fearful faces produced enhanced activation in comparison to neutral faces. The results for the unattended locations, however, conflicted with the conclusions of the previous fMRI study (Vuilleumier et al., 2001). Holmes et al. (2003) did not find a significant difference between ERP responses to fearful and neutral face stimuli that were presented at peripheral locations. These results indicated that ERP waveforms elicited by difference in the emotional salience of stimuli are gated by spatial attention.

Although diverting spatial attention seems to attenuate the influence of emotional stimuli, researchers questioned if the effects would be the same for emotional stimuli presented at fixation. When the face stimuli were presented at fixation, and attention was directed to peripheral tasks, these emotional faces were automatically perceived, regardless of directed spatial attention (see Eimer & Holmes, 2007 for review). Eimer et al. (2007) do suggest, however, that the nature of these effects may be specific to perception of face stimuli and may not generalize to emotionally salient non-face stimuli.

A recent behavioral study that used pictures with extreme emotional content indicated that emotional processing of pictures may be location specific (Most & Wang, 2011). This study examined the effect of spatial attention on EIB using two simultaneously presented RSVP streams of images. Subjects were informed that both the target and the emotional distractor could be presented in either of the two simultaneous streams. Results indicated that target detection was worse when the target and distractor appeared in the same stream compared to the different stream. Therefore, the impaired awareness for targets that followed emotional distractors was restricted to the spatial location of the emotional distractor.

Based on these results, the present experiment aims to investigate the nature of emotional images perception for pictures presented in the same spatial location as a concurrently performed, attentionally demanding MOT task. If the perception of emotional stimuli is a preattentive process, manipulations of attention should not affect the recognition of these emotional images. On the other hand, if emotional stimuli require attention for perception, performing concurrent multiple object tracking should decrease accuracy of image detection and recognition.

1.5 Event Related Brain Potentials

1.5.1 Electroencephalography Recording

Existing behavioral data do not enable a direct examination of the underlying mechanisms of attentional capture by emotional images. Neuroimaging methods provide tools for examining processing of irrelevant material that doesn't depend on behavioral measures. In particular, methods with excellent temporal resolution, such as electroencephalography (EEG), are ideal for elucidating the rapid series of processes responsible for the perception of emotionally salient images.

EEG uses electrodes placed on the scalp to record the electrical activity of the human brain. This signal is then amplified and averaged over a large number of trials to isolate specific responses, known as event-related potentials (ERP), which represent the unique neural events associated with processing a particular stimulus. Researchers commonly use specific peaks or *components* of ERP waveforms, as indices of underlying neural activity at specific points in time (Luck, 2005). In addition, the location of ERP components on the scalp, in conjunction with source localization software, can be used to provide some information about the location of neural generators in the brain.

1.5.2 The EPN Component

Previous studies suggest that several ERP components are related to the valence or arousal associated with emotional images (see Olofsson, Nordin, Sequeira, & Polich, 2008 for a review). One of the most frequently investigated components in the context of emotion is referred to as the EPN or “early posterior negativity” which usually follows the appearance of an emotional picture. The EPN peaks over posterior visual areas approximately 200 to 300 ms after onset of the picture.

Researchers have debated whether the EPN component is uniquely related to negative emotional stimuli or if the EPN is elicited by any stimulus with motivational significance, even positive ones. Previous studies reported larger EPN components for both positive (erotic) and negative (mutilated) emotional images, in comparison to neutral or baseline images (Schupp, Junghöfer, Weike, & Hamm, 2003a). These results suggest that the EPN may be more closely related to the “arousal” aspect of a stimulus than to its emotional valence.

Other studies suggest that the EPN is elicited in response to the physical features of an image, rather than the emotional content. A systematic investigation of the EPN including content of the image (objects or people), emotional arousal (high or low), and picture type (foreground object or complex scene), indicated that EPN amplitude was correlated with the perceptual features of a stimulus (Schupp, Flaisch, Stockburger, & Junghöfer, 2006). For example, images containing people or distinct foreground objects have been shown to elicit larger EPN amplitudes than images containing objects or complex scenes.

Another study by Bradley, Hamby, Low, and Lang (2007), however, examined the perceptual complexity of the scene in terms of two categories defined as a major foreground object vs. a scene containing numerous objects in direct comparison to emotional valence. Bradely et al. found that the EPN component was more pronounced for images with emotional content and was not affected by the perceptual complexity of the scene. These results provide support for the idea that the EPN is related to the emotional valance of an image rather than the perceptual complexity, or physical salience, of the image.

Some investigators assert that EPN amplitude depends not only on the inherent features (emotional or physical) of the stimulus, but is also affected by the attentional demands of the current task. Previous studies reveal that the EPN component is larger for negative than neutral images, and this amplitude further increases when the images are task relevant (Schupp, Stockburger, Codispoti, Junghofer, Weike, & Hamm, 2007b).

A study by Weins, Sand, Norberg, and Andersson (2011) manipulated the attentional demands of image perception to explore the nature of the EPN component for task-irrelevant emotional pictures. In this experiment, stimuli consisted of a centrally located negative or neutral image surrounded by six letters. In the "letter condition," subjects were instructed to ignore the pictures and push the space key if the letter "N" was shown. In a separate block, participants performed the "picture condition" in which they were instructed to ignore the letters and press the space bar if the picture was the same as the one shown on the previous trial. In the picture condition, the EPN was significantly larger for negative than neutral pictures. In the letter condition, however, there was no significant difference between the EPN for negative and neutral emotional pictures. These results indicate that negative emotional pictures do not automatically elicit a large EPN and that changing the attentional demands of the task can alter the amplitude of the EPN.

A study by Kennedy et al. (2013) investigated the EPN in the EIB paradigm. They found that both targets (rotated scene pictures) and task-irrelevant emotional distractor images elicited an EPN component. In addition, EPN amplitude was smaller for targets that failed to reach awareness (i.e. targets that subjects could not correctly report). The EPN component to the emotional picture was also larger for trials in which the emotional distractor impaired perception of a relevant target picture. If the EPN amplitude in the current study is smaller for conditions with higher attentional loads, then the results will support the idea that the EPN is a marker of attentional capture. Based on the previous findings, we predict that the EPN will be larger for negative than neutral emotional pictures in the full attention conditions of the current experiment.

1.5.3 The Pd Component

Experiments that use salient task-irrelevant distractors have found a contralateral posterior positivity that immediately follows the EPN component (Kiss et al., 2008). This posterior positivity, referred to as the "distractor positivity" or the Pd component, peaked around 400 ms after stimulus onset and is maximal at lateral occipito-temporal sites (Sawaki & Luck, 2010). The presence of this positivity in experiments with salient distractor stimuli indicates that the Pd component may reflect the active suppression of the task-irrelevant distractors (Kiss, Grubert, Petersen, & Eimer, 2012; Sawaki, Geng, & Luck, 2012; Sawaki & Luck, 2010).

A study examining the attentional capture of task-irrelevant singletons found that task-irrelevant distractors in a visual search display elicited a negative deflection followed by a Pd component (Kiss et al., 2012). According to Kiss and colleagues, this negative deflection reflects attentional capture by the task irrelevant distractors, and the subsequent Pd component reflects rapid suppression or disengagement of this attention. The similar scalp topography between these two components supports the idea that the Pd is elicited during the disengagement of attention (Sawaki et al., 2012).

Other investigations reveal that the Pd component can be elicited prior to attentional capture of irrelevant stimuli. An experiment by Hickey et al. (2008) discovered that when a task requiring discrimination between a target and distractors was changed to a target detection task, the Pd component was eliminated. Another study by Sawaki and Luck (2010) found that salient task-irrelevant stimuli elicited the Pd component, regardless of spatial attention. In this experiment, the amplitude of the Pd component was the same for salient, task-irrelevant stimuli presented in attended and unattended locations. Furthermore, Sawaki et al. found that the Pd component was elicited only in response to salient distractor stimuli (i.e. different colored letters), rather than target similar distractors. Thus the Pd component may reflect deployment of attentional resources to suppress distractor stimuli.

Most of the research on the recently discovered Pd component used paradigms with salient singletons as distractors. A study by Kennedy et al. (2013), however, found that the Pd component was also elicited in response to task-irrelevant emotional stimuli. Since threatening emotional pictures have been shown to be particularly salient distractors (Vuilleumier et al., 2001), the current experiment uses negative emotional pictures to investigate the nature of the Pd component. If the Pd component reflects attentional disengagement, as we suspect, the Pd component should be larger for stimuli with negative valence than neutral stimuli. We also manipulate the attentional demands of the task to examine the automaticity of the Pd component. If the Pd component is automatically elicited by distracting stimuli, it should be larger when the picture can be ignored, than conditions of divided attention, in which the picture must be captured and then suppressed. The Pd component should not be elicited by conditions of full attention to the task relevant emotional stimuli.

1.5.4 The P3b Component

Emotionally salient pictures in the current study are evaluated for perception by the presence of a late component referred to as the P3b. The P3b component is a positive waveform that is maximal over the posterior parietal electrodes and has a latency of approximately 250 ms to 500 ms (see Polich, 2007 for review). Previous ERP studies have shown that the P3b component reflects working memory consolidation for attentionally engaging and emotionally arousing images (Kennedy et al., 2013; Vogel & Luck, 2002). The P3b component has also been used in previous EIB experiments as a measure of the working memory consolidation of emotional images (Kennedy et al., 2013). The importance of the P3b component for the current experiment is that it is typically elicited when attentional resources are engaged by stimuli that are task-relevant. The P3b component is significantly smaller, however, when the same stimuli are passively viewed or ignored (Polich, 2007).

In the present study, the P3b should be elicited by conditions of full attention to the picture stream, since subjects will be asked to report the emotional picture. If the P3b is elicited in conditions of divided attention, then we can assume that subjects are processing the emotional picture to the level of working memory consolidation. We do not expect conditions of inattention to the picture stream to elicit a P3b component because these pictures are entirely irrelevant to the current tracking task. However it is possible that task-irrelevant, emotional stimuli may also automatically make their way into working memory.

Chapter 2

METHODS

2.1 Participants

Twenty right-handed, neurologically normal participants (13 women, 7 men, mean age: 21, age range: 19-28) were recruited through a university-sponsored classified ad. One subject was excluded for excessive eye movements (more than 10% of trials). Another subject was excluded for poor behavioral performance on the MOT task (11% accuracy). All subjects gave informed consent and were paid $10/hr for their participation. Participants were naïve as to the purpose of the experiment and reported normal or corrected- to-normal vision. The University of Delaware Institutional Review Board approved the experiment. All subjects gave informed consent and were debriefed at the end of the experiment.

2.2 Stimuli

Subjects performed the tasks in a dimly lit, electrically shielded room with a chinrest that maintained a 70-cm viewing distance. A Dell 2.99-GHz computer running custom software written with Blitz3D (Sibly, 2005) generated the stimuli, which were presented on a Samsung Syncmaster 2233RZ LCD display (Wang & Nikolic, 2011) with a refresh rate of 120 Hz and a viewing area of 34 x 24.4 degrees of visual angle (dva). Eye fixation was monitored using an Eyelink 1000 infrared eyetracker running at 500 Hz. The stimuli appeared in the center of the screen, with the remainder of the screen being black. A fixation-cross of 0.37˚x 0.37˚ was presented in the center of the screen for the duration of each trial.

Displays contained six identical disks (1˚ in diameter), each consisting of a white inner ring surrounded by a black outer that made it visible on light and dark parts of the picture. Each ring moved along independent, random trajectories and bounced off each other as well as the sides of the picture frame (see figure 2.2). Disks appeared in front of the RSVP sequence of pictures. Each image was 9.6 ˚ x 6.4 ˚ . The disks had a constant velocity of 7.2 ˚/sec. Each picture was shown for 100 ms and was followed immediately by the next picture in the sequence.

The majority of the background pictures were landscape and architectural photographs (see figure 2.1). . Two thirds of the sequences contained an "out-of-category" picture, which was classified as an image that contained an animal or person. The "out-of-category" images were taken from the International Affective Picture System (IAPS), a set of picture stimuli normalized and rated for arousal and emotional valance (Lang, Bradley, & Cuthbert, 1997). Fifty-six of these "out-of-category" images had neutral valence. There were also 56 negative "out-of-category" pictures that contained depictions of violence, medical trauma, or threatening animals. Subjects were shown a sample of the potentially unpleasant images prior to the onset of the experiment and were informed they could terminate participation at any point. Streams containing only background pictures were used as a control condition.

Before beginning the experiment, each subject completed 15 practice trials with an RSVP rate of 5 images per second under supervision of the experimenter. The RSVP rate increased to 10 images per second for the actual experiment. Participants began each trial by pressing the left mouse button, which initiated the RSVP sequence.

Subjects were instructed to main fixation on the cross at the center of the screen for the duration of the experiment and refrain from blinking or making unnecessary movements. Participants were provided feedback at the end of each trial if they moved their eyes from the fixation point.

2.3 Experimental Paradigm

The experiment consisted of 540 trials divided into nine blocks, each of which consisted of three repetitions of the picture-only, track-only and dual conditions in that order.

2.3.1 Picture-only Condition

In the picture-only task, subjects were told to ignore the moving disks that were present and focus only on the pictures. At the end of each trial, subjects were prompted to indicate by pressing a mouse button whether the sequence of images included an out-of-category picture (left button for "yes" and right for "no"). A maximum of one out-of-category picture was present in each sequence. If an out-of-category image was present, participants were then asked to select the image from of a set of 4 pictures. The choices were from the same set (i.e. neutral or negative) as the presented picture. The location of the correct choice was randomized among the four possible locations. Subjects were asked to select an image even if they did not indicate that an out-of-category picture was present in the previous step. A colored box appeared around the image to provide the subject with feedback on the selection (green for a correct choice and red for incorrect). At the completion of the trial, the screen automatically reverted to the initial state.

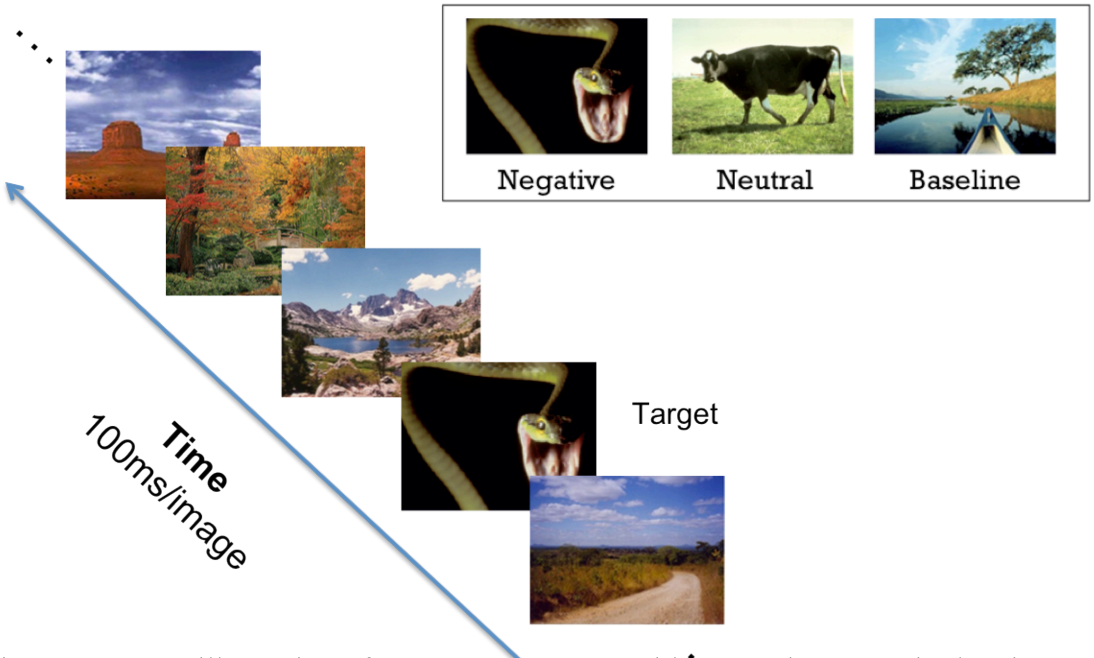


Figure 2.1 An illustration of an RSVP sequence with a negative target in the picture-detection task. The target could be either a negative or neutral out-of-category picture or a baseline picture that did not require recognition. Pictures had six moving disks in front of them, which have been removed for clarity

2.3.2 Track-only Condition

In the track-only task, subjects were instructed to attend only to the moving circles and ignore the images. Each trial in the track-only condition began with six stationary disks on top of a RSVP of scene images. Subjects clicked the mouse to start each trial, causing three of the disks to flash green. These green circles marked the objects as targets to be tracked for the remainder of the trial. The green disks returned to the neutral color once the objects began to move. At the end of each trial, the RSVP stream was terminated and the disks became stationary. Subjects were instructed to select the target circles by clicking on them with the mouse. Clicking on a target caused the disk to turn green while clicking on a distractor changed the color to red.

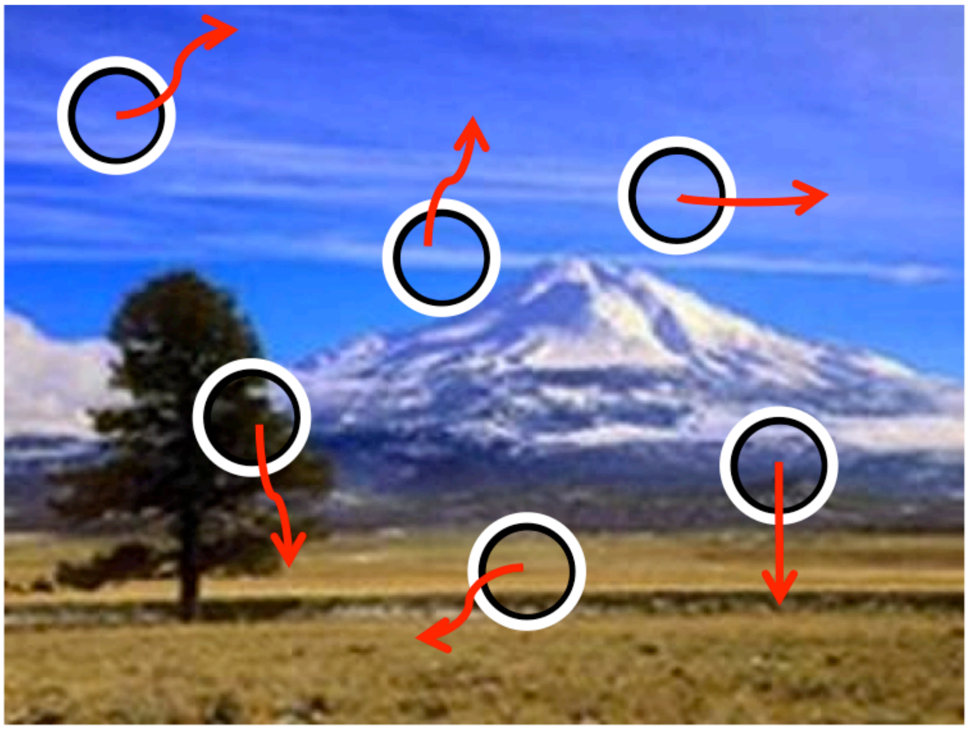


Figure 2.2 Example of the MOT tracking task. Arrows represent the pseudorandom trajectory of the black and white circles over the RSVP stream of images.

2.3.3 Dual-Task Condition

In the dual-task condition, subjects were asked to track the circles and attend to the RSVP sequence. Emphasis was placed on accurate tracking of the circles as the primary task. At the end of the trial, picture detection and identification responses followed the choice of MOT targets.

2.4 Electrophysiological Recording and Analysis

A continuous electroencephalogram (EEG) was recorded with an Electrical Geodesics Inc. (EGI; Eugene, OR) 128-Geodesic Sensor Net. As recommended by the manufacturer, individual electrode impedances were kept below 50-75 kΩ. The data were referenced online to the vertex, band-pass filtered (0.01 to 80 Hz), and digitized at 200 Hz. EGI Net Station 4.1.2 was used offline for subsequent processing. The data were low-pass filtered (cutoff=40 Hz) and segmented using an epoch that began 200 ms prior to stimulus onset and ended 1000 ms. post-stimulus.

Individual segments that contained eye movements or blinks (threshold = 70 μV) were corrected using the regression method of Gratton and colleagues (Gratton et al., 1983). Channels were marked as bad if the maximum voltage range exceeded 70 μV. Individual segments were rejected if more than 10 channels were marked as bad. Finally the segments were averaged, re-referenced to the average reference, and baseline corrected using the 200 ms pre-stimulus interval.

2.5 Data Analysis Procedures

2.5.1 Analysis of ERP Data

Baseline ERPs were subtracted from negative and neutral out-of-category waveforms to isolate the ERP components elicited by-of-category pictures from the periodic ERP activity generated by the rapid sequence of pictures (see Vogel, Luck, & Shapiro, 1998). Clusters of 3-6 sensors that displayed the maximum amplitude difference waves were averaged and analyzed with repeated measures Analysis of

Variance (ANOVAs) with Greenhouse-Geisser corrections. Sensor locations were similar to those used by Kennedy et al. (2013) who used the same pictures in an EIB task. Following the ANOVAs, we performed post hoc comparisons on the group means using Fisher's Least Significant Difference (LSD) test and produced the p-values presented in the results section.

2.5.2 Principal Components Analysis (PCA)

As the results section will reveal, the partially overlapping scalp topography and time windows for the Pd, and P3 components elicited by the distractor pictures posed a challenge to disentangling these components. In order to increase confidence that the Pd and P3b were indeed separate components, we employed a complimentary technique for quantifying ERP components known as *principal components analysis* (PCA). The PCA analysis that we employed was the ERP PCA (EP) Toolkit version 2.34 for MATLAB (Dien, 2010). Analyses were based on the covariance matrix with Kaiser normalization. As recommended by Dien (2010), the first step was a temporal PCA using a Promax rotation, which was followed by a spatial PCA using an Infomax rotation. The "parallels" test (Dien, 2010) was used to determine the number of factors to be retained in each step. The temporal PCA was performed on average waveforms for each subject consisting of 240 time points representing the 200 msec prestimulus period and 1000 msec. post-stimulus period. Waveforms were recorded from 129 sensors. Each set of 129 waveforms was recorded in one of nine conditions consisting of thee task conditions (dual-task, picture-only, and MOT-only) X three types of valence (negative, neutral, and baseline On the basis of the parallels test, we retained 10 temporal factors. In the second step, we performed a spatial PCA on the 10 temporal factors discovered in step 1 and once again employed combinations of task (dual-task, picture-only, and MOT-only), valence (negative, neutral, and baseline). This spatial PCA resulted in the retention of 8 spatial factors for an overall total of 80 factor combinations (10 temporal X 8 spatial factors). After retention, we serially inspected these factors for the broadly distributed positivity over the posterior electrodes, which indicated the presence of the Pd component. The same inspection was applied for the P3b component, which was defined as having a midline positive maximum over posterior scalp locations centered around Pz. Using this approach, we found separate spatial factors representing the Pd and P3b components.

Chapter 3

RESULTS

3.1 Behavioral Results

Subjects were more accurate at detecting the presence of an out-of-category image in the picture-only condition than the dual-task condition (Figure 3.1). A two-factor repeated measures ANOVA compared image valence (negative, neutral, and baseline) to task (picture-only vs. dual-task) and revealed that there was a significant main effect of task (F (1, 17)=15.521, p =0.001) on image detection. There was no significant influence of image valence (negative vs. neutral) on image detection (F (2, 17)=3.461, p =0.057).

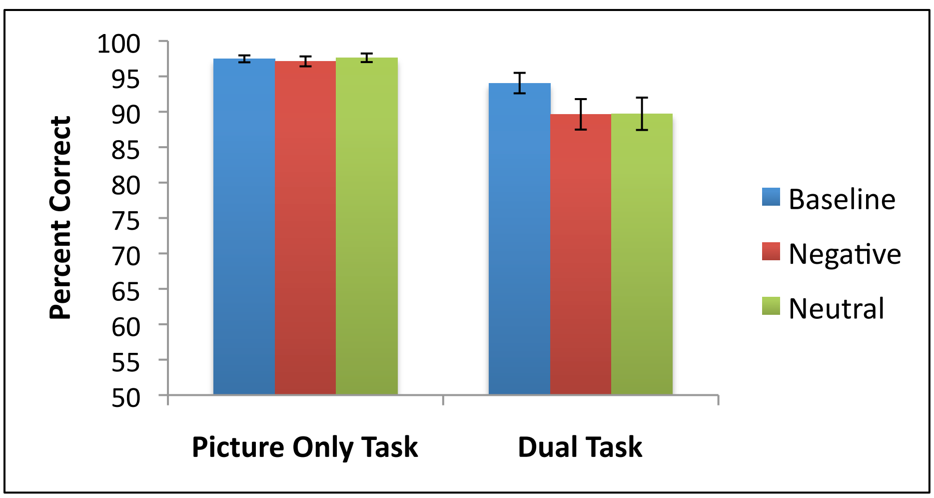


Figure 3.1 Behavioral Results for picture detection accuracy. Baseline detection was deemed accurate if the participant correctly reported the absence of an out-of-category picture. Error bars represent standard error from the mean.

Figure 3.2 shows the accuracy of reporting the picture for the negative and neutral images as a function of task. Unsurprisingly, recognition accuracy was lower in the dual-task condition compared to the picture-only task. Recognition accuracy was also higher for neutral compared to negative pictures. A two-factor repeated measures ANOVA with factors of image valence (negative vs. neutral) and task (picture-only vs. dual-task) revealed significant main effects for task ($F(1, 17)=23.640$, $p < 0.001$) and image valence ($F(1, 17)=38.816$, $p < 0.001$). There was also an interaction between task and image valence, ($F(1, 17)=13.812$, $p = 0.002$), reflecting larger valence differences in the dual-task condition compared to the picture-only condition.

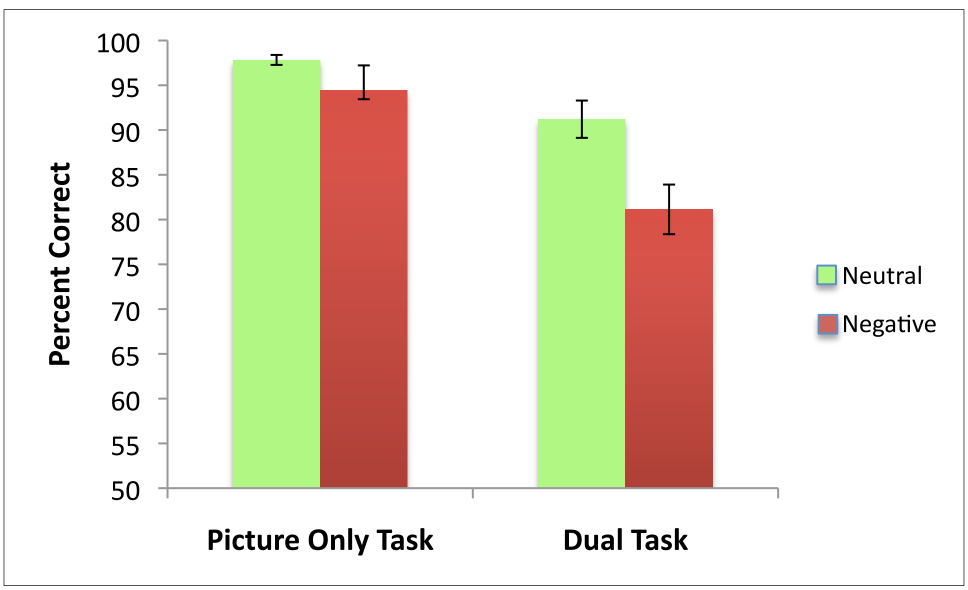
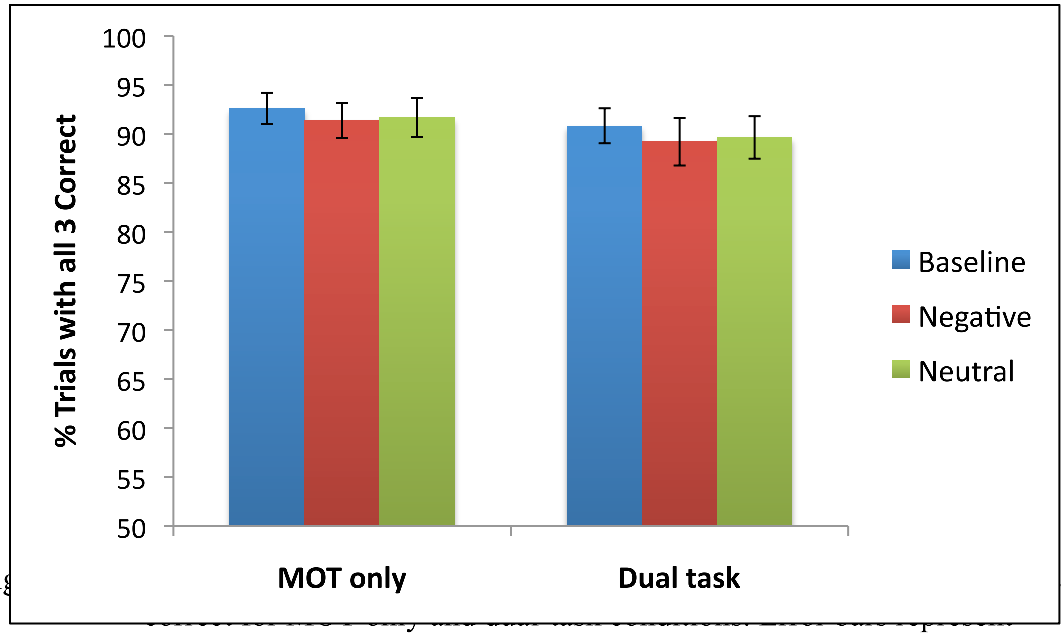


Figure 3.2 Behavioral Results of picture recognition accuracy. Error bars represent standard error from the mean.

During the MOT task, an accurate response was recorded if subjects correctly selected all three targets. Tracking accuracy was higher during the MOT-only task than under dual-task conditions (Figure 3.3). A two-factor repeated measures ANOVA on MOT accuracy with factors of image type (negative, neutral, and baseline) and task (MOT-only vs. dual-task) revealed a significant main effect of task (F (1, 17)=7.932, p =0.012). There was no significant effect of image valence (F (2, 17)=1.936, p=0.165). The interaction of valence and task was not significant (F (2, 17)=0.024, p=0.974).

These behavioral results indicate that subjects were better at recognizing and detecting the neutral picture than the negative picture. Both picture detection and recognition performance was better during conditions of full attention (i.e. picture-only condition) than conditions of divided attention (i.e. dual-task conditions). Image valence also exerted a larger effect on performance during dual-task than picture only conditions. Tracking accuracy was higher when subjects the tracking task alone (MOT-only) compared to when it was paired with picture recognition. In addition, tracking accuracy was unaffected by the type of picture appearing in the picture stream, even in the dual-task condition. This is surprising because in the dual-task condition, the occurrence of an out-of-category picture required participants to attend to the picture stream and encode the relevant picture. In contrast, in the baseline condition, participants could ignore the pictures and concentrate on the MOT task.



Fig

standard error from the mean.

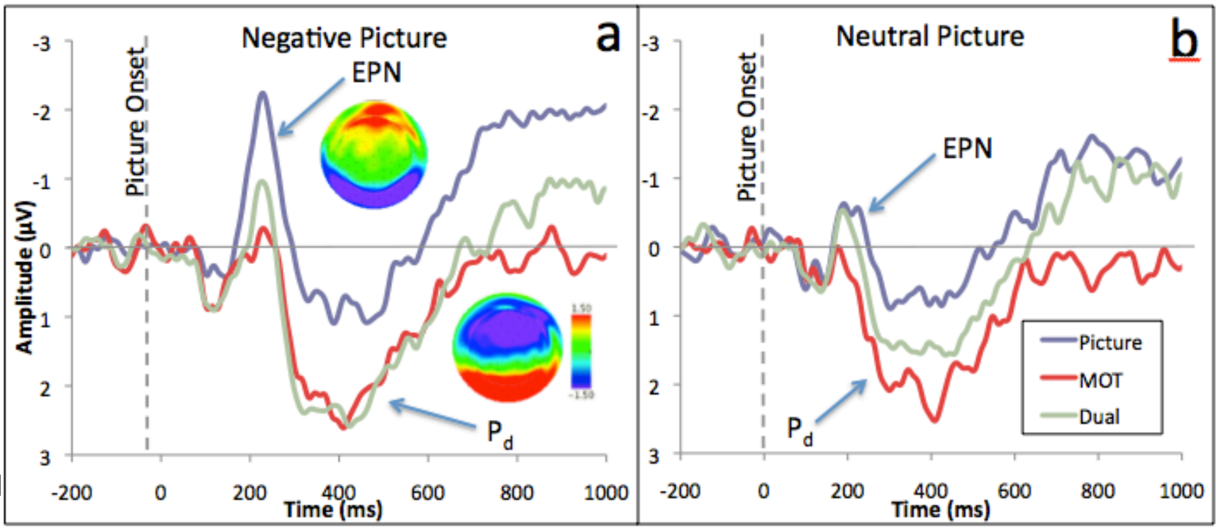
3.2 ERP Results

3.2.1 EPN Component

An EPN component to the emotional picture was observed in the picture-only and dual-task conditions as shown in Figure 3.4. The EPN peaked approximately 228 ms following onset of the emotional image, which is consistent with previous findings (Kennedy et al., 2013). A subtraction of the baseline waveform from the emotional picture waveform isolated the EPN component associated with the emotional picture from unrelated ERP activity. This subtraction was also performed between the neutral and baseline condition,

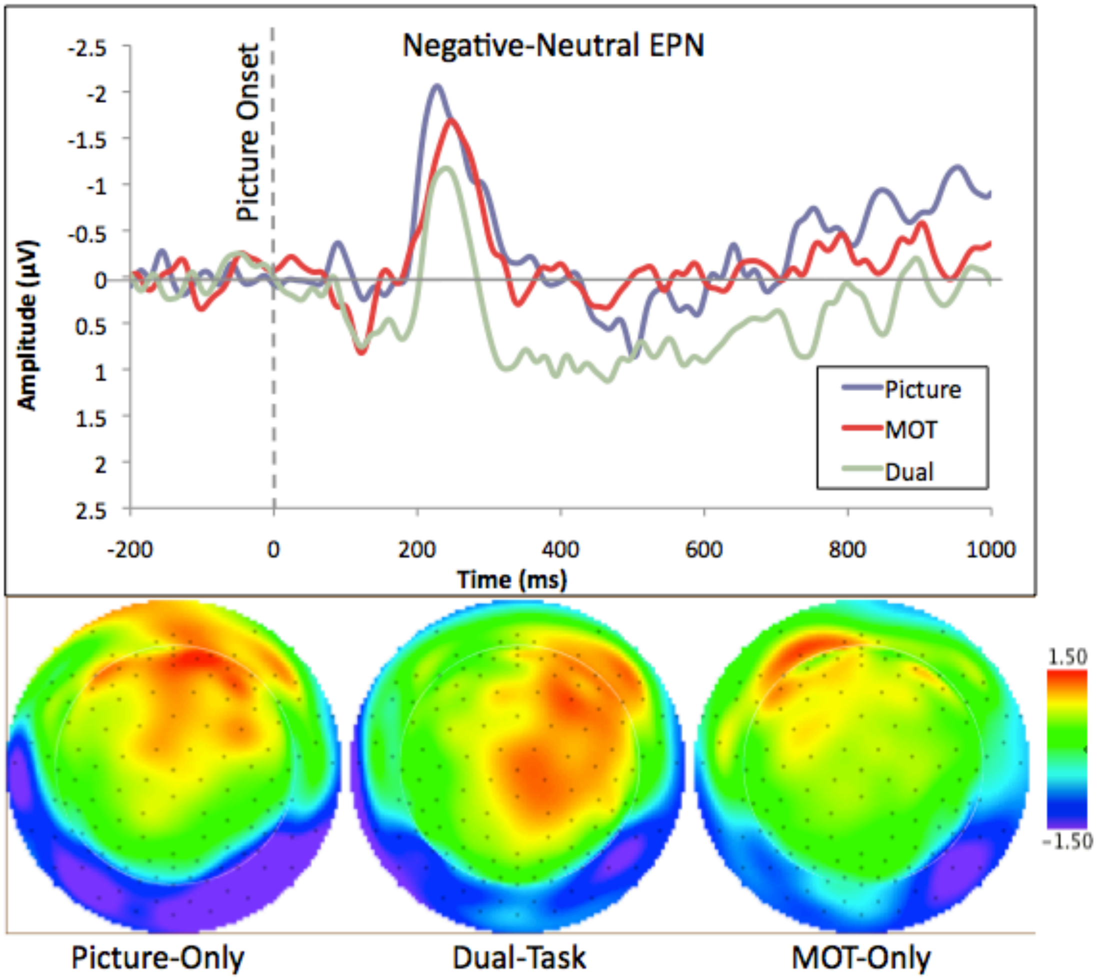
These subtraction curves are shown in Figure 3.4. A clear EPN component is evident in the picture-only condition as a broadly distributed negativity appearing over posterior electrodes (Figure 3.4a). The amplitude of the EPN was measured in a time window extending from 185 to 275ms after onset of the out-of-category image using the half maximal amplitude points on either side of the peak (Luck, 2005). The waveforms in Figure 3.4 were calculated from averages of three contiguous electrodes (90, 95, and 96) in the posterior right hemisphere and three electrodes (64, 65, and 69) in the posterior left hemisphere. These electrodes were selected based on the peak amplitude, or the point at which the EPN was maximal, which was 228ms after onset of the out-of-category picture. They are in close agreement with the sensors used in a previous study that used the same stimuli (Kennedy et al., 2013).

A three factor repeated measures ANOVA was conducted on the difference scores using factors of image valence (negative vs. neutral), hemisphere (left vs. right) and task (dual-task, MOT-only, and picture-only). There were significant main effects for hemisphere ($F(1, 17)=13.542$, $p=0.002$), image valence ($F(1, 17)=13.542$, $p=0.002$), and task ($F(2, 17)=13.123$, $p<0.001$). In addition, the two-way interactions of hemisphere by image valance ($F(1, 17)=15.232$, $p=0.001$), hemisphere by task ($F(2, 17)=4.202$, $p=0.030$), and valence by task ($F(2, 17)=4.202$, $p=0.030$) were also significant. The three-way interaction between image valance, hemisphere, and task did not reach significance ($F(2, 17)=1.461$, $p=0.248$).



after the onset of the negative picture in the picture-only condition. The lower topographic map displays the Pd component peaking at 324ms after the onset of the negative picture in the dual-task condition. The scale, displayed on the right side of the Pd topoplot, represents the amount of activation on the interval +/- 1.5 µV. Red signifies positive potential and blue/purple signifies negative potential.

The interactions involving hemisphere were further analyzed by performing separate ANOVAs on each hemisphere. A two factor repeated measures ANOVA of image valence (negative vs. neutral) X task (dual-task, MOT-only, picture-only) was performed separately on the data from the left and right hemisphere. Separate ANOVAs indicated that there was a main effect for task in both the right (F(2, 17)=7.805, p=0.002) and left (F(2, 17)=13.295, p<0.001) hemispheres. The right hemisphere ANOVA revealed a main effect of valence (F(1, 17)=33.554, p<0.001) as well as a task by valence interaction (F(2, 17)=4.600, p=0.030). The left hemisphere ANOVA, however, indicated that there was no main effect of valence (F(1, 17)=0.606, p=0.447) or valence by task interaction (F(2, 17)=0.286, p=0.748) .



conditions in the right hemisphere reveals the effect of valence on the EPN component. The topographic maps (bottom) display the EPN component for all three tasks. The scale, displayed on the right side of the topoplot, represents the amount of activation on the interval +/- 1.5 µV. Notice that the scalp topography from the subtraction curves is similar to the activation for the EPN component in Figure 3.4. The Pd component, clearly visible in Figure 3.4 has also disappeared as a result of the subtraction.

In order to investigate the nature of this lateralized valence effect, we analyzed the valence subtraction curves (i.e. the negative conditions minus the neutral conditions) for each task (Figure 3.5). The difference curves should reveal valence effects by isolating activity that is unique to the conditions with the negative emotional pictures. Since the valence subtraction curves displayed a later onset than the baseline subtraction curves, a different time window (185ms to 270ms) was selected for analysis.

As the previous ANOVA and visual inspection of the topographic plots in Figure 3.5 reveal, the EPN exhibits a larger valence effect in the right hemisphere. Therefore, we conducted a one factor repeated measures ANOVA for task (Picture-only, MOT-Only, and Dual-Task) on the time window for the valence subtraction curves in the right hemisphere. The ANOVA revealed that there was a significant main effect of task (F (2, 17)=5.980, p=0.014) in the right hemisphere. Post hoc comparisons indicate that the EPN elicited by the picture-only condition was significantly larger than the MOT-only (p=0.048) and the dual-task (p=0.011) conditions. The MOT-only and Dual-task conditions, however, were not significantly different from each other (p=0.070). Furthermore, we performed t-tests to determine if the valence curves were significantly different than zero and found that there was a valence effect for all three tasks (p's < 0.001). The valence subtraction curves indicate that the valence effect is largest during conditions of full attention, but it is still present during conditions of inattention.

Since the valence subtraction curves displayed different EPN latencies for each task (Figure 3.5), we also performed peak analyses order to further quantify the effect of attention on the EPN component. A one factor repeated measures ANOVA for task (Picture-only, MOT-Only, and Dual-Task) was conducted on the peak amplitude of the valence subtraction curves. The results of these ANOVAs revealed that there was no main effect of task on the EPN peak amplitude in the right hemisphere (F(1, 17)=3.648, p=0.055). T-tests revealed that the peaks of all of the valence curves were significantly different than zero, which suggests that there was a valence effect for all three tasks (p's < 0.001).

In summary, these results show that the EPN was larger in response to negative pictures than neutral pictures during the MOT-only and picture-only conditions. The valence of the picture did have an effect on the EPN elicited during all three task conditions. The image valence effect appeared to be lateralized and displayed larger effects on the EPN amplitude in the right hemisphere than the left.

3.2.2 Pd Component

A prominent posterior positivity, known as the Pd component, was observed following the EPN component. This positivity displayed a similar scalp topography to the EPN component but had opposite polarity (Figure 3.4a). The Pd component was isolated using the same subtraction and sensors as the EPN component. The measurement window for the Pd component was 275 – 665 ms after the onset of the out-of-category picture.

A three factor repeated measures ANOVA hemisphere (right vs. left) X image valence (negative vs. neutral) X task (MOT-only, dual-task, and picture-only) revealed a significant main effect for hemisphere (F(1, 17)= 13.778, p=0.002), reflecting a larger Pd component in the right hemisphere compared to the left. There was no interaction between hemisphere and image valence (F(1, 17)= 0.930, p=0.348) or task (F(2, 17)= 0.735, p=0.485), and consequently, the results were averaged across hemisphere for the analysis presented below.

A two-factor repeated measures ANOVA using image valence (negative vs. neutral) and task (MOT-only, dual-task, and picture-only) revealed a main effect of task (F (2, 17)= 7.301, p=0.004) and a valence by task interaction (F (2, 17)= 4.218, p=0.031). There was no significant main effect of valence (F (1, 17)= 1.423, p=0.249). Thus, valence of the picture did not affect the amplitude of Pd component elicited during the MOT-only or picture-only conditions. During dual-task conditions, however, the Pd amplitude was significantly larger in response to the negative picture than the neutral picture (p=0.032).

The amplitude of the Pd component elicited during dual-task conditions changed as a function of image valence. Post hoc comparisons revealed that the emotional picture elicited a larger Pd component in dual-task conditions than picture-only conditions (p=0.001), but the Pd components elicited during the MOT-only and dual-task conditions were not significantly different from each other (p=0.865). The Pd components elicited by neutral pictures during dual-task and picture-only conditions (p=0.095), however, were not significantly different. The neutral picture also elicited a Pd component during the MOT-only condition that was significantly larger than the picture-only condition (p=0.001).

In summary, the Pd component elicited by the emotional picture was larger during conditions of inattention than conditions of full attention to the picture stream. Like the EPN component, the Pd was larger in the right hemisphere than the left. Negative and neutral pictures elicited similar Pd components with one exception: in dual-task conditions, the Pd was larger for negative pictures compared to neutrals.

3.2.3 P3b Component

The P3b component was isolated by subtracting the baseline conditions from the negative and neutral conditions. The P3b was maximal at posterior central electrodes (54, 55, 61, 62, 78, 79), which were averaged for analysis. The waveforms in Figure 3.6 depict P3b activity elicited by the negative out-of-category picture for all three tasks. The P3b was largest in the picture-only condition, and the P3b was smaller, as well as broader, in the dual task condition. No P3b component was evident in the MOT-only condition. The topography of the P3b displayed in Figure 3.6 is clearly different from the Pd component (Figure 3.4a). In the picture-only condition, the P3b peaked at 483 ms after onset of the emotional picture. For the dual-task condition, however, the peak occurred at 519 ms. Based on the different shape of the waveforms for each task, we choose two time windows for analysis. The P3b for the picture-only condition was almost entirely contained in an early time window from 355ms to 630 ms. The dual-task P3b component began during the early time window and appeared to be sustained into a later time window from 630 ms to 930 ms. The broader P3b in the dual-task condition might be due to observers being delayed on some trials in switching attention from the MOT task to the pictures. The P3b is smaller for the neutral images in comparison to the negative images, and the MOT condition does not appear to elicit a P3b component.

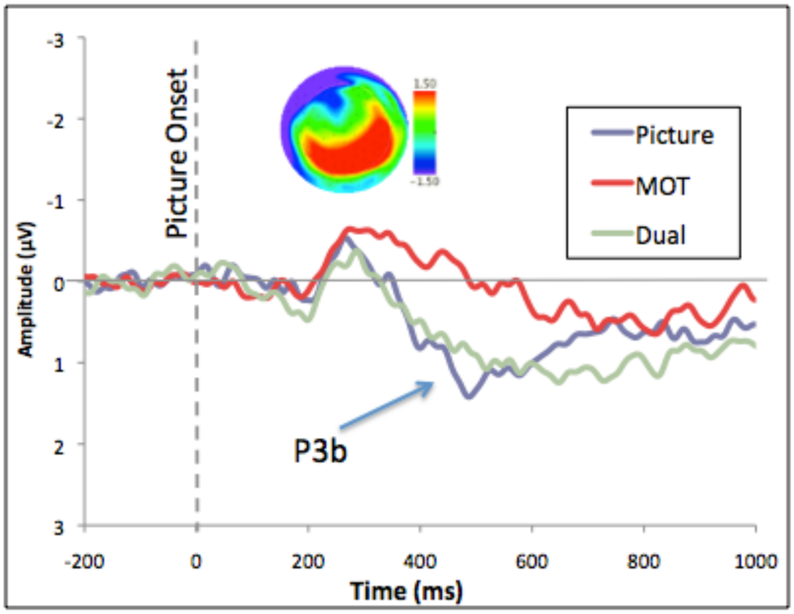


Figure 3.6 P3b component elicited by negative pictures and neutral target pictures. The P3b for the picture only condition has the largest peak, while the dual-task condition displays a broad P3b. The MOT-only condition does not appear to elicit a P3b component. The topographic map displays the P3b component at 484ms after the onset of the negative picture in the picture-only condition. The scale, displayed on the right side of the topoplot, represents amplitude as +/- 1.5 µV.

A two-factor repeated measures ANOVA with factors image valence (negative vs. neutral) X task (MOT, dual-task, and picture-only) indicated that there was significant main effect of task ($F(2, 17)= 7.227$, $p=0.003$) in the first time window. The ANOVA revealed that there was no main effect of image valence in the first time window ($F(1, 17)= 2.607$, $p=0.125$). Since there was no main effect of valence, the graph in Figure 3.6 displays P3b amplitude averaged over neutral and negative valence. There was no task by valence interaction ($F(2, 17)= 1.542$, $p=0.229$). Post hoc comparisons revealed that both of the P3b components elicited during the dual-task (*p*=0.011) and picture-only (*p*=0.003) conditions were larger than the P3b for the MOT-only condition. While the P3b component in Figure 3.6 appears to be larger for picture-only conditions than the dual-task conditions, post hoc tests reveal that this comparison did not reach significance (*p*=0.291). The P3b component elicited by the neutral images, displayed in Figure 3.6b, was larger for the picture-only condition (*p*=0.019) and the dual-task condition (*p*=0.029) than the MOT-only condition. We employed a second ANOVA to analyze the P3b components in the later time window and did not find any significant effects of task (F (2, 17)= 1.592, p=0.218) or image valence (F(1, 17)= 0.019, p=0.981). These results indicate that the P3b component is elicited during conditions of full attention to the picture stream was larger than the P3b elicited during conditions of inattention.

3.2.4 Principal Components Analysis

The similar time window and scalp topography for the P3b and the Pd components create difficulties for differentiating them. A mathematical procedure based on *principal components analysis* (PCA) was used to quantify these components.

3.2.4.1 EPN Component PCA

The PCA revealed an EPN component that peaked at 240 ms after the onset of the negative picture (Figure 3.7a), which is relatively close to the peaks for the subtraction curves (228 ms). The scalp topography for this PCA factor in the picture-only condition, displayed in Figure 3.6a, was remarkably similar to the scalp topography of the subtraction curves (Figure 3.4a). The EPN component elicited by the neutral picture was also evident in this factor, and peaked at 245ms after onset of the picture (Figure 3.7b).

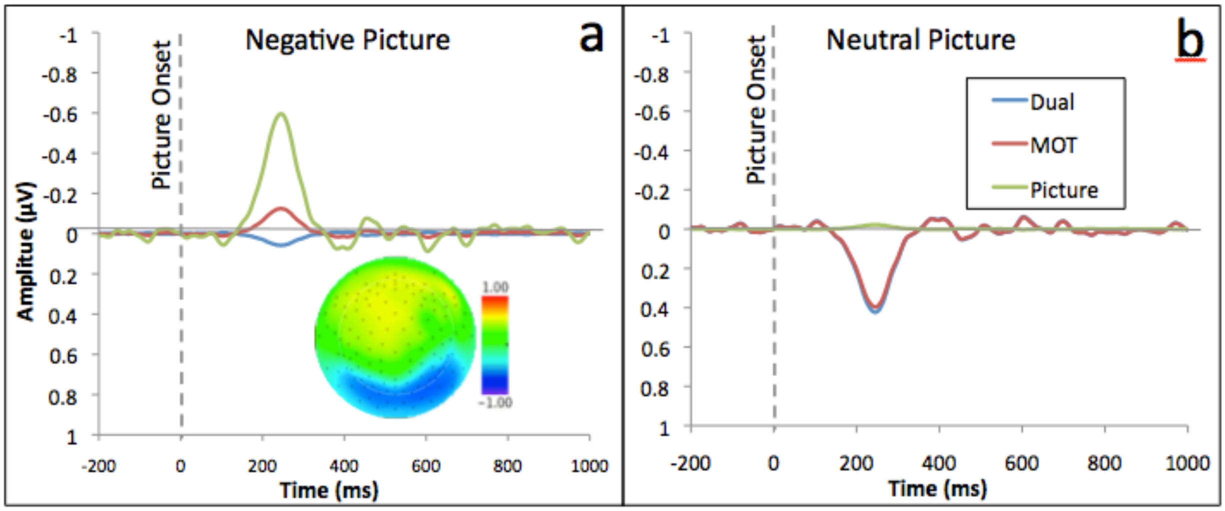
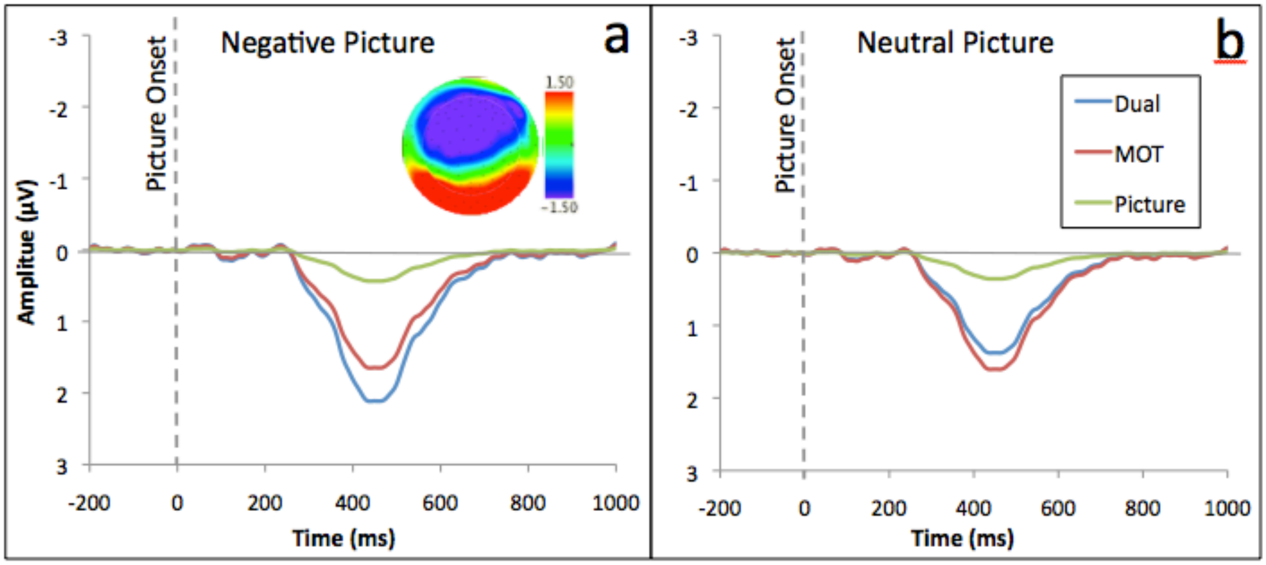


Figure 3.7 EPN Topography elicited 240 ms after onset of the negative picture (**a**) and the neutral picture (**b**) for Temporal Factor 7, Spatial Factor 1 from the PCA. The topoplot represents the scalp topography for the EPN in the picture-only condition with a sensitivity of +/- 1.0 µV.

A two-factor repeated measures ANOVA compared image valence (negative, neutral, and baseline) to task (MOT-only, dual-task, and picture-only) and indicated that the amplitude of the EPN factor displayed a significant main effect for task (F (2, 17)=11.643, p <0.001). Post hoc tests revealed that the EPN elicited during the picture-only conditions was significantly larger than the EPN elicited in the MOT-only (p=0.013) and dual-task conditions (p<0.001). Although there was no main effect of valence (F (2, 17)=3.458, p =0.075), the ANOVA did expose a task by valence interaction (F (2, 17)=3.202, p =0.027). This interaction indicated that the negative picture elicited a larger EPN component during the picture-only condition than during the MOT-only and dual-task conditions (Figure 3.7a). The EPN component elicited by the neutral picture was approximately zero for the picture-only condition and exhibited a similar positive polarity for the MOT-only and dual-task conditions (Figure 3.7b) Post hoc tests indicated that there was no significant difference between the negative (p=0.138) or neutral conditions (p=0.591) and baseline conditions. Despite the lack of significant difference between the negative and neutral conditions and baseline, the EPN elicited by the negative picture was significantly larger than the EPN elicited by the neutral picture (p<0.001).

3.2.4.2 Pd Component PCA

Figure 3.8 shows the Pd component factor extracted by the PCA. The topoplot exhibits the broadly distributed posterior positivity in conjunction with negativity over the anterior electrodes. This negativity appears to be dipolar to the posterior positivity. The Pd component elicited by the emotional picture peaked at 463ms.



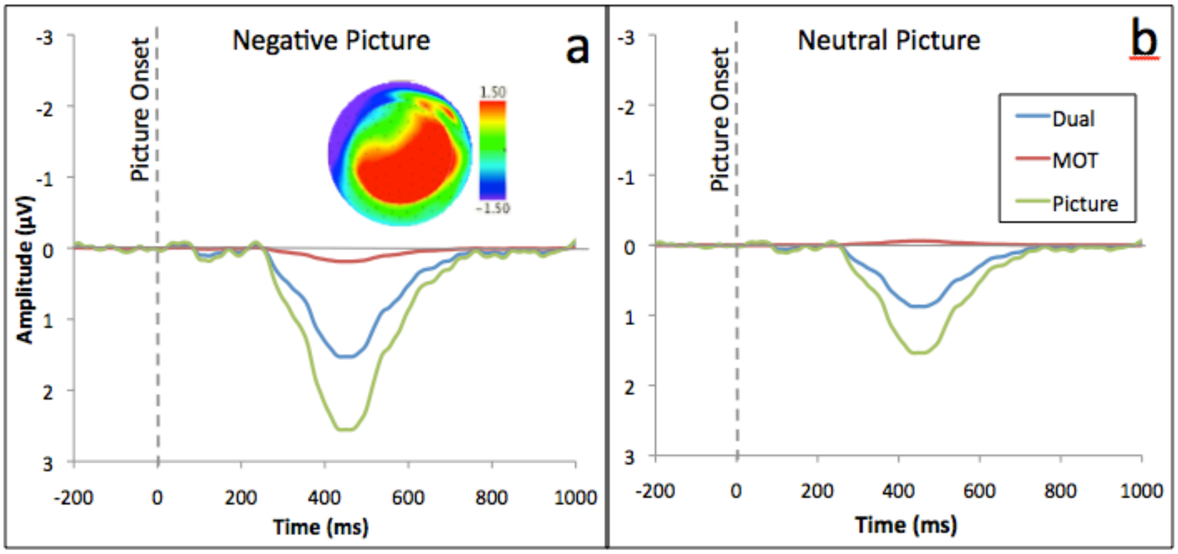
PCA. The topoplot represents the scalp topography for the Pd in the dual-task condition with a sensitivity of +/- 1.5 µV.

A two-factor repeated measures ANOVA using image valence (negative, neutral, and baseline) X task (MOT-only, dual-task, and picture-only) revealed main effects of image valence (F (2, 17)=12.976, p <0.001) and task (F (2, 17)=4.673, p =0.001) as well as a task by valence interaction (F (2, 17)=4.673, p <0.007). The Pd component was larger during the dual-task and MOT-only conditions than during the picture-only condition. Post hoc comparisons of the main effect of task indicated that the amplitudes of the Pd components elicited during MOT-only (p=0.007) and dual-task conditions (p <0.001) were significantly larger than the picture-only condition. The Pd component was larger in response to the negative pictures than the neutral pictures. Post hoc comparisons of the main effect of valence indicated that dual-task and MOT-only conditions did not differ (p =0.360). Both the negative (p =0.001) and neutral (p =0.003) pictures elicited larger Pd components than the baseline condition, but they were not significantly different (p =0.088). The image valence and task interaction was such that the Pd for the negative picture was larger in the dual-task condition than the MOT-only conditions, but the Pd component was approximately the same during dual-task and MOT-only conditions in response to the neutral picture.

3.2.4.3 P3b Component PCA

The PCA was effective in differentiating the P3b and Pd components as evident by the scalp topography of the P3b shown in Figure 3.9a, which is quite different than the Pd component shown in Figure 3.8a. Figure 3.9 also shows the waveforms for all three tasks. A two-factor repeated measures ANOVA with factors of image valence (negative, neutral, and baseline) and task (MOT-only, dual-task, and picture-only) found a significant main effect of task (F (2, 17)=27.048, p <0.001) and image valence (F (2, 17)=21.304, p <0.001).

Post hoc examination indicated that the P3b component was significantly different between all pairs of task (all p's <0 .001). For the main effect of valence, pair wise comparisons indicated that the P3b amplitude elicited by the negative picture was larger than neutral (p=0.004) and baseline pictures (p<0.001). The neutral condition (Figure 3.9b) was significantly larger than the baseline (p=0.001).



and the neutral picture (b) for Temporal Factor 2, Spatial Factor 2 from the PCA. The topoplot represents the scalp topography for the P3b in the picture-only condition to the negative picture with a sensitivity of +/- 1.5 µV.

The ANOVA also revealed a task by valence interaction ($F(1, 17)=9.418$, $p < 0.001$). Post hoc comparisons (all p's < 0.001) revealed that the nature of this interaction was such that valence exhibited the greatest effect on the P3b component in the picture-only condition. The valence exhibited a somewhat intermediate effect on the P3b component elicited during dual-task conditions. Furthermore, the P3b amplitude was barely affected by the valence of the picture in the MOT-only condition. Therefore, the amplitude of the P3b component depended on the valance of the picture and the conditions of the task.

The PCA results indicate that the PCA successfully separated the P3b and Pd components. The analysis also showed that the out-of-category images elicited a Pd component with the same scalp topography and opposite polarity as the EPN component.

Chapter 4

DISCUSSION

4.1 Behavioral Performance

Previous studies suggest that the intrinsic significance of emotional stimuli may attract attentional resources from a capacity limited process (Schupp et al., 2007b). These effects are particularly pronounced for faces when presented in the same spatial location as a directed task (Eimer et al., 2007). In order to test this theory with emotionally salient images, high-priority negative pictures were presented in the same spatial location as an attentionally demanding tracking task.

The behavioral results of the MOT and picture tasks in this experiment support the claim that dual-task conditions were more challenging than each task alone. Participants were more accurate at detecting the presence of an out-of-category picture and recognizing the presented picture during the picture-only condition than during dual-task conditions. Participants were also more accurate at tracking all three target objects during the MOT-only conditions than during the dual-tasks. Taken together, these results support the idea that the dual-task conditions were more difficult than the individual tasks.

While the valance of the image did not affect the accuracy of out-of-category image detection, subjects were more accurate at recognizing neutral pictures than negative pictures during both picture-only and dual-task conditions. Contrary to our expectations, the image valence did not affect tracking accuracy during dual-task or MOT-only conditions.

One possible reason for the lack of an image valence effect is that subjects exhibit individual differences in tracking ability combined with the difficulty of the tracking task. Some of the subjects in this study displayed a “ceiling effect,” in which tracking accuracy was close to 100%, while other subjects were close to the minimum tracking accuracy (70% correct). Research indicates that individual differences, such as the amount of time spent playing video games, create differences in over all tracking ability (Dye, Green, & Bavelier, 2009). It is possible that the primary tracking task did not deplete all attentional resources for some of these participants and left resources available for subjects to devote to the picture identification task. Therefore, if the attentional demands of the tracking task were increased to subject’s maximal capacities, image valence could pull necessary attentional resources from the tracking task and exert an effect on tracking accuracy.

Previous studies have indicated that increasing the speed of objects increases tracking difficulty (Alvarez and Franconeri, 2007). Future studies could increase tracking demands and control for individual differences by manipulating the speed of the objects such that subjects consistently obtain a predefined tracking accuracy. This manipulation would make the task more challenging for each subject based on his or her tracking ability and require subjects to allocate more attentional resources to maintain accurate tracking.

4.2 EPN

This study used ERPs to investigate the time course of brain activity underlying emotion-induced blindness, particularly the capture of attention by task irrelevant emotional pictures. We proposed that the EPN component of the ERP might serve as a marker for attentional capture. In order to investigate the capacity for task-irrelevant pictures to capture attention automatically, we examined the amplitude of the EPN component when subjects were engaged in another attentionally demanding task (i.e. the MOT-only task). Contrary to the idea that emotional stimuli automatically capture attention, the results of the baseline subtraction curves indicated that the EPN to the emotional picture was largely eliminated during conditions of inattention. The absence of an EPN component during conditions of inattention supports the claim that the EPN is a measure of attentional capture. If emotional stimuli were automatically processed, then the amplitude of the EPN component should remain the same, regardless of top-down attentional manipulations. These results are consistent with the claim by Weins et al. (2011) that the EPN is responsive to changes in attentional demands of the current task.

While there does not appear to be a difference between the EPN elicited by the negative and neutral pictures in the dual task conditions, a subtraction between these conditions reveal that an EPN component is present. In fact, when the valence effect is examined as a subtraction between negative and neutral conditions, an EPN is present in all three conditions. These findings are in agreement with previous studies (Schupp et al., 2003; Schupp et al., 2007b) that indicated that the EPN component was larger for negative pictures compared to neutral pictures. We suspect that the diminished EPN component during dual-task conditions was partially affected by the Pd immediately following the EPN component.

Although the EPN component was expected to be larger for the negative pictures than neutral pictures due to their intrinsic emotional salience, we cannot ignore the finding that the neutral pictures also produced an EPN component. The finding that neutral pictures elicit an EPN component, despite their lack of emotionality, suggests that some common feature between the neutral and negative images may be partially responsible for eliciting the EPN component. Both the negative and neutral pictures differed in physical salience from the baseline images. The baseline images consisted mainly of sprawling landscapes, while the many of the negative and neutral images displayed prominent foreground objects (i.e. close-ups of faces, people, or animals). These prominent objects may trigger attentional engagement, simply because they are different than the other pictures in the sequence. Therefore, the negative pictures may capture attention based on unknown physical salience differences between the negative images and the neutral images, rather than the emotional valence of the pictures.

Based on these findings, we suspect that the EPN component reflects a combination of bottom-up, salience driven attentional capture and top-down directed attention. Future studies should investigate the effect of valence while controlling for the physical salience of the images to determine if the enhanced attentional capture by negative images is a truly a result of valence or merely a product of physical feature differences.

4.3 Pd

Regardless of the attentional capture mechanism that emotional pictures employ, these pictures appear to require immediate suppression to avoid disruption of the attentionally demanding tracking-task. Since the moving disks in the tracking task and the emotional picture in the RSVP stream both occurred in the same spatial location, the Pd component may have been elicited to prevent attentional capture by the emotional stimulus that would produce errors in the tracking task.

We found that the Pd component was enhanced for negative images in comparison to neutral images. This difference in Pd amplitude likely reflects increased effort to suppress the compelling attentional capture of the negative pictures. These findings are consistent with previous studies, which suggest that the Pd component reflects attentional suppression of irrelevant distractor stimuli (Kiss, et al., 2012; Sawaki, et al., 2012; Sawaki et al., 2010). The presence of a Pd component elicited by task-irrelevant emotional stimuli suggests that the ignored pictures were detected, at some level, by the visual system and subsequently triggered a suppression response.

The robust positivity associated with the Pd component was also observed immediately after the EPN component in dual-task conditions. Although the EPN component elicited by MOT-only conditions was significantly smaller than the EPN during dual-task conditions, the amplitude of the Pd component was essentially the same magnitude in both conditions. These results indicate that the Pd component may be involved in the suppression of distractor stimuli, as previously believed (Kiss, et al., 2012; Sawaki, et al., 2012; Sawaki et al., 2010), as well as provide attentional disengagement from a previously attended stimulus. The suppression response elicited to disengage attention from a potentially distracting stimulus may be responsible for the reduced EPN component that we see in the dual-task and MOT-only conditions.

The absence of a Pd component following task relevant emotional stimuli during the picture-only condition provides supporting evidence for the claim that the Pd component is not elicited in response to all salient stimuli (Sawaki and Luck, 2010). The similar scalp topography and opposite polarity for the EPN and Pd components also supports the idea that the Pd component reflects a process that *suppresses* attentional engagement, which is reflected in the EPN component. This suppression would be unnecessary, even detrimental, during conditions where the picture was task relevant and no other task was being performed. Therefore, we believe that the Pd component is elicited as a mechanism of distractor suppression that enables simultaneous performance of attentionally demanding tasks.

4.4 P3b

The emotional picture elicited a P3b component during both the dual-task and picture-only conditions. Since the P3b is typically elicited during working memory consolidation (Vogel et. al, 2002; Kennedy et al., 2013), the presence of a P3b component during conditions of full and divided attention to the picture stream support our behavioral results that subjects were functioning a level well above chance at recognizing the emotional picture in both conditions.

While analysis of the general waveforms did not reveal any effect of image valence on the P3b component, the PCA analysis indicated that the P3b elicited by the negative pictures was larger than the P3b elicited by the neutral pictures, a common finding in previous studies (see Hajcak, et al., 2011 for a review). The overlapping scalp topography and latency of the Pd and the P3b components may be responsible for the broad appearance of the P3b for the dual-task condition general waveform. The PCA analysis separated the Pd component and the P3b components during the dual-task conditions and revealed that a P3b component was present for both negative and neutral pictures during conditions of full and divided attention.

The finding that the P3b component was larger for negative pictures than neutral pictures supports the claim that there is some feature associated with the negative picture that enhances working memory consolidation. As with the enhanced EPN component, it is impossible to determine if the enlarged P3b component is a result of the physical salience or emotional valence differences between the negative and neutral stimuli.

The implications of the Pd component results are further supported by the absence of a P3b during the MOT-only condition. The lack of a P3b component to emotional pictures during conditions of inattention suggests that emotional pictures are subject to attentional manipulations and are not automatically captured for working memory consolidation. Overall, the ERP results suggest that perception of emotional images, to the point of working memory consolidation, is not fully automatic and is subject to manipulations of attention. Despite the lack of working memory consolidation, ignored emotional images are perceived at some level and initiate suppression mechanisms.

4.5 Summary

Researchers have debated whether the biologically salient nature of emotional stimuli initiates automatic processing of these stimuli, despite concurrent attentional engagement in a challenging task. The present study reveals that directing attention to an emotional picture enhances attentional engagement. The EPN to emotional pictures increased when attention was exclusively directed towards the picture stream, in comparison to conditions of divided attention. Furthermore, this EPN was larger for negative than neutral pictures, indicating that the EPN component reflects manipulations of attention as well as stimulus valence. The results suggest that the EPN component probably reflects a common mechanism for attentional capture in which negative pictures capture more attention than neutral pictures, and increasing the task relevance of the pictures draws attention to pictures of both valences.

Simultaneous performance of an attentionally demanding task, however, appears to diminish the capacity of the emotional stimuli for attentional capture. The absence of a robust EPN component to the emotional picture during conditions of inattention implies that consciously directed attention gates engagement in emotionally salient stimuli. However, the reduction in attention to emotional pictures when participants are engaged in another task may reflect an active suppression process. When people were performing an attentionally demanding MOT task, we observed that out-of category pictures elicited a large Pd component, reflecting attentional disengagement from these pictures. This Pd component was larger for negative than neutral images, which suggests that the negative emotional pictures require enhanced suppression of the distractor stimuli. Note that the elicitation of a Pd component by *irrelevant* negative pictures indicates that the presence of these pictures was detected at some point leading to an active suppression of the picture. Consequently, it does appear that the visual system has a mechanism that is automatically sensitive to change, which in this case, is the appearance of a picture that is different from the background pictures in the stream. This difference appears to reflect the presence of people and animals in the out-of-category picture, as the Pd component was elicited by the appearance of both neutral and negative pictures in the stream.

When attention is divided between an emotionally salient stimulus and an attentionally demanding tracking task, the attentional capture of the emotional stimulus requires immediate suppression to preserve tracking accuracy. The suppression of emotionally salient stimuli in the divided attention condition produced the same neural signature as suppression of emotionally salient distractor stimuli in the inattention condition. This attentional disengagement, indexed by the Pd component, appears to reflect direct suppression of the attentional engagement indicated by the EPN component. Taken together, these results suggest that some feature of the negative emotional stimuli initiate enhanced attentional capture and subsequently increase suppression of salient stimuli. Further investigation is required to determine if the specific feature responsible for enhanced attentional capture of salient stimuli is dependent on emotional valance or some other physical salience feature of the stimuli.

REFERENCES

Alvarez, G. A., & Franconeri, S. L. (2007). How many objects can you track?: Evidence for a resource-limited attentive tracking mechanism. *Journal of Vision*, *7*(4), 1–10.

Bradley, M. M., Hamby, S., Low, A., & Lang, P. J. (2007). Brain potentials in perception: Picture complexity and emotional arousal. *Psychophysiology,* 44, 364-373.

Brainard, D. H. (1997). The Psychophysics Toolbox, *Spatial Vision*, *10,* 433-436.

Cavanagh, P., & Alvarez, G. A. (2005). Tracking multiple targets with multifocal attention. *Trends in cognitive sciences*, *9*(7), 349–354.

Cohen, M. A., Alvarez, G. A., & Nakayama, K. (2011). Natural-scene perception requires attention. *Psychological science*, *22*(9), 1165–1172.

Dye, M. W. G., Green, C. S., & Bavelier, D. (2009). Increasing Speed of Processing With Action Video Games. *Current directions in psychological science*, *18*(6), 321–326.

Eimer, M., & Holmes, A. (2007). Event-related brain potential correlates of emotional face processing. *Neuropsychologia*, *45*(1), 15–31.

Eimer M., Holmes A., & McGlone F. (2003). The role of spatial attention in the processing of facial expression: An ERP study of rapid brain responses to six basic emotions. *Cognitive, Affective, and Behavioral Neuroscience*. 3, 97–110.

Folk, C. L., & Remington, R. (2006). Top-down modulation of preattentive processing: Testing the recovery account of contingent capture. *Visual Cognition*, 14, 445–465.

Folk, C. L., Remington, R., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology*, *18*(4), 1030-1044.

Hajcak, G., Weinberg, A., MacNamara, A., & Foti, D. (2012). ERPs and the Study of Emotion. In S.J. Luck & E.S. Kappenman (Eds.), *Oxford Handbook of ERP Components.* New York: Oxford University Press, 441-474.

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of cognitive neuroscience*, *18*(4), 604–613.

Holmes A, Kiss M, & Eimer M. (2006). Attention modulates the processing of emotional expression triggered by foveal faces. *Neuroscience Letters*, 394, 48–52.

Holmes A., Vuilleumier P., & Eimer M. (2003). The processing of emotional facial expression is gated by spatial attention: Evidence from event-related brain potentials. *Cognitive Brain Research*. 16, 174–184.

Mack, A., & Rock, I. (1998). *Inattentional blindness: Perception without attention.* Cambridge, MA: MIT Press.

Most, S.B., Chun, M.M., Widders, D.M., & Zald, D.H. (2005). Attentional rubbernecking: Cognitive control and personality in emotion-induced blindness. *Psychonomic Bulletin & Review,* 12*,* 654-661.

Most, S.B., & Wang, L. (2011). Dissociating spatial attention and awareness in emotion-induced blindness. *Psychological Science, 22*(3), 300-305.

Kiss, M., Grubert, A., Petersen, A., & Eimer, M. (2012). Attentional capture by salient distractors during visual search is determined by temporal task demands. *Journal of cognitive neuroscience*, *24*(3), 749–59.

Kennedy, B. L., Rawding, J., Most, S. B., & Hoffman, J. E. (2013). Emotion-induced blindness reflects an early perceptual disruption: An ERP study. *Manuscript in preparation.*

Koch, C., & Tsuchiya, N. (2007). Attention and consciousness: two distinct brain processes. *Trends in cognitive sciences*, *11*(1), 16–22.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). International Affective Picture System (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-6. University of Florida, Gainesville, FL.

Li, F., VanRullen, R., Koch, C., & Perona, P. (2013). Rapid natural scene categorization in the absence of attention. *Proceedings of the National Academy of Sciences*, *99*(14), 9596–9601.

Luck, S. J. (2005). *An introduction to the Event-Related Potential Technique*. Cambridge, MA: MIT Press.

Nakatani, C., Baijal, S., & van Leeuwen, C. (2012). Curbing the attentional blink: Practice keeps the mind's eye open. *Neurocomputing,* 84*,* 13-22.

Ohmn, A., Flykt, A., & Esteves F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General*, 130, 466-478.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies, *Spatial Vision*, 10, 437-442.

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical neurophysiology*, *118*(10), 2128–2148.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology,* 32, 3-25.

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: evidence for a parallel tracking mechanism. *Spatial vision*, *3*(3), 179–97.

Rousselet, G., Fabre-Thorpe, M., & Thorpe, S. (2002). Parallel processing in high-level categorization of natural images. *Nature Neuroscience*, 5, 629–630.

Sawaki, R., Geng, J. J., & Luck, S. J. (2012). A common neural mechanism for preventing and terminating the allocation of attention. *The Journal of Neuroscience, 32*(31), 10725-10736.

Sawaki, R., & Luck, S. J. (2010). Capture versus suppression of attention by salient singletons: electrophysiological evidence for an automatic attend-to-me signal. *Attention, Perception, & Psychophysics, 72*(6), 1455-1470.

Scholl, B. J. (2001). Objects and attention: the state of the art. *Cognition*, 80(1-2), 1–46.

Schupp, H.T., Flaisch, T., Stockburger, J., & Junghöfer, M. (2006). Emotion and attention: Event-related brain potential studies. *Progress in Brain Research,* 156, 31-51.

Schupp, H.T., Junghöfer, M., Weike, A.I., & Hamm, A.O. (2003a). Emotional facilitation of sensory processing in the visual cortex. *Psychological Science, 14*(1), 7-13.

Schupp, H.T., Stockburger, J., Codispoti, M., Junghofer, M., Weike, A.I., & Hamm, A.O., (2007b) Selective visual attention to emotion. *Journal of Neuroscience,* 27, 1082–1089.

Sibly, M. (2005). Blitz3D (Version 1.90) [Computer software]. Auckland, New Zealand: Blitz Research Ltd.

Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta psychologica*, *135*(2), 77–99.

Vogel, E.K., & Luck, S.J. (2002). Delayed working memory consolidation during the attentional blink. *Psychonomic Bulletin & Review, 9*(4), 739-743.

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2001). Effects of attention and emotion on face processing in the human brain: an event-related fMRI study. *Neuron*, *30*(3), 829–41.

Wang P. & Nikolic D. (2011). An LCD Monitor with Sufficiently Precise Timing for Research in Vision. *Frontiers in human neuroscience, 5*(85), 1-10.