IS SEMANTIC PROCESSING AUTOMATIC?

by

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ABSTRACT

Emotion-induced blindness (EIB) occurs when an emotionally salient, irrelevant distractor grabs attention and causes impaired awareness for subsequent relevant targets. The extent of processing target pictures receive before emotional pictures block them from awareness remains unclear. The central interference theory proposes a two-stage model of processing that must occur for awareness of targets. During the first stage, stimuli are rapidly detected and semantically processed and if they contain target features, they are selected to enter stage 2. Stage 2 processing involves consolidation into working memory (Chun & Potter, 1995). The current study focused on whether missed target pictures were semantically processed before being blocked from awareness, as predicted by the central interference theory. We measured semantic processing using the N400 event-related potentials. We also examined whether or not targets were processed through early selection phases using the N2 component and whether or not they were consolidated into working memory using the P3b component. Participants viewed streams of pictures that could contain a negative (emotionally arousing picture), neutral (a nonthreatening picture of people or animals), or baseline (landscape) picture followed by a target picture that was related or unrelated to a previously presented object picture. We found that the N400 to an unrelated picture presented in the lag 2 position was similar across all distractor conditions. Behavioral data suggested that participants were impaired in detecting targets pictures presented at lag 2 when they were preceded by negative or neutral distractors. On the other hand, the ERP data hinted that participants were experiencing an emotional blink. The data support the central interference theory and suggest that semantic processing can occur without awareness.

Chapter 1

INTRODUCTION

Emotional scenes tend to grab our attention. For example, drivers may take their attention off of the road in order to catch a glimpse of a car accident on the side of the road. These “rubberneckers” may miss other important stimuli in their environment like brake lights or road signs. This phenomenon is called emotion-induced blindness (EIB).

Most, Chun, Widders, and Zald (2005) were the first to study the EIB phenomenon in the laboratory. They presented RSVP (rapid serial visual presentation) streams consisting of 17 pictures presented for 100ms each. Fifteen of the pictures were upright background architectural or landscape pictures. A negative, neutral, or a scrambled negative distractor picture was presented as the 4th, 6th, or 8th picture in the stream. The target picture was a background scene rotated 90° to the left or right and appeared two pictures (lag 2) or 8 pictures (lag 8) after the distractor picture. Subjects were told to ignore pictures of people or animals. Most et al. (2005) observed that participants were significantly worse at reporting the direction of rotation of the target picture when it was preceded by a negative picture at lag 2 compared to a neutral or scrambled negative picture. However, no significant effect of distractor type was observed at lag 8. They concluded that irrelevant emotional pictures temporarily impair visual processing of relevant targets.

Important questions regarding EIB remain unanswered. The extent blinked targets are processed before they are blocked from awareness remains unknown. Is processing of the targets interrupted at early, perceptual levels or does interruption occur during later stages like during semantic processing or consolidation into working memory?

1.1 Similarities between Emotion-Induced-Blindness and the Attentional Blink

Superficially, EIB seems very similar to another paradigm, the attentional blink (AB). The relevance of the first target is the crucial difference between the two tasks. The emotional picture is irrelevant in EIB tasks while in AB tasks two relevant targets are presented.

The attentional blink phenomenon was discovered by Raymond, Shapiro, and Arnell (1992). They presented stimuli in an RSVP stream which contained background stimuli that were black letters. Within the stream, a white letter was presented as the first target and then a black letter “X” appeared as the second target. The number of background stimuli between the two targets varied. In this study, the lag between the targets varied. Participants reported the identity of the white letter and whether an “X” was presented in the stream. Raymond et al. found that when the second target followed the first target with one or two intervening pictures (lag 2 or lag 3) detection of the second target was severely impaired. This decrease in performance is referred to as the attentional blink. However, performance in the lag 1 condition was quite high (82%). This phenomenon is referred to as lag 1 sparing.

Several theories have been developed to explain the AB phenomenon. One of the most influential is the central interference theory. This theory states that there are two stages of processing a target must go through for detection to occur. Stage 1 involves parallel identification and semantic processing of all stimuli. Attended stimuli enter stage 2 processing by passing through a “bottleneck” that is limited to a single stimulus or event. Stage 2 is capacity-limited and involves the consolidation of the task-relevant stimulus. When the bottleneck leading to the consolidation process is occupied, subsequent stimuli must wait to gain access and are subject to masking by following stimuli in the stream. In the case of the AB, the first target gains access to stage 1, blocks access by the second target when it follows at short time intervals, (Chun & Potter, 1995). However, because stage 1 processing is automatic and not subject to capacity limits, the second target is identified and semantically processed even when it is unreportable (Vogel et al., 1998).

To study the stages of processing targets reach, researchers frequently use measures based on the electroencephalogram or EEG. The EEG is measured using sensors placed on the scalp which pick up weak electrical activity produced by neural activity in the brain. These signals are amplified and plotted as a voltage over time. It is difficult to discern specific activity in the EEG that is associated with particular cognitive processes as the background activity of the brain is much larger than the specific activity that is related to the participant's current task. However, synchronizing recordings to the onset of a relevant stimulus and averaging the EEG over many trials can reveal the specific activity associated with processing of the relevant stimulus. This averaged activity is known as an event-related potential or ERP (Luck, 2005). ERP waveforms consist of positive and negative deflections referred to as ERP components. Several ERP components have been identified and through extensive research scientists have been able to theorize what cognitive processes they index.

The current study uses ERPs to evaluate the level of processing targets receive when they are blinked following an irrelevant emotional picture. The study was designed based on previous AB and EIB research. We will examine the effect emotional pictures have on the early selection phase (using the N2pc component), consolidation of the target into working memory (using the P3b component), and semantic processing (using the N400 component).

1.2 N2: Early Selection

In the current study, we will be indexing target selection with the N2 component. The N2 is a negativity that appears over posterior parietal scalp locations approximately 200-300ms after stimulus presentation. Luck and Hillyard (1994) were the first to identify this component using a visual search paradigm. They found that the N2 occurred in response to finding a target among many non-targets. They suggested that this component reflected filtering or selection of targets from non-targets.

Using an AB paradigm Sergent et al. (2005) observed N2s in response to two targets designated as T1 and T2. At short lags, they found that when the N2 in response to T1 was large, the N2 to T2 was small. Sergent et al. (2005) suggested that the N2 was the first of several components needed for awareness of T2. Using an EIB paradigm, Kennedy et al. (*in press*) examined the N2 in response to distractor pictures and targets. They observed that emotional pictures elicited larger N2s than did neutral distractor pictures which, in turn, elicited larger N2s than background pictures. Targets preceded by background pictures were easy to detect and also elicited large N2s. However, they observed suppression of the target N2 when it was preceded by a distractor picture. The suppression was larger when a negative distractor preceded the target compared to when the target was preceded by a neutral distractor. Similar to Sergent et al. (2005), they found that when the N2 to the distractor picture was large, the N2 to the subsequent target picture was small and vice versa. This implies that the selection of T1 can interrupt the selection of T2. Importantly, the size of the N2 to the distractor was related to participants' accuracy in reporting the target. This suggests that distractor pictures impede the selection of the target indicated by the target N2 which in turn impedes the awareness of the target.

Kennedy et al. (*in press*) concluded that the N2 was associated with object-based attention for relevant targets and emotional distractors that were task-irrelevant, but salient nonetheless. They suggested that longer selection times for emotional distractors may prevent the target from entering the selection process for working memory consolidation. To relate this to the central interference theory, if the distractor picture remains in the selection processor for too long, the processor may miss the target picture.

1.3 P3b: Consolidation into Working Memory

To index consolidation of information into working memory, we will be examining the P3b component. The P3b component is a positivity that is maximal over posterior parietal sites with a latency of 200-500ms post-stimulus (for review see Polich, 2007). Previous research indicates that the P3b is related to consolidation of information into working memory (Donchin, 1981, Donchin & Coles, 1988).

Several studies have looked at the P3b in response to T1 and T2 in an AB paradigm. For example, Vogel et al. (1998) measured ERP components during the attentional blink task to identify what stage of processing targets reach before they are eliminated from awareness. They studied the P1, N1, N400, and P3b components. P1 and N1 which are indexes of early perceptual processing were unaffected by the attentional blink suggesting that blinked targets are perceptually processed before they are blocked from awareness. The N400 component was used as a measure of whether or not a target word presented during the AB was processed for meaning though it could not be reported. All trials began with the presentation of a context word and subjects were asked to identify a number (T1) and whether or not a target word (T2) matched the given context. Vogel, Luck, and Shapiro (1998) found that the N400 was not suppressed during the AB. This finding suggests that the words must have been identified during the AB despite subjects' inability to report the words. Using a slightly different AB task, Vogel et al. (1998) found that the P3b in response to a T2 at lag 3 was suppressed.

The results from Vogel et al. (1998) suggest that, as predicted by the central interference theory, targets were perceptually and semantically processed in stage 1 before being blocked from awareness. Also predicted by the central interference theory, the targets were not consolidated into working memory and could not be reported at short lags because the bottleneck leading to working memory consolidation was occupied by the first target.

Kranczioch et al. (2007) extended these findings and measured the P3b, elicited by both targets in an AB task. They found that when T1 elicited a large P3b, T2 elicited a small P3 and vice versa. In addition, studies have found that on incorrect trials, T1 elicited a large P3b, but T2 elicited a small P3b (Shapiro et al., 2006). These results suggest in cases where the P3b to T1 is large and the P3b to T2 is small that T1 occupies the bottleneck and enters working memory and prevents T2 from entering the bottleneck. In cases where the P3b to T1 is small and the P3b to T2 is large, the T1 does not occupy the bottleneck and does not prevent T2 from entering the bottleneck and working memory.

Kennedy et al. (in press) also examined the P3b in EIB to determine whether negative distractor pictures are consolidated into working memory though they are irrelevant and whether the distractor pictures prevent target pictures from entering working memory as the central inference theory postulates. They found that emotionally arousing pictures elicited a P3b which suggests these pictures enter working memory even though they are task irrelevant. Critically, on incorrect trials, emotional pictures elicited a larger P3b than on trials when the participants were correct suggesting that emotional pictures occupied the bottleneck and entered working memory and prevented the target from entering the bottleneck and, therefore, working memory.

To put these data in the perspective of the central interference theory, T1 in AB and the emotional distractor in EIB enter stage 1, are selected as salient information, and enter stage 2 processing. At short lags, T2 in AB and the single target in EIB enter stage 1 processing, are unable to be selected as salient information, and cannot enter stage 2 because the bottleneck is still occupied by T1 or the emotional distractor. T2 and single target are masked by the subsequent objects in the stream, fail to enter the consolidation phase and cannot be reported. The central interference theory appears to provide a good account of both EIB and AB.

1.4 N400: Semantic Processing

The current study aims to determine whether semantic processing of targets occurs during the emotional blink period. We will be using the N400 component to index semantic processing.

Kutas and Hillyard (1980) studied the ERP elicited by the final word in short sentences. Seven word sentences were presented one word at a time to participants and

ERP responses to the final word in each sentence were recorded. This word could be semantically congruent (75% of trials) or incongruent (25% of trials). An example of a congruent sentence is “I have planted seeds in my garden.” An example of an incongruent sentence is “I put my keys in my blender.”

Kutas and Hillyard observed a prominent negativity occurring approximately 400ms following the final word. This component, which is called the N400, had a broad scalp distribution with a parietal maximum and was larger when the final word was strongly semantically incongruent compared to when it was moderately semantically incongruent. “I took a drink from my pot.” is an example of a moderately incongruent sentence. Strongly incongruent sentences were anomalous. For example, “I took a drink from my bike.” The physical appearance (font size) of the final word in sentences was also manipulated, but this did not elicit a N400, but rather a positive component similar to the P3. Kutas and Hillyard concluded that the N400 represents an interruption of the semantic processing of the sentence by the incongruent word followed by reprocessing of the sentence (1980).

Since its discovery, the N400 has been studied in great detail. The N400 is largest over central parietal sites and tends to be slightly larger and longer in duration over the right hemisphere compared to the left hemisphere (Kutas & Hillyard, 1982). Experimental manipulations of the N400 show that the amplitude can vary, but the latency of the component is very stable. Scalp topography is consistent for visual stimuli, but can vary when stimuli are presented through different modalities (reviewed in Kutas & Federmeier, 2011).

In addition to the importance of the N400 in the study of language, it can also be used as a measure of semantic processing in non-language tasks. Critically, pictures, line drawings, and faces can elicit N400s. Nigam, Hoffman, and Simons (1992) directly compared the N400 resulting from words and pictures presented at the end of sentences. They found that the N400 elicited by an incongruent word presented at the end of a sentence was very similar in scalp topography, amplitude, and latency to the N400 elicited by an incongruent picture presented at the end of a sentence. These results suggest that the N400 reflects activity in a conceptual system that represents the meaning of both words and pictures (Nigam, Hoffman, & Simons, 1992).

In a follow-up study, Ganis, Kutas, and Sereno (1996) compared N400s elicited by written words and pictures in a with-in subject design as opposed to the between-subject design used by Nigam, Hoffman, and Simons (1992). Nigam et al. (1992) they presented sentences with congruent or incongruent words or pictures appearing at the ends of short sentences. Sentences with a picture or a word at the end were blocked for some subjects and mixed for others. Results showed an N400 effect for mixed and blocked conditions and the time courses of the N400s elicited by pictures and words were very similar. N400 elicited by pictures had a larger frontal extent and written words had a larger posterior extent. Because there are similarities and differences in the N400s in response to pictures and words, Ganis, Kutas, and Sereno concluded that two functionally similar neural systems may exist that processes pictures and words, but have some overlapping and non-overlapping elements.

McPherson and Holcomb (1999) observed N400s in response to pictures of real objects. They presented subjects with a prime picture, a blank screen, and then a second picture and were asked to identify whether the second picture was related or unrelated to the first. Similar to Ganis et al. (1996), McPherson and Holcomb (1999) found that unrelated pictures elicited an anterior N400-like response. Because this N400 in response to pictures is different in topography than N400s in response to words, McPherson and Holcomb (1999) concluded that words and pictures activate different neural systems.

1.4.1 Attentional Blink and the N400

Several studies have been designed to evaluate the automaticity of semantic processing. The previously discussed paper by Vogel et al (1998) was the first to study the N400 during the attentional blink, but several studies have been developed to test their findings.

Giesbrecht, Sy, and Elliott (2007) manipulated the attentional resources needed to encode T1 and evaluated whether this would have an effect on N400s in response to T2. Participants were given a context word, presented with T1 which was a high-load (>> < >>) or low-load stimulus (>> > >>), and then presented with T2 which was a white word among strings of black numbers and letters that was related or unrelated to the context word. At the end of the trial, participants were asked to report the direction of the central arrow and whether T2 was related or unrelated to the context word. They found that the N400 was attenuated on trials where T1 had a high perceptual load, but a typical N400 effect was observed when T1 had a low perceptual load. Giesbrecht et al. showed that attentional resources devoted to T1 play a role in whether T2 elicits an N400. This study suggests that semantic processing can, but may not always occur during the blink period.

Batterink, Karns, Yamada, and Neville (2009) sought to determine whether semantic processing is an automatic or a controlled process. They showed participants a context word, followed by an RSVP stream of blue consonant strings that contained a T1 (a red number word) and a T2 (a related or unrelated word also appearing in red). If the N400 reflects an automatic process, the N400 would be the same on correct and incorrect trials. However, their results showed that the N400 was larger for correct trials relative to incorrect trials. This suggests that T2 was not semantically processed before being blocked from awareness when T2 was blinked. Their results provided evidence that the N400 reflects a controlled process. Their results refute the claim made by Vogel et al (1998) semantic processing occurs on every trial. Instead, their results suggest that the semantic processing does not occur on incorrect trials, but does occur on correct trials.

Rolke, Heil, Streb, and Hennighausen (2001) aimed to study the semantic processing of a blinked target much like Vogel et al. (1998), Giesbrecht et al. (2007) and Batterink et al. (2009), but created a different paradigm to do so. Rolke, Heil, Streb, and Hennighausen (2001) created a study to investigate whether or not a T2 presented during the blink period is semantically processed by using T3 as a probe and measuring ERPs in response to T2 and T3. Participants were instructed to report three white target words among an RSVP stream of black words. T2 was presented in the blink position. T3 was either semantically unrelated, weakly semantically related, or strongly semantically related to T2. Rolke et al. (2001) found that when primes were recognized, an N400 effect was observed. When primes were missed, this N400 effect remained. Their results suggest that T2 was semantically processed before being blocked from awareness which allowed the N400 effect in response to T3 to occur. These results support Vogel, Luck, and Shapiro (1998).

In a very similar study, Pesciarelli, Kutas, Dell'Acqua, Peressotti, Job, and Urbach (2007) used the attentional blink paradigm to examine semantic priming. The major difference between this study and Rolke et al. (2001) is that prime pairs were repeated in Rolke et al. (2001), but were not repeated during the course of the study. They inserted 3 colored (T1 was green and T2 and T3 were red) word targets in a stream of black consonant strings. T2 was placed in a blink period after T1 presentation. T2 was either the same word as T3, semantically related to T3, or semantically unrelated to T3. They found that in cases when T2 was reported, N400s in response to unrelated T3s were larger than N400s in response to related T3s. This effect was not observed during trials in which T2 was not able to be reported suggesting that the N400 was attenuated. Their results suggest that semantic processing of T2 did not occur when the word was unable to be reported after presentation during the blink period. This resulted in a lack of an N400 effect in response to related and unrelated T3s. This study and Rolke et al. (2001) do not measure N400s during the blink period, however. The authors rely on responses to T3 to infer the extent of processing of T2 during the blink period

Semantic processing has not been well studied in EIB paradigms. The current study will be the first of its kind.

1.5 The Current Study

To this point, no one has evaluated the semantic processing of a target presented during the blink period in an EIB task. In addition, semantic processing during the blink period of an AB task has only been evaluated using words, not pictures. Studies like Rolke et al. (2001) and Pesciarelli et al. (2007) are limited in that they did not measure N400s during the blink period, but rather manipulated awareness of a prime word during the blink period which in turn manipulated N400s to probe words outside of the blink period.

The current study was designed to use the N400 component of the ERP to evaluate whether processing of emotional pictures interrupts semantic processing of subsequent target pictures. The current study is similar to the previously discussed study by Vogel, Luck, and Shapiro (1998), but uses pictures rather than words in an EIB paradigm rather than an AB paradigm. This design allowed us to evaluate whether processing of an irrelevant emotional picture interrupts semantic processing of a subsequent target picture or whether semantic processing of the target picture is automatic and occurs without awareness.

After participants are presented with a picture of a context object, they will be asked to determine whether a target picture indicated by a surrounding red frame is related or unrelated to the context object. A target picture will be presented in the blink position (200ms after the presentation of the distractor picture). We will then evaluate whether or not the N400 is attenuated when the target picture is blinked from conscious awareness. Attenuation of the N400 in response to a blinked target picture suggests that the processing of emotional pictures does interrupt semantic processing of the target picture. However, the N400 in response to a blinked target picture may not be attenuated, similar to Vogel, Luck, and Shapiro (1998), suggesting that processing of emotional pictures does not interrupt semantic processing and that semantic processing is automatic.

The central interference theory predicts that stage 1 processing which includes sematic processing occurs for all stimuli which would predict that a similar N400 would occur to unrelated targets regardless of whether a negative, neutral, or baseline picture preceded the target. The central interference theory also predicts that targets presented at lag 2 will likely not be consolidated into working memory as they will not make it to stage 2 because stage 2 is occupied with the distractor picture. Because the current study is designed much like Vogel et al. (1998), but uses an EIB task like Kennedy et al. (*in* press), we predict that our results will mirror their results. The results from Kennedy et al. (*in* press) and Vogel et al. (1998) support the central interference theory and we suspect that our study will follow suit.

In the current study, the target picture should elicit both an N400 and a P3b. These two components overlap in time and space which poses challenges to obtaining separate measures of their amplitude. In order to disentangle these components, a principal components analysis will be used (see section 2.5.1 for more information).

Chapter 2

METHODS

2.1 Participants

Fifteen right-handed neurologically normal participants (4 males and 11 females, mean age: 20, age range: 18-22) were recruited through distributed flyers to participate in this experiment. All participants gave informed consent and were reimbursed $10/hour for their participation. Participants were naïve to the purpose of the experiment. Participants reported their vision as normal or corrected-to-normal. The University of Delaware Institutional Review Board approved this experiment. Each participant received debriefing at the conclusion of the experiment. Three participants were eliminated due to noisy data.

2.2 Stimuli

Participants performed the task in a dimly lit, electrically shielded room. They were instructed to place their chin in a chinrest that maintained a viewing distance of 70cm from the screen. A Dell 2.99-GHz computer running custom software written with Psychopy generated the stimuli, which were presented on a Samsung Syncmaster 2233RZ LCD display (Wang & Nikolic, 2011) with a refresh rate of 60Hz and a viewing area of 34 x 24.4 degrees of visual angle (dva). Eye fixation was monitored with an Eyelink 1000 infrared eyetracker running at 500Hz. The stimuli were presented in the center of the screen, while the remainder of the screen was black. A square fixation point was presented at the beginning of each trial and disappeared upon the presentation of the first picture.

To begin each trial, a 200x200pixel object picture was shown. These were pictures of everyday objects presented on a white background (Figure 2.1a). An RSVP stream appeared containing 320x240pixel pictures each presented immediately after the preceding picture. Most of the pictures in the RSVP stream were background pictures of landscapes or cityscapes (Fig 2.1f).

Two-thirds of the RSVP sequences contained a negative or neutral distractor picture. Negative and neutral pictures were taken from the International Affective Picture System (IAPS) which is a set of pictures normalized and rated for arousal and emotional valence (Lang, Bradley, & Cuthbert, 1997). Neutral pictures contained people and animals, but were not emotionally arousing (Fig 2.1e). Negative pictures depicted threatening animals, violence, or medical trauma (Figure 2.1d). Participants were shown examples of these potentially unpleasant pictures prior to engaging in the experiment. They were told that they could terminate the experiment at any time should the pictures upset them and they would be compensated for their time. RSVP streams that contained only background pictures were used as a control condition.

Within the RSVP stream, target pictures were presented with a red frame around them. Target pictures contained everyday objects in a natural scene (Figure 2.1b and Figure 2.1c). Participants were instructed to identify whether the target picture was related or unrelated to the object picture presented prior to the RSVP stream.

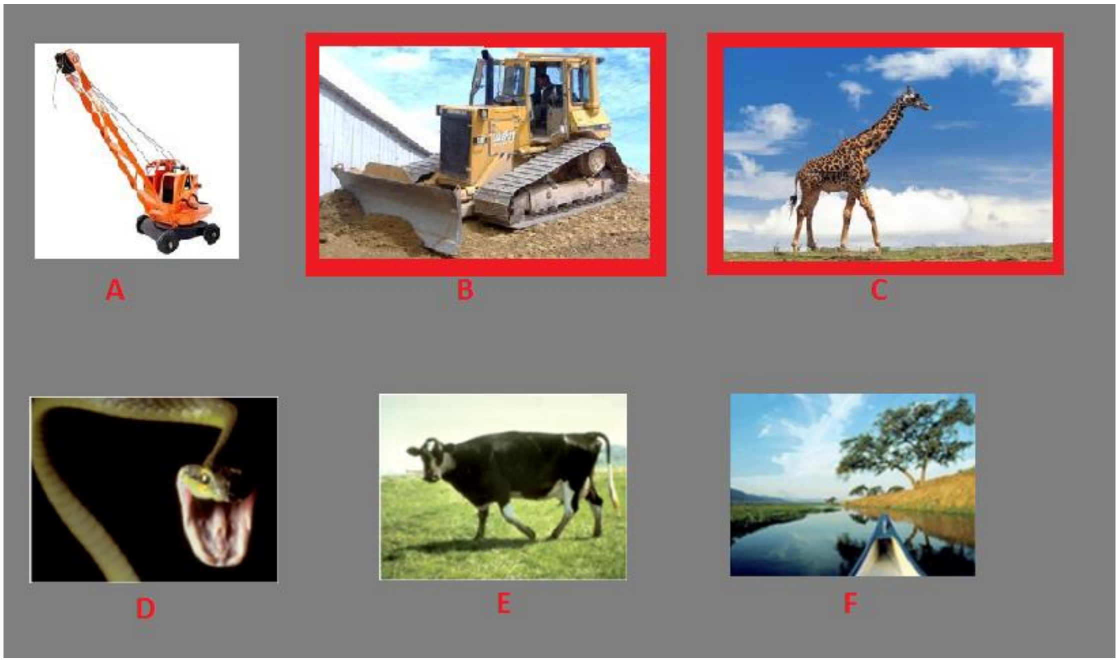

Figure 2.1 Examples of (**a**) an object picture, (**b**) a related target picture, (**c**) an unrelated target picture, (**d**) a negative distractor picture, (**e**) a neutral distractor picture, and (**f**) a background picture or baseline distractor picture.

2.3 Experimental Procedure

The experiment consisted of 600 trials split into six blocks of 100 trials each (See Figure 2.2 for an abbreviated description of each trial). A break was given after each block of trials. At the beginning of the experiment, participants were instructed to maintain fixation on the fixation point. Once the fixation point disappeared, participants were instructed to maintain fixation at the center of the pictures and to avoid blinking and moving their eyes while the RSVP stream was presented. At the end of the trial, participants received feedback if they had moved their eyes from the center of the pictures or blinked during the stream. Participants were also instructed to keep the mouse still during the RSVP stream.

The fixation point was presented and the participant made a left click to start the trial. After the click, an object picture is presented for 1500ms. A 100ms blank occurs and then an RSVP stream begins containing 15 pictures each presented for 83ms. The target picture was always presented in the lag 2 position relative to the distractor picture.

When the RSVP stream ended, a response screen with five buttons appeared. Two buttons labelled ‘Related’ and ‘Unrelated’ were presented at the top of the screen. In a row underneath three buttons labelled ‘Sure’, ‘Not Sure’, and ‘Guess’ were presented. The participant was asked to identify whether the target picture was related or unrelated to the object picture presented at the beginning of the trial and how sure they were about their decision. For data analysis, trials in which the participants indicated their confidence as “Guess” were considered incorrect. Upon clicking related or unrelated and one of the confidence buttons, the participant received feedback about whether their relatedness decision was correct. A green ‘Correct’ or a red ‘Incorrect’ appeared between the rows of buttons. After feedback was given, a fixation point appeared in the center of the screen which cued the participant to that the computer was ready to present the next trial.

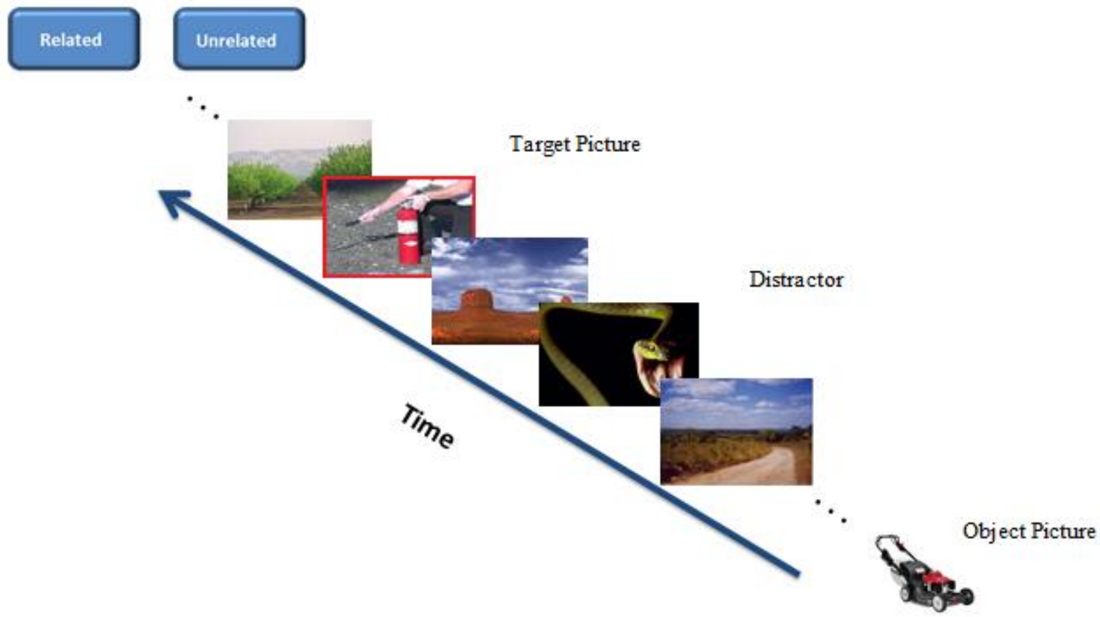

Figure 2.2 An illustration of a typical trial during the current experiment. Target pictures were presented on a white background for 1500ms. The RSVP stream began after a 100ms blank with each picture presented for 83ms. A negative (shown here), neutral or baseline picture was presented. Two pictures later, a target picture with a red frame was presented. Once the stream ended, participants were asked whether the target picture was related or unrelated to the object picture and how confident they were about their decision.

2.4 Electrophysiological Recording and Analysis

Using an Electrical Geodesics Inc. (EGI, Eugene, OR) 128-Geodesic Sensor Net, a continuous electroencephalogram (EEG) was recorded. Individual electrode impedances were kept below 50-75kΩ as recommended by the manufacturer. Data were referenced online to the vertex, band-pass filtered (0.01-80Hz), and digitized at 200Hz. EGI Net Station 4.1.2 was used offline for later processing. Data were low-pass filtered with a cutoff of 40Hz and segments using an epoch that started 200ms before stimulus onset and ended 1000ms post-stimulus.

Segments containing eye blinks or eye movements (threshold = 70µV) were rejected. If the maximum voltage range exceeded 70µV, the channel was marked as bad. Segments were rejected if more than 10 channels were marked as bad. The segments were averaged, re-referenced to the average reference, and baseline corrected using a 200ms pre-stimulus interval.

2.5 Data Analysis Procedures

2.5.1 Principal Components Analysis (PCA)

The P3b component and N400 component have partially overlapping scalp topographies and time windows which caused concern for disentangling the two components. In order to separate them, we applied principal components analysis (PCA) using the ERP PCA (EP) Toolkit, version 2.34 for MATLAB (Dien, 2010). Analyses were based on the covariance matrix with Kaiser normalization. First, a temporal PCA was completed using a Promax rotation. Then, a spatial PCA was completed using an Infomax rotation. A "parallels test" (Dien, 2010) was used to determine the number of factors retained in the temporal and spatial PCAs. Temporal PCAs were performed on the average waveforms for each subject which consisted of 240 time points representing both the prestimulus (200ms) and post-stimulus periods (1000ms). 129 sensors recorded each waveform. There were 6 conditions consisting of two target picture conditions (related or unrelated target picture) X three distractor conditions (negative, neutral, or baseline).

On the basis of the parallels test, we retained 6 temporal factors. In the next step, we performed a spatial PCA on the 6 temporal factors and retained 8 spatial factors for a total of 48 factor combinations (6 temporal X 8 spatial). We inspected the resulting factors to identify a midline positivity maximal over posterior scalp sites centered over Pz (P3b) and a negativity over anterior scalp cites (N400).

Chapter 3

RESULTS

3.1 Behavioral Results

Figure 3.1 shows participants' target detection accuracy across the three distractor conditions (negative, neutral, and baseline). Subjects were highly accurate in detecting target pictures across all three distractor conditions. A repeated measures ANOVA revealed a significant main effect of distractor type ($F(2, 22) = 21.169$, $p < .0001$). A post hoc test revealed that participants were significantly less accurate in negative conditions ($p = .001$) and neutral conditions ($p < .001$) compared to baseline conditions. Negative and neutral conditions were not significantly different ($p = .492$)

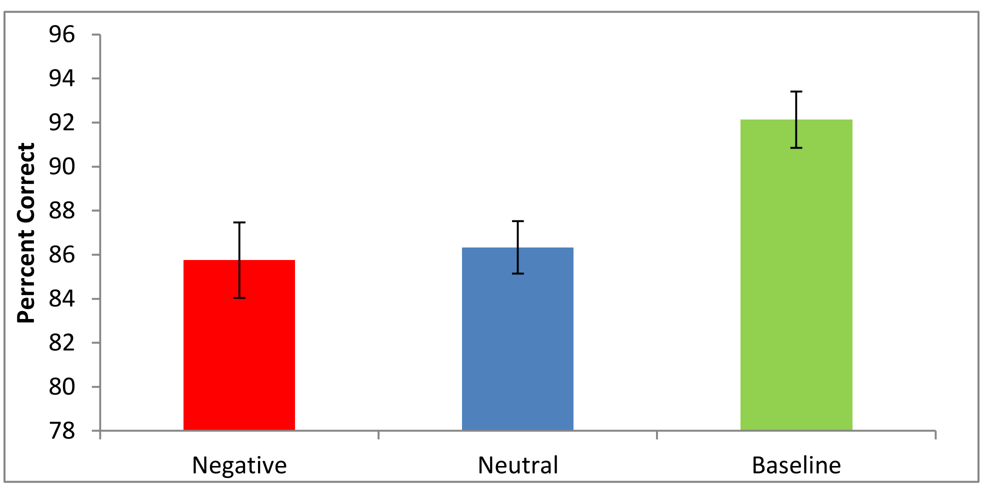

Figure 3.1 Behavioral results for target detection accuracy in the three distractor conditions. Error bars show the standard error of the mean.

Fig 3.2 shows subjects' accuracy in detecting target pictures across all six conditions (negative related, negative unrelated, neutral related, neutral unrelated, baseline related, and baseline related). A repeated measures ANOVA revealed a significant main effect of semantic relatedness ($F(1, 11) = 5.691$, $p = .036$). There was also a significant interaction of distractor type and semantic relatedness ($F(2, 22) = 9.573$, $p = .001$). This suggests that participants were more accurate on related than unrelated trials in negative and neutral conditions, but there was no effect of relatedness in the baseline condition.

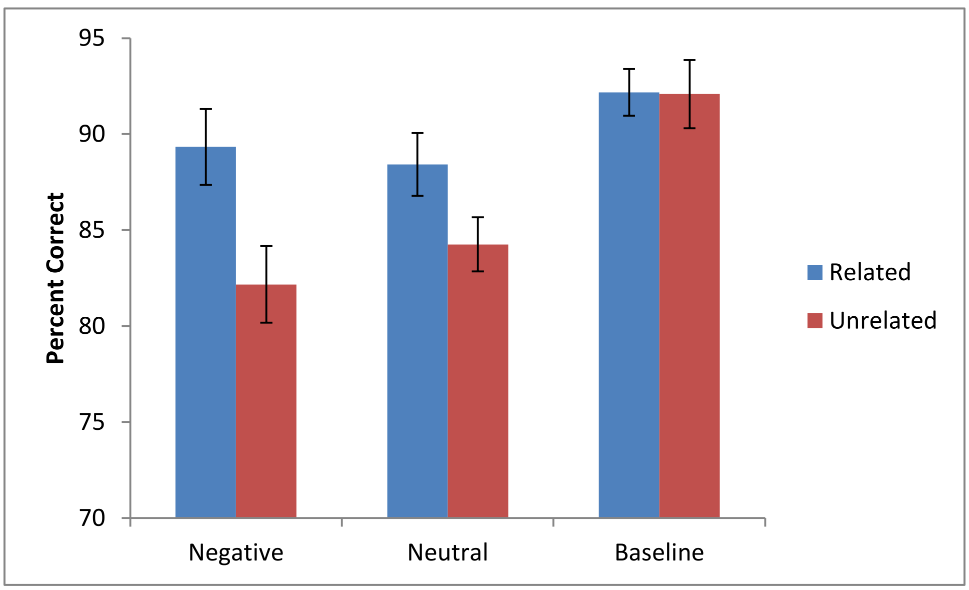

Figure 3.2 Behavioral results for all 6 conditions. Error bars show the standard error of the mean.

The behavioral results show that subjects did not perform worse on negative trials compared to neutral trials ($p = .492$) which suggests that the emotionally salient content of the negative distractor did not impair detection of target pictures more than neutral distractors. Subjects were worse at detecting related pictures compared to unrelated pictures (p = .036) which suggests that the related picture may have "popped out" of the stream as a result of semantic priming from the preceding object picture. In addition, the effect of distractor type on accuracy depended on the semantic relatedness of the target picture. The pop-out effect of the related picture may have prevented a blink from occurring on trials with related targets.

3.2 Electrophysiological Results

3.2.1 The N400 Component

Figure 3.3 shows the N400 component extracted by the PCA. The curves were created by subtracting related trials from unrelated trials. The topoplot displays a broad negativity over central frontal electrodes. The N400 component peaked 410ms after the presentation of the target. A two-factor repeated measure ANOVA revealed a significant main effect of semantic relatedness ($F(1, 11) = 34.68$, $p = 0.00046$). There was no main effect of distractor type ($F(2, 22) = 2.663$, $p = .092$) and no distractor type by semantic relatedness interaction ($F(2, 22) = .295$, $p = .747$).

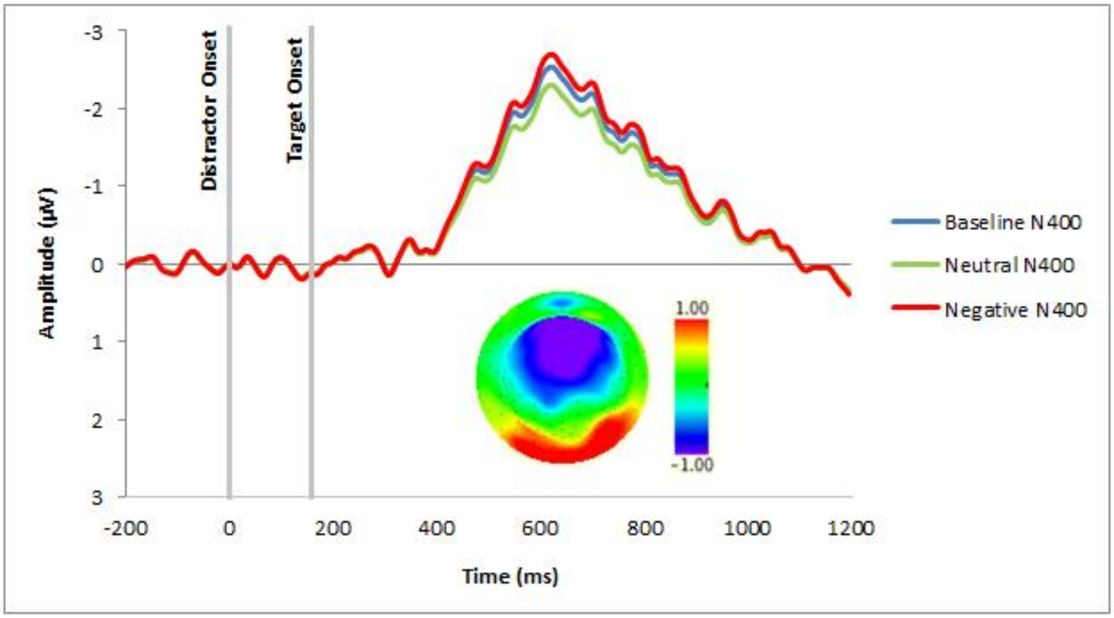

Figure 3.3 N400 in response to targets following baseline, neutral, and negative distractor pictures. Curves represent (unrelated trials – related trials) subtraction. The topoplot shows the N400 for baseline conditions 410ms after target presentation for Spatial Factor 1 Temporal Factor 1 from the PCA.

These results show that there was a significant difference in the N400 to related and unrelated targets ($p < .001$) which suggests that we were able to observe N400s to pictures in an EIB task. The N400 was not significantly different across the three distractor conditions ($p = .092$) suggesting that the distractors had no effect on the presence of an N400 component in response to targets.

3.2.2 The P3b Component

Figure 3.4 shows the P3b component in response to targets extracted by the PCA. The curves were created by subtracting unrelated trials from related trials for each distractor condition. The topoplot displays the broad positivity over central posterior electrodes. The P3b component peaked 443ms after the presentation of the target. A two-factor repeated measures analysis revealed a significant main effect of distractor type ($F(2, 22) = 5.078$, $p = 0.015$). A post hoc test revealed that targets following baseline distractors elicited a significantly larger P3b than targets following a negative distractor ($p = .019$). The P3b in response to targets following a neutral distractor was not significantly different than the P3b in response to targets following baseline distractors ($p = .190$). The P3b in response to targets following negative distractors was not significantly different than the P3b in response to targets following neutral distractors ($p = .072$). There was also a main effect of semantic relatedness ($F(1, 11) = 60.284$, $p < .001$). In addition, there was a distractor type by semantic relatedness interaction ($F(2, 22) = 4.799$, $p = .019$). This suggests that the difference in amplitude between related and unrelated trials was larger for targets in the baseline condition compared to targets in the negative and neutral conditions.

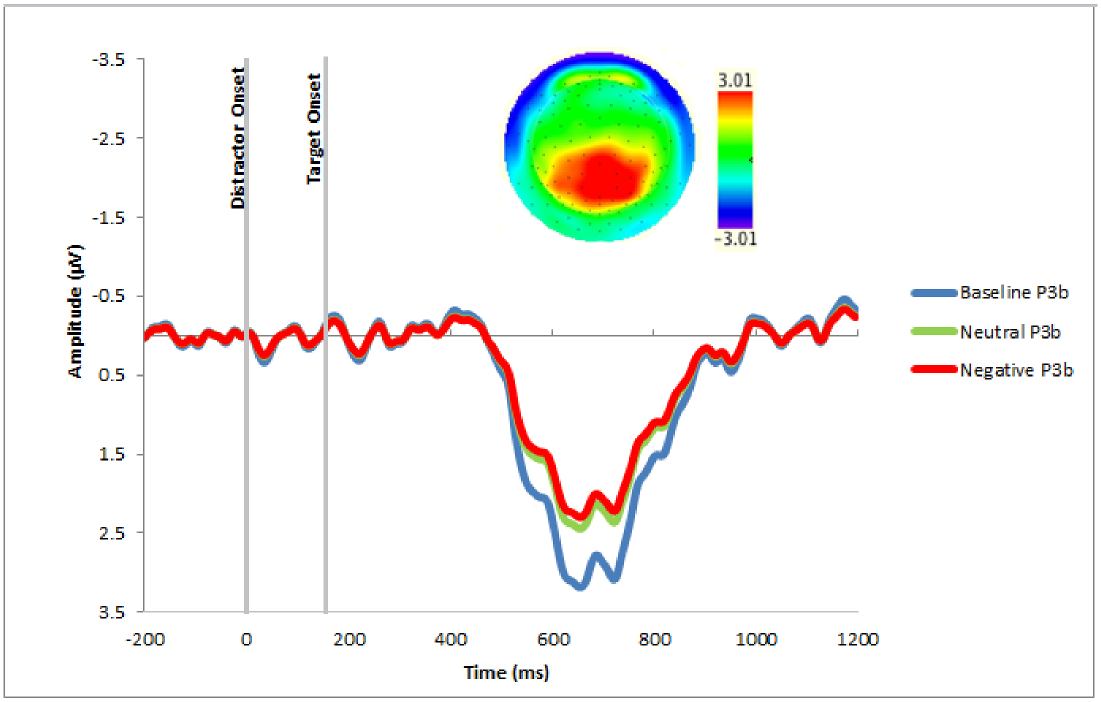

Figure 3.4 P3b in response to targets following baseline, neutral, and negative distractor pictures. Curves represent (related trials – unrelated trials) subtraction. The topoplot shows the P3b for baseline conditions 443ms after target presentation for Spatial Factor 3 Temporal Factor 2 from the PCA.

The larger P3b in response to related pictures compared to unrelated pictures may reflect the pop-out effect associated with related pictures. The pop-out effect may also result in related pictures gaining access to the limited-capacity bottleneck involved in consolidation of information into working memory. As reviewed earlier, greater consolidation should lead to a larger P3b component. Similarly, the smaller the P3b associated with negative distractor pictures may reflect a failure of the target picture to gain access to the bottleneck because it would be occupied by the distractor.

If the distractor pictures are gaining access to the bottleneck, they should elicit a P3b. Figure 3.5 confirms that the negative distractor picture did elicit a P3b. A repeated measures analysis of variance on the distractor P3b amplitude revealed a main effect of distractor type ($F(2, 22) = 6.666$, $p = .005$). A post hoc test revealed that the P3b in response to negative distractor pictures was greater than the P3b in response to neutral distractors ($p<.001$) and baseline distractors ($p = .033$). Neutral and baseline distractors did not differ ($p = .929$).

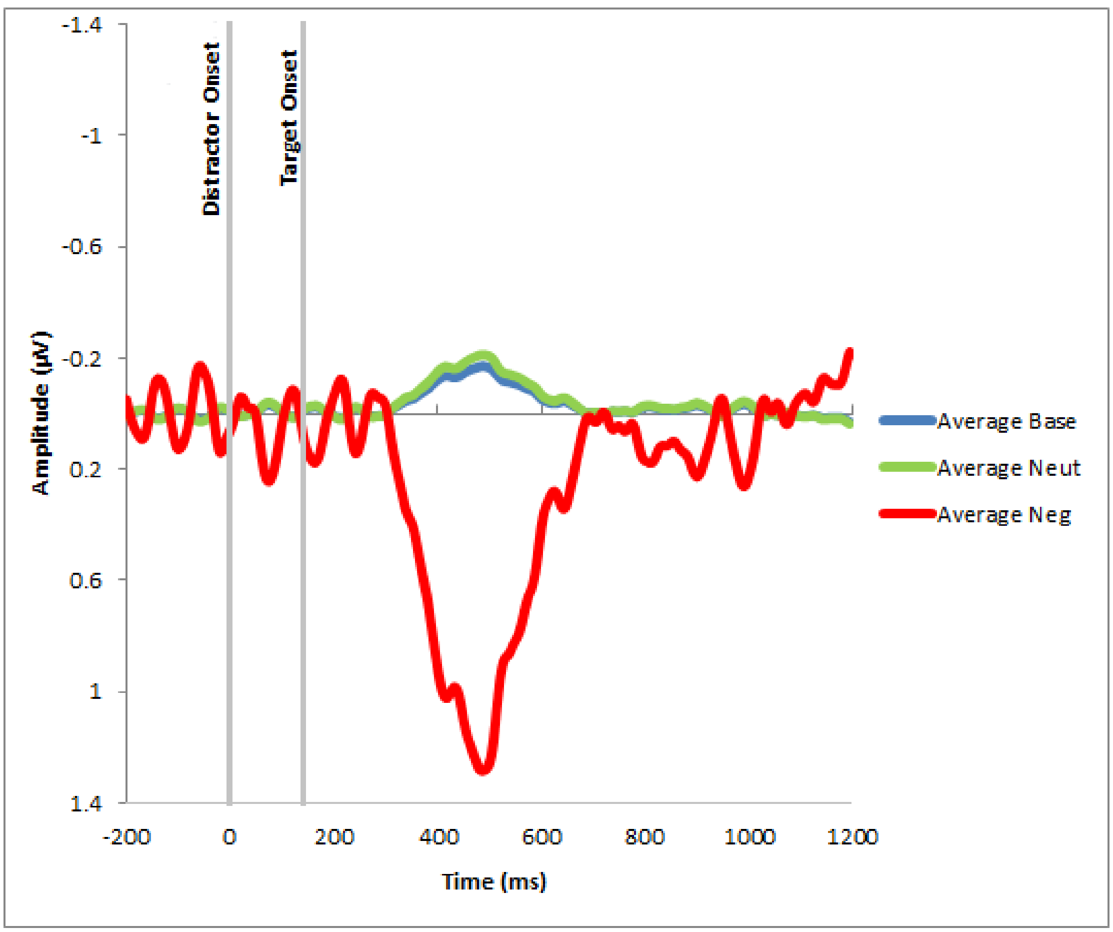

Figure 3.5 P3b in response to distractor pictures. Curves shown are the average of related and unrelated trials in each of the three conditions.

3.2.3 The N2 Component

Figure 3.6 shows the N2 component in response to targets extracted by the PCA. The topoplot in Figure 3.6 displays the negativity over posterior electrodes. The N2 component peaked 303ms after the presentation of the target. A two-factor repeated measure ANOVA examined amplitude as a function of distractor type (negative, neutral, and baseline) and semantic relatedness (unrelated vs. related). There was a significant main effect of distractor type ($F(2, 22) = 34.007$, $p<.001$). A post hoc test revealed that targets following baseline distractors produced a larger N2 than targets following negative ($p< .001$) and neutral ($p= .002$) distractors. The post hoc test also revealed that targets following neutral distractors produced a larger N2 than targets following negative distractors ($p< .001$) There was no main effect of semantic relatedness ($F(1, 11) = .462$, $p= 0.511$) and no distractor type by semantic relatedness interaction ($F(2, 22) = 1.464$, $p= 0.253$).

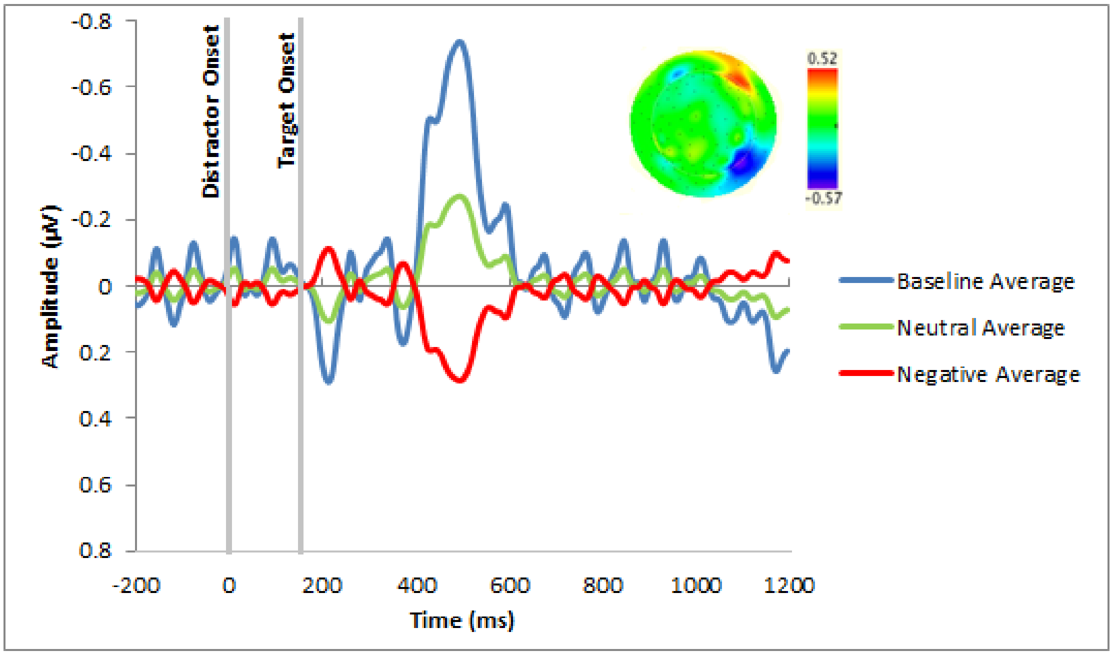

Figure 3.6 N2 in response to targets following baseline, neutral, and negative unrelated distractor pictures. Curves are not subtraction curves, but represent the average of the related and unrelated trials. The topoplot shown is the N2 for baseline unrelated trials 305ms after target presentation for Spatial Factor 7 Temporal Factor 3 from the PCA.

These results suggest that neutral and negative distractors suppress the N2 in response to target pictures, replicating the findings of Kennedy et al. (*in press*). These results may indicate that negative distractors and neutral distractors can prevent subsequent targets from being selected into the bottleneck phase of stage 2 processing.

Chapter 4

DISCUSSION

Our behavioral results indicate that participants were impaired in detecting target pictures presented at lag 2 when they are preceded by negative or neutral distractor pictures. We were able to replicate Kennedy et al. (*in press*) to a degree, as we saw impaired detection when distractors were present, but we did not see a difference in accuracy among negative and neutral conditions as Kennedy et al. (*in press*) did. The emotional content of the negative distractor pictures did not impair detection of target pictures to a greater extent than neutral pictures. This suggests that the emotional salience of the negative distractors did not affect performance on the task. These results regarding negative distractors do support the central interference theory because negative distractors elicited a P3b implying that they entered the bottleneck and working memory preventing the target from entering the bottleneck. Neutral distractors, on the other hand, did not elicit a P3b, but did produce the same size blink as negative distractors. Neutral pictures did not enter the bottleneck and working memory, but did prevent participants from accurately detecting the target, replicating the findings in Kennedy et al. (*in press*). Thus, the results regarding neutral distractors do not support the central interference theory.

This study was the first to attempt and successfully record N400s to pictures presented in an EIB task. We observed an N400 to pictures which supports findings from Nigam et al. (1992), Ganis et al. (1996), & McPherson and Holcomb (1999). In support of McPherson and Holcomb (1999), we found that the N400 elicited by pictures had a more anterior topography compared to the topography associated with word stimuli. In addition, we found that the N400 in response to target pictures was similar across the three distractor conditions similar to findings from Vogel et al. (1998). Our results suggest that semantic processing of target pictures occurred even when targets were blocked from awareness. In addition, we were able to provide more evidence that the central interference theory is a good explanation for EIB mechanisms because semantic processing occurred for all target pictures regardless of whether they were accurately detected. Our results support that semantic processing is a part of high-capacity stage 1 processing.

We also found that the N2 in response to targets was modulated by the preceding distractor. The N2 in response to targets was largest in baseline conditions, smaller in neutral conditions, and smallest in negative conditions. These findings replicated Kennedy et al. (*in press*) and suggest that the selection of the target, reflected in the N2 component, was interrupted by attention to the irrelevant distractor picture. These results also support the central interference theory which postulates that selection of the emotional picture into the bottleneck would prevent the target from being able to enter the bottleneck and produce an N2 in the process.

In addition, we found that the P3b in response to targets following negative distractors was smaller than the P3b for targets in neutral and baseline conditions. We were able to partially replicate the Kennedy et al (*in press*) with our P3b results. Our ERP results suggest that target pictures were entering working memory in baseline and neutral conditions despite the behavioral results indicating a blink for neutral conditions. The P3b in response to targets in negative conditions did support the central interference theory as negative picture occupied the bottleneck and prevented target pictures from entering the bottleneck and entering working memory. The P3b in response to targets in neutral conditions provide evidence that was inconsistent with the central interference theory. The target P3b was not significantly attenuated despite the impairment in detecting target pictures in the neutral condition. This suggests that occupation of the bottleneck by the distractor picture, as the central interference theory implies, must not be the only mechanism for impaired target detection.

The P3b in response to distractor pictures was also examined. We replicated Kennedy et al (*in press*) and observed a large P3b to negative distractors and no P3b to neutral and baseline distractors. These results suggest that emotional distractor pictures enter working memory even when they are irrelevant to the task. Importantly, we found that the P3b was larger for the negative distractor compared to the neutral distractor, but both negative and neutral conditions produced impairments in target detection. This suggests that the blink reflects more than just competition for the bottleneck, but may also be caused by other things such as competition for visual attention. Further research will be needed to evaluate this possibility.

We can only speculate about the reasons for our failure to observe a larger blink for the emotional picture compared to the neutral distractor. We suspect that the related pictures “popped out” during the stream of background pictures more than unrelated pictures as the related pictures were primed by the presentation of the object picture. This explains why subjects were more accurate on related trials compared to unrelated trials. This may also explain why the blink effect is very small in this experiment. Seemingly, related pictures were able to break through the blink and were reported with accuracy.

Another possibility for the absence of an *emotional* blink is that the background pictures may not have sufficiently masked the target picture. The interval between the target picture and the subsequent background picture may have been too long, resulting in relatively accurate perception of the target, even when it was preceded by an emotional distractor.

4.1 A Follow-up Study

Currently, a study is being run that is intended to resolve some of the issues with the current study. The new study is using a very similar paradigm to the one discussed in this paper, but has been designed to fix many of the short-comings.

At the end of each trial in the new study, subjects are asked what the target picture contained, how sure they are about this decision, and whether the target picture was related or unrelated to the object picture presented prior to the RSVP stream. Four words are given to the subject, two of which are related and two of which are unrelated to the object picture given on that trial. This is intended to give us a better measure of whether subjects are aware of the contents of the target pictures. This eliminates the possibility that subjects could use the strategy of guessing “Unrelated” at the end of trials in which the target picture did not pop out at them.

The interval following the target picture will also be adjusted so that participant’s accuracy is kept around 85% on baseline trials. At the beginning of the study, subjects are given practice trials and the program uses a staircase method to find the correct interval between the target and the subsequent picture. This should prevent participants from reaching ceiling on all trials.

4.2 Summary

Previous research has shown that emotional pictures can interrupt processing of subsequent target pictures (Most, Chun, Widders, and Zald, 2005), but this study seems to conflict with this well-studied phenomenon. This conflict may, however, be a result of the pop out effect seen in related trials or the use of stimulus durations that were too long, leading to good performance in all conditions. The new study being run will help to clarify these possibilities. Future research will need to be done to clearly answer whether or not semantic processing occurs automatically, as the central interference theory postulates, or whether it is interrupted by processing of emotional pictures.

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