Beyond the attentional blink: An electrophysiological study of processing facial emotional expression

by
Alicia Stewart

A THESIS

submitted to

Oregon State University

Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Psychology
(Honors Associate)

Presented April 12, 2017
Commencement June 2017

AN ABSTRACT OF THE THESIS OF

Alicia Stewart for the degree of Honors Baccalaureate of Science in Psychology presented on April 12, 2017.

Title: Beyond the attentional blink: An electrophysiological study of processing facial emotional expression.

Abstract approved:____

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Behavioral studies have observed facial recognition bypass attentional limitations when performed with non-facial recognition tasks (e.g., a digit task). Awh et al. (2004) proposed this was due to multi-channel processing, where non-facial objects utilize a feature-based channel leaving the configural-based channel available for facial processing. We tested this hypothesis using the N400 event-related potential (ERP) component, thought to reflect context mismatch. Participants performed an emotional word discrimination Task 1 and a facial emotion discrimination Task 2, while emotional congruency between these targets was manipulated. The tasks were embedded in a series of distractors that were presented in rapid succession at the same location, as the relative positions between these two targets varied (by Lag 1, 3, or 7). Identification of the second target is commonly impaired when closely following the first (i.e., at Lag 2 or 3), known as the attentional blink (AB). We found a relatively small AB effect for Task 2 face emotion accuracy, indicating facial emotion was not immune to ABs. The N400 effect (difference in ERPs between mismatch and match trials) also showed AB effects for Task 2 angry faces. Our findings suggest facial emotions are subject to attentional limitations.

Key Words: Attentional Blink, Emotional Perception, Multi-Channel of Face Recognition, N400 Event-Related Potentials

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I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

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Introduction

Faces are a key identifier of individuals and in relaying non-verbal communication signals. Facial non-verbal communications specifically convey a person's "mood and intention and attentiveness" (Bruce & Young, 1986). Determining facial emotions as "friend" or "foe" is important for social interactions. Thus, a clear understanding of how we process facial emotions have some survival value. Previous studies have shown that attending faces started early in infancy (e.g., Valenza, Simion, Cassia, & Umiltá, 1996), and the ability to discriminate between happy and fearful faces has been established in newborns (e.g., mean age of 46 hours in Farroni, Menon, Rigato, & Jonson, 2007; mean age of 7 months in Nelson, Morse, & Leavitt, 1979). These studies suggest that processing facial expressions, perhaps for evolutionary reasons, are innate. Nevertheless, those findings do not necessarily indicate that processing facial emotions is involuntary (i.e., does not require attentional resource).

Although researchers have attempted to uncover processing mechanisms underlying processing facial emotions, it remains to be inconclusive to whether processing facial emotions are modulated by attentional resources availability (e.g., see Lien, Ruthruff, & Allen 2011, for a review). Some studies have exclusively relied on behavioral measures (e.g., accuracy; Awh et al., 2004; Landau & Bentin, 2008), which are indirect indicators of processing faces. Some studies have used schematic faces (e.g., Fox et al., 2000, Simione et al., 2014), which lack of ecological validity (Ferreira-Santos, 2015). The present study addressed these issues using photographic faces and multiple converging measures (both behavioral and electrophysiological [i.e., event-related brain potentials]). Before discussing the details of the present study, I first provided a review of studies on face recognition, followed by a review on the attentional blink paradigm that I used in the present study.

Processing Facial Emotion

Ability to identify facial emotion is essential in social interactions and determining how individuals respond to their surroundings. Positive and negative emotions especially, evoke very different reactions and may rely on different attentional processing. Happiness, as the most commonly associated positive emotion, has been found as the easiest expression to recognize reaching mean response accuracies of 100% at times (Posamentier & Abdi, 2003). It has also been found as one of the quickest emotions to detect (Goren & Wilson, 2006; Grady, Keightley, Hongwanishkul, Lee, & Hasher, 2007; Miyazawa & Iwasaki, 2010). Even the age of the individual can influence results. For instance, Grady et al. (2007) found that, comparing to younger adults, older adults showed similar accuracies in recognizing positive faces but lower accuracies in recognizing negative faces. This could be due to the brain aging and there being less alterations to the memory when the amygdala encounters negative stimuli. Another possibility is that, according to the socioemotional selectivity theory, older adults have learned better emotional regulation skills and can focus on positive events rather than the negative ones (Grady et al., 2007).

Negative emotions, on the other hand, have been found to have large effects on the attentional system due to its involvement in threat detection. Detecting and responding to a negative stimulus quickly serves an evolutionary purpose in allowing an individual to react to a dangerous stimulus and stay out of harm's way. To see if this threat detection effect relates to angry facial emotions, Fox et al. (2000) used schematic faces to test participants' accuracy and response times in detecting an angry or happy face among a crowd of neutral faces. They found angry faces, on average, had shorter response times and less errors than the discrepant happy faces. From which Fox et al. assessed the angry faces as being more effectively detected and/or processed. Their study also found that participants took more time in ascertaining a crowd of angry schematic faces showing the same emotion (where no discrepant emotional face was present) than a crowd of happy schematic faces showing the same emotion (981 ms compared to 870 ms). Both schematic crowds consisted of four faces, so the extra time it took to account for all of the angry faces indicated a greater disruption to attentional processes due to the faces' emotion rather than quantity of stimuli (Fox et al., 2000). Several studies have replicated their findings of negativity bias using different paradigms, photographic faces, and approaches (such as ERP) (e.g., a cuing paradigm in Lien, Taylor, & Ruthruff, 2013; a dual-task paradigm in Shaw, Lien, Ruthruff, & Allen, 2011).

The Attentional Blink Paradigm

One approach to study how face recognition is modulated by facial emotions is to use the Attentional Blink (AB) paradigm (e.g., see Bach, Schmidt-Daffy, & Dolan, 2014 for an example). In a standard AB paradigm, a string of stimuli such as letters are presented successively at a single location, with an interval between stimuli being less than 100 ms (see Figure 1; e.g., Raymond, Shapiro, & Arnell, 1992). This method is known as Rapid Serial Visual Presentation (RSVP). In Raymond et al.'s study for example, their Experiment 2 required participants to name the white letter (Task 1) among a series of black text letters and to indicate whether an X was present in the series (Task 2). If an X was present it would appear anywhere from 0-8 serial positions following the white letter (i.e., Lag 0-8), while the dependent variables measured were Task 1 and Task 2 response accuracies. A typical finding is that while Task 1 accuracy was not affected by lag manipulation, Task 2 accuracy decreased at shorter lags (e.g., lag 2 or lag 3). The finding of failing to identify Task 2 target when both Task 1 and Task 2 appeared in close temporal succession is referred to the *attentional blink* effect.

A common theory that explains the attentional blink effect is the bottleneck model (Dux & Marois, 2009). The bottleneck model suggests there are two stages of processing: an immediate, volatile stage preceding a restricted, consolidation stage that transfers the stimuli into the working memory. Accordingly, the AB occurs when Task 1 is still being encoded into the working memory and Task 2, having already undergone the immediate stage, has to wait for consolidation leaving it susceptible to decay. Other theories have focused on the interference though, and how the weight a stimulus is assigned gives it a precedence to resources in the visual working memory and its ability to be reported later on (Dux & Marois, 2009).

There's also evidence of higher response accuracies at Lag 1, known as Lag 1 sparing. Explanations for this effect suggest it is due to the temporal location of the stimuli being 100 ms apart or the characteristics of Task 2 being admitted with Task 1 for identification resulting from no distractors separating the stimuli (Dux & Marois, 2009; McHugo, Olatunji, & Zald, 2013).

Emotion and Attentional Blink

RSVP research has indicated that emotional factors can influence the AB effect. Where an emotional distractor can create an emotion-induced blindness and impact the accuracy in detecting or responding to a task. Most, Chun, and Widders (2005) found that task-irrelevant negative pictures (compared to scrambled or neutral critical distractors) diminished participants' ability in determining the rotation of Task 2 landscape/architectural picture at Lag 2. This shaped the researchers' idea that emotions receive preferential attention even when they are task-irrelevant and will consequently impair the task the participant is actively searching for (for a review, see McHugo, Olatunji, & Zald, 2013).

Huang, Baddeley, and Young (2008) used RSVPs, alternatively, to assess emotional words as distractors and their effect on the single word task's accuracy within semantical, perceptual, and phonological contexts. They used semantical tasks (of participants typing the fruit word they saw), perceptual tasks (of the target word being in upper case while the distractors were all in lower case), and phonological tasks (where participants looked for a task that rhymed with a previously prompted word). They found that emotional word distractors impaired semantical processing accuracy but not perceptual or phonological processing accuracy. In other words, irrelevant emotional words induced an attentional blink effect only for tasks that required semantical processing. Huang et al.'s result seems to be in contrary to Most et al.'s (2005) finding where the attentional blink effect was observed with irrelevant emotional pictures and a non-semantical architectural/landscape rotation Task 2. Note that Huang et al. (2008) used irrelevant emotional words whereas Most et al. (2005) used irrelevant emotional pictures. Thus, it is possible that AB effects occurs when both irrelevant emotional objects and Task 2 targets rely on the same processing channel (e.g., both semantic or both pictorial).

To see if faces expressing irrelevant emotions influence identification accuracies of the task itself or the task proceeding/following in attentional blinks, Bach et al. (2014) had participants identify face photographs for Tasks 1 and 2 in an AB paradigm. They varied emotions expressed by those faces (angry, happy, or neutral), with the emotion being irrelevant to the task, in different experiments. They found ABs in every condition regardless of emotional expressions for both tasks. Furthermore, their results depicted angry Task 1 faces decreased the overall accuracy of identifying neutral Task 2 faces more than neutral and happy Task 1. In addition, happy Task 2 faces (when compared to Task 2 neutral, $F(1, 39) = 11.3$, $p < .01$, or angry Task 2 faces, $F(1,39) = 9.1$, $p < .01$) had the lowest accuracies following a Task 1 neutral face. This indicates faces with happy expressions are less likely to be correctly identified later on when they are the second face to be detected. Overall, this study confirmed Most et al.'s (2005) finding of emotions in Task 1 face images impacting Task 2 face accuracy.

<u>Is Processing Face Objects Immune to the AB Effect?</u>

Most studies discussed above have suggested that emotional faces impeded the identification of a subsequent Task 2 in the AB paradigm. Awh et al.'s (2004) study revealed that processing non-facial objects does not hinder the identification of a subsequent facial objects. Numbers, letters, faces, and greebles were all used at some point in their experiments as task stimuli, while masks consisted of either a jumble mask or a face of the opposite gender (for face tasks). To gain a clearer image of any AB outcomes, 10 possible stimulus onset asynchronies (0, 59, 118, 176, 235, 294, 353, 412, 529, and 706 ms) between Task 1 and Task 2 were used which is synonymous with lags in its specification of the time separating Task 1 and Task 2's onset in a standard AB paradigm.

Starting with discriminating numbers for Task 1, Awh et al. (2004) found an AB effect for Task 2 letters but not for Task 2 faces in Experiments 1 and 2, respectively. A follow-up experiment showed that the absence of the AB effect with Task 2 faces wasn't due to Task 1 accuracy being reduced and allowing more capacity for Task 2 faces since there was no main effect of Task 2 type (letters or faces) on Task 1 accuracy (shown in Experiment 3; $F(1,15) = .03$, $p = .87$). Experiment 4 reversed the order of tasks in Experiment 2 and showed that a Task 1 face produced an AB for a Task 2 number. The absence of AB effects when faces were Task 2 (in Experiment 2) but not when faces were Task 1 (in Experiment 4) led Awh et al. to argue that "AB interference does not result from the disruption of a single resource for visual perception" (p. 107). Otherwise, the AB effect should have been observed in both Experiments 2 and 4, which is not the case. Awh et al. continued to vary the masks and tasks to try and achieve an AB for Task 2 faces, and what they found was that only when a Task 2 face followed a Task 1 face or greeble an AB would occur (Experiments 6 and 9).

To explain the absence of the AB effect with Task 2 face objects and the presence of the AB effect with Task 2 non-facial objects, Awh et al. (2004) proposed a multi-channel model, suggesting that digits and letters relied on featural processing whereas faces relied on a configural processing. The multi-channel processing theory of Awh et al. focuses on the fact that if Task 1 and Task 2 are both faces there is an attentional blink, and that this results from both stimuli relying on the same attentional processing (i.e., the configural processing channel). Vice versa, when other stimuli fail to produce a Task 2 'blink' it's because they rely on different processing channels. In other words, when a face object (Task 2) follows a non-face object, the configural channel is available for processing the face object. To account for the presence of the AB effect with Task 1 face objects and Task 2 non-face objects in Experiment 4, Awh et al. suggested that the face discrimination places a significant cognitive load in the featural processing channel, resulting in an AB effect. Supporting their idea further, was the fact that "greebles" caused a small AB on Task 2 faces. Greebles can rely on configural processing and activate the fusiform face area similar to faces when individuals are trained in their identification (Awh et al., 2004). Nevertheless, Awh et al.'s explanation for the presence of AB effect with Task 1 face objects is not satisfied. Note that in an AB paradigm, participants uploaded both Task 1 and Task 2 targets to their memory and reported both at the end of the trial. Thus, a significant cognitive load onto the featural processing channel elicited by face objects should have occurred and impaired the non-facial object performance regardless whether face objects were presented as Task 1 or Task 2, which was not what Awh et al. observed.

Landau and Bentin (2008) argued that if the use of multiple channels suggested by Awh et al. (2004) is the key factor determining the presence or absence of the AB effect, any Task 1 and Task 2 utilizing different processing channels would produce no AB effects, which is not what Awh et al. observed in their Experiment 4. To test this idea, Landau and Bentin (2008) recreated Task 2 faces' immunity to AB and tested if the reverse was true- where a Task 1 face should fail to have an AB effect on a Task 2 object. They used Lags 1, 3, and 7 (at 70 ms, 210 ms, and 490 ms respectively) with distractors consisting of random furniture objects. Their Experiment 1 replicated Awh et al.'s findings, by Task 1 flower discriminations (tulip or sunflower) attentionally blinking the detection of Task 2 watches, and not attentionally blinking detection of Task 2 faces.

Furthermore, their Experiment 2 showed that discriminating Task 1 face (Asian vs. Caucasian) followed by detecting a Task 2 watch produced no AB effect, supporting a multi-channel hypothesis. Nevertheless, increasing the difficulty of Task 1's face identification by including Indian and Israeli ethnicities produced an attentional blink effect on detecting Task 2 watches. Thus, they argued that Task 1 difficulty, and not the type of Task 1 processing determines the AB effect.

Landau and Bentin (2008) provided further evidence arguing against the multi-channel hypothesis in their Experiment 5. In that experiment, participants identified if the Task 1 flower was a tulip or sunflower and which direction the Task 2 face's eyes were looking. Both tasks were assumed to rely on featural processing. Thus, the multi-channel model would predict an attentional blink. Yet no AB was found, indicating that other variables may be affecting and/or determining whether Task 2 accuracy is impaired. Interestingly, faces seem to be the only stimuli among the stimuli that have been tested in RSVPs that show this unique privileged processing for Task 2. This can be reflected by all of the Task 2 faces in Landau and Bentin's experiments having higher accuracy rates than other Task 2 stimuli at lag 3. Following those results, Landau and Bentin argued that the perceptual salience of identifying faces or face features arises from participants' expertise and reliance on this ability in their daily lives, and that this salience then requires less perceptual resources for detection.

Concerns

Both Awh et al.'s (2004) study and Landau and Bentin's (2008) study found cases where facial identification tasks produced no AB effects. However, Awh et al. (2004) attributed it to multi-channel processing, whereas Landau and Bentin (2008) suggested it's due to faces' perceptual salience requiring less attentional resources. Bach et al. (2014), on the other hand, used facial recognition tasks for both tasks in the AB paradigm but manipulated emotion expressed by those faces. Although emotional expression was irrelevant to both tasks, AB effects were found in all emotional expression combinations. Thus, it remains unclear why emotions would unlock the immunity of AB effects by facial recognition. It is possible that using face images for both tasks in Bach et al.'s study limits the access to different processing channels (i.e., both rely on the configural channel as suggested by Awh et al.'s multi-channel model). In other words, facial emotion may not be the key to unlock the immunity of AB effects in Bach et al.'s study. Furthermore, all of these studies discussed above relied on response accuracies which are an indirect measure of facial recognition.

The present study therefore was designed to address those concerns by using emotional tasks that rely on different processing channels – the emotional word task (the featural-based channel) and the emotional face task (the configural channel). In addition to behavioral measures (e.g., accuracies), we used electrophysiological (event-related potentials [ERPs]) measures. ERPs provide online, continuous measures of cognitive processing, which often review evidence of deeper processing than is apparent in behavioral data (e.g., Heil, Rolke, & Peccinenda, 2004; Vogel, Luck, & Shapiro, 1998).

The Event-Related Potentials

Of particular usage are electrophysiological measures such as brain wave components measured in event-related potentials (ERP). ERPs provide continuous measures of cognitive process, which allow us to examine whether processing Task 2 occurs during short lags in the AB paradigm. In this study, we used the N400 effect of

ERPs. This N400 component is an increased negativity found over the frontal, central, and parietal regions of the scalp resulting from semantical expectancies (Kutas & Hillyard, 1984). To elaborate, the N400 was a calculated voltage difference between semantically mismatching contexts and matching contexts. It is supposed to reflect violations to semantics (i.e., "I petted the shoe", rather than "I petted the cat") and is oriented towards linguistics and meaningful stimuli. By utilizing this ERP component there can be an assessment of ABs in relation to spatial and temporal processing in the brain (Luck, 2014).

The study by Vogel et al. (1998) was an excellent example of using ERP measures to uncover cognitive processes that behavioral measures could not. In addition to Task 2 accuracy in the AB task, Vogel et al. examined ERP components of P1 and N1 (reflecting sensory processing), P3 (reflecting working memory updating), and N400 (reflecting semantic processing) to assess the locus of suppression for ABs. They used various Rapid Serial Visual Presentation set-ups to exhibit the different ERP components and look at whether the ERP components were present during the lag 1, 3, and 7 periods of ABs. In Experiment 2, participants performed a digit parity Task 1 (odd vs. even) that was formed by seven-string repeated number (e.g., 3333333 or 4444444) among distractors of seven-string capitalized consonants (e.g. DFGHKLM). Task 2 was a word relatedness task, where participants determined a word as semantically related to a context word that appeared before the trial (i.e., doctor-nurse rather than doctor-chicken). They found an AB at lag 3 on Task 2 accuracy. Yet the difference waveforms of the N400 effect (semantically mismatching-matching context) showed no effect of lag and only a general attenuation compared to a single task experiment, indicating that semantic process for Task 2 occurred at lag 3. This led to their unique interpretation that the AB resides in a working memory limitation since the P3 component was shown to be suppressed in Experiment 3.

Kutas and Federmeier (2011) showed the N400 component's frequent use in semantical priming contexts of picture stimuli and words, where pictures elicit a more frontally distributed N400. Kutas and Federmeier argued that this priming often relies on activation states being modulated "by internally generated events, such as recalling a stimulus or predicting an upcoming one" (p. 640). This N400 effect can likewise be impacted by a variety of factors such as the proportion of mismatching and matching contexts (Kutas & Petten, 1998). N400 effects for familiarity of mismatching and matching faces has even been studied and shown a more occipitally distributed N400 (Kutas & Federmeier, 2011). This versatility of the N400 effect has allowed a large scope of topics to be observed and indicates whether the semantical processing of stimuli occurs.

The Present Study

The present study examined whether processing facial emotion is subject to the AB effect using both behavioral measure (i.e., accuracy) and electrophysiological measures (i.e., N400 effects). To minimize the use of same processing channel for both tasks (e.g., Awh et al., 2004), we used a word emotion Task 1 (assuming to rely on the featural processing channel) and a facial emotion Task 2 (assuming to rely on the configural processing channel). Participants were asked to identify the emotional word for Task 1 ("angry" or "happy") and emotional face for Task 2 (angry or happy) presented within a stream of neutral face distractors (see Figure 2). Therefore, the emotional content between Task 1 word and Task 2 face could be either congruent (both angry or both happy) or incongruent (one angry and one happy). This would allow us to measure N400 effects (context mismatch vs. match) for Task 2. The lag between Task 1 and Task 2 was 1, 3, or 7 randomly determined. To examine whether Task 1 difficulty modulates attentional blink for processing Task 2 facial emotion, as suggested by Landau and Bentin (2008), we manipulated Task 1 difficulty using mixed-case words (e.g., “aNgRy”) relative to consistent lowercase words (e.g., “angry”). Studies with a case-mixing manipulation have revealed shorter response times (RTs) for consistent lowercase than for mixed-case words, suggesting that processing mixed-case words is more difficult than the consistent lowercase words (e.g., Allen, Wallace, & Weber, 1995; Lien, Allen, & Crawford, 2012).

According to Awh et al.’s (2004) multi-channel model, we hypothesize that discrimination of a Task 2 face’s emotion will be immune to the AB Paradigm when following a non-facial stimulus for Task 1 (i.e., no AB effects). This prediction is derived from the hypothesis that processing faces utilizes a configural processing channel and processing words utilizes a featural processing channel.

We also hypothesize that the positivity and negativity bias will influence the overall accuracy of Tasks 1 and 2, where an angry Task 2 is expected to be detected with overall greater accuracies while an angry Task 1 will decrease response accuracies of recalling a Task 2 face’s emotion as found in Bach et al. (2014).

Thirdly, we hypothesize that the presence or absence of AB effects on Task 2 face should be determined by Task 1 difficulty (e.g., Landau & Bentin, 2008). That is, if a Task 2 face follows a difficult, mixed-case Task 1 word, an AB effect should be present.

When a Task 2 face follows an easy lowercase Task 1 word, an AB effect should be absent. This is based off the idea that more attentional resources are then allocated to the difficult Task 1 which limits the attentional processing resources available for the subsequent Task 2 face (Landau & Bentin, 2008).

We used three converging measures to test these hypotheses: (1) response accuracies of Task 2, (2) the N400 effect for Task 2, and (3) emotional congruency effects between Tasks 1 and 2 on accuracies. Specifically, our prediction of no AB indicates that response accuracies should not vary across Lags 1, 3, and 7. Lag 3 will not exhibit the characteristic response accuracy decrease that typically recovers by Lag 7 since Tasks 1 and 2 should rely on separate processing channels. Secondly, if no AB occurs, the semantical priming of Task 1 words and their emotion mismatching or matching Task 2 faces should elicit N400 effect for Task 2 at short lags. Our last measure, assessing the emotional congruency effect, would allow us to provide a converging evidence for whether processing Task 2 emotion occurs at short lags.

Method

Participants. Thirty-three undergraduates from Oregon State University participated in 2-hour study to receive extra credit for psychology courses. Seven participants' data were excluded from the final analyses due to either excessive eye movement artifacts in the electroencephalographic (EEG) data (N=5, see below) or less than 50% accuracy in Task 1 discrimination (N=2). The remaining 26 participants had a mean age of 20 years (range: 18-26). They were randomly assigned to the Task 2 Female-face group (N=13) and the Task 2 Male-face group (N=13), with 9 females and 4 males in each group. All participants were right handed and native English speakers.

Apparatus and stimuli. Stimuli were presented on a 19-inch ViewSonic monitor viewed from approximately 55 cm. Task-1 stimulus was an emotional word "angry" or "happy" printed in white, against a black background, in the center of the screen. The words were presented in consistent lowercase or mixed case (e.g., "aNgRy") in a Times New Roman 24-point font. Each letter was appropriately $.83^0$(width) × 1.46^0(height) for lowercase and 1.35^0(width) × 1.46^0(height) for uppercase.

Task-2 stimulus was an emotional face (angry or happy). A total of 108 face images in color with 36 different actors expressing 3 different emotions (angry, happy, and neutral) were used in this study. Half of them were males and the other half were females. Each picture was 8.99^0(width) × 12.41^0(height). These images were taken from Tottenham et al. (2009). Figure 2 shows an example of the face stimuli used in the present study.

Design and procedure. Participants were assigned to a group condition that determined whether participants were looking for a Task 2 Female emotional face among neutral Male distractors (Group 1) or for a Task 2 Male emotional face among neutral Female distractors (Group 2). Trials began with a 1000 ms fixation screen that consisted of a white plus centered on a black background. The neutral male or female face distractors were then presented for 100ms each while Task 1's emotional word (angry or happy) was randomly located in the 3^{rd}-8^{th} object position for 100ms. Task 1 difficulty varied from trial to trial where the emotional word could be a difficult, mixed-case task (i.e., AnGry) or an easy, lowercase task (i.e., angry).

Following Task 1's emotional word there were more neutral face distractors and a Task 2 emotional face located at the 1^{st}, 3^{rd}, or 7^{th} position after the emotional word (see

Figure 2). After the end of each trial, which consisted of 16 objects (14 distractors and 2 targets), the participant was asked to determine the word's and face's emotion. For Task 1's emotion, the screen presented an untimed prompt question, "Word?" where the participant was to press the 1-key with their left-middle finger if they saw the word "angry" or press the 2-key with their left-index finger if the word was "happy". As soon as the participant had specified Task 1's emotional word, a second untimed prompt of "Face?" asked the participant to identify Task 2's emotional face by pressing the 4-key with the right-index finger indicating an angry face and pressing the 5-key with the right-middle finger indicating a happy face.

The behavioral study had 5 variables consisting of Group (female target face vs. male target face; a between-subject variable), Lag (1, 3, and 7; a within-subject variable), Task 1 Difficulty (easy vs. difficult; a within-subject variable), Task 1's word emotion (angry vs. happy; a within-subject variable), and Task 2's face emotion (angry vs. happy; a within-subject variable). This led to a 2 x 3 x 2 x 2 x 2 mixed design. Participants were given a practice block of 24 trials. In the 12 regular experimental blocks, there were 96 trials so that each trial type was repeated 3 times within each block.

At the end of each block, participants received a summary of their accuracy for Task 1 and Task 2 for that block and were encouraged to take a break. The overall study lasted approximately 2 hours, and the computerized portion lasted anywhere from 1 hour to 1½ hours.

EEG recording. The EEG activity was recorded from F3, FZ, F4, C3, CZ, C4, T7, T8, P3, PZ, P4, P7, P8, PO7, PO8, O1, OZ, and O2. These sites and the right mastoid were recorded in relation to the left mastoid reference electrode. The horizontal electrooculogram (HEOG) was recorded bipolarly from electrodes at the outer corners of both eyes, and the vertical electrooculogram (VEOG) was recorded from electrodes above and below the midpoint of the left eye. Electrode impedance was kept below 5k Ω. EEG, HEOG, and VEOG were amplified using Synamps2 (Neuroscan) with a gain of 2000 and a bandpass of 0.1 – 100 Hz. The amplified signals were digitized at 250 Hz.

Trials with possible ocular and movement artifacts were identified automatically using a threshold of 75 V for a 1,000-ms epoch beginning 200 ms before Task 2 stimulus onset to 800 ms after Task 2 stimulus onset. Each of these candidate artifact trials was then inspected manually. This procedure led to the rejection of 6% of the trials, with no more than 25% rejected for any individual participant in the final data analyses.

The averaged ERP waveforms were time locked to the onset of the Task 2 emotional face. To quantify the overall magnitude of the N400 effect, we focused on the time windows 300-600ms after Task 2 face onset, relative to the 200-ms baseline period before Task 2 face onset. Difference waves (i.e., the N400 effect) were constructed by subtracting the ERP waveforms elicited by Task 2 emotional faces that was congruent with Task 1 emotional word (e.g., Task 2 angry face and Task 1 word "angry") from the ERP waveforms elicited by Task 2 emotional faces that was incongruent with Task 1 emotional word (e.g., Task 2 angry face and Task 1 word "happy"; see Equation 1), collapsed across the three central (C3, CZ, and C4) and parietal electrode sites (P3, PZ, and P4).

$$\textit{N400 Effect on Task 2} = \textit{Incongruent ERP} - \textit{Congruent ERP} \quad (1)$$

Results

In addition to trials with ocular artifacts (see above), trials with incorrect Task 1 responses were excluded from the final analyses of Task 2 accuracy and the EEG data. An alpha level of .05 was used to ascertain statistical significance. Whenever appropriate, p-values were adjusted using the Greenhouse-Geisser epsilon correction for nonsphericity.

Behavioral Data Analyses. An analysis of variance (ANOVA) on response accuracies for Task 1 and Task 2 were conducted including Group (female target face vs. male target face), Task 1 Emotion (Angry vs. Happy), Task 2 Emotion (Angry vs. Happy), Task 1 Difficulty (Easy vs. Difficult), and Lag (1, 3, or 7). We report only the effects that are critical for our study. The complete summary of the ANOVA is given in Appendix A. Table 1 and Table 2 show the mean accuracy for Task 1 and Task 2, respectively, for each of the conditions averaged across groups. Note that any interactions involved Task 1 Emotion and Task 2 Emotion would be explained in terms of a congruency effect between Task 1 emotion and Task 2 emotion. We expected the accuracy for congruent trials to be higher than the accuracy for incongruent trials. Therefore, different from ERP measures, the congruency effect on accuracy was measured by subtracting the accuracy of incongruent trials from the accuracy of congruent trials.

For Task 1 accuracy, the main effect of Task 1 difficulty was significant, $F(1, 24) = 4055.90$, $p < .0001$. Task 1 difficulty effect (the accuracy difference between a mixed-case, difficult word and an easy, lowercase word) was 0.19, suggesting that our Task 1 difficulty manipulation was successful. The interaction between Task 1 difficulty and Task 1 emotion was also significant, $F(1, 24) = 590.59$, $p < .0001$, reflecting that the Task 1 difficulty effect was more pronounced when Task 1 was an “angry” word (0.33) than when Task 1 was a “happy” word (0.05).

This significance of Task 1 difficulty and Task 1 emotion remained significant when Task 2 emotion was taken into consideration, $F(1, 24) = 236.09$, $p < .0001$. When Task 1 was angry, the congruency effect was small in the easy condition (.009) but large and positive in the difficult conditions (.077), and when Task 1 was happy, the congruency effect was negligible in the easy condition (.002) but large and positive in the difficult condition (.082).

Task 1 emotion also had a significant main effect, $F(1, 24) = 530.90$, $p < .0001$. Task 1 accuracy was approximately .16 higher when Task 1 was happy than angry. This Task 1 emotion then significantly interacted with Task 2 emotion, $F(1, 24) = 232.98$, $p < .0001$, where congruent emotions (e.g., a word “happy” followed by a “happy” face) were approximately .42 higher than incongruent emotions (e.g., a word “angry” followed by a “happy” face). Task 1 emotion also interacted significantly with group, $F(1, 24) = 5.03$, $p = .034$. Task 2 female target group produced .026 higher in accuracy for a happy Task 1 word but .005 lower for an angry Task 1 word than Task 2 male target group, indicating an association of greater accuracies for Task 1 when happy words were followed by female faces and angry words were followed by male faces. Finally, the 4-way interaction of lag, Task 1 difficulty, Task 1 emotion, and Task 2 emotion was significant, $F(2, 48) = 3.95$, $p = .026$. When Task 1 was angry, a large, positive congruency effect was observed for all lags in the difficult condition (.073, .084, and .074 for Lag 1, 3, and 7, respectively) but only for Lag 1 in the easy condition (.028, -.001, and -.001 for Lag 1, 3, and 7, respectively). When Task 1 was happy, a large, positive congruency effect was observed for all lags in the difficult condition (.076, .085, and .085

for Lag 1, 3, and 7, respectively) but was negligible in the easy condition (.006, -.008, and .008 for Lag 1, 3, and 7, respectively).

With Task 2 accuracy, the main effect of lag was significant, $F(2, 48) = 1.32$, $p < .001$. However, in contrast to previous AB studies, Task 2 accuracy increased with increased lag (0.87, 0.89, and 0.91 for Lag 1, 3, and 7, respectively). Lag and Task 1 emotion had a significant interaction, $F(2, 48) = 9.59$, $p < .001$, showing that the greatest difference between angry and happy Task 1 words for Task 2 face accuracy occurs at lag 1 (.038) followed by lag 3 (.010) and lag 7 (-.002). Similarly, lag and Task 2 emotion had a significant interaction, $F(2, 48) = 39.23$, $p < .0001$, where the greatest difference between angry and happy Task 2 words for Task 2 accuracy occurred at lag 1 (.117) followed by lag 3 (.066) and lag 7 (-.017). Combined, these variables then interacted significantly in a 3-way interaction between lag, Task 1 emotion, and Task 2 emotion, $F(2, 48) = 6.24$, $p = .0039$. Differences in congruency effects between an angry and happy Task 1 showed a continual decrease from lag 1 (.234) to lag 3 (.132) and lag 7 (.035). Within this decrease, the congruency effect for a happy Task 1 word was absent at lags 1 (-.049) and 3 (-.022), whereas an angry Task 1 retained the congruency effects across all lags (.185, .110, and .044 for lag 1, 3, and 7, respectively).

Also, worth consideration is that group assignment did have a significant interaction with Task 2 accuracy, $F(1, 24) = 5.39$, $p = .0291$. Task 2 accuracy was approximately .06 higher for the female target group than the male target group. For Task 2 accuracy, Group assignment also interacted significantly with Task 2 emotion and lag, $F(2, 48) = 3.46$, $p = .039$. The differences in Task 2 accuracy (between angry and happy Task 2 emotions) from the two groups (the female target group – the male target group) was .098, .045, and .006 for Lag 1, 3, and 7, respectively. Task 2 angry faces had consistently increased Task 2 response accuracies than Task 2 happy faces, and this difference in accuracy (due to Task 2 emotion) was greater for the female target group across all three lags.

Another significant main effect for Task 2 accuracy was Task 1 emotion, $F(1, 24) = 12.56$, $p = .002$. Task 2 accuracy was .08 higher when Task 1 word was happy than when it was angry. Task 2 Emotion also had a significant main effect on Task 2 accuracy, $F(1, 24) = 20.52$, $p < .001$, indicating that angry Task 2 faces produced .07 higher in Task 2 accuracy than happy Task 2 faces. Finally, Task 1 emotion and Task 2 emotion interacted significantly, $F(1, 24) = 17.80$, $p < .001$, reflecting a larger congruency effect when Task 1 word was angry (.113) than happy (-.021). Neither the main effect of Task 1 difficulty, $F(1, 24) = 2.96$, $p = .0984$, nor its interactions with other variables were significant, $F(2, 48) = 1.35$, $p = .269$.

ERP Analyses. The mean amplitudes of the difference waveforms (i.e., the N400 effect [incongruent ERP – congruent ERP]) were analyzed as a function of Site (parietal [P3, Pz, P4] vs. central [C3, Cz, C4]), Lag (1, 3, and 7), Task 1 Difficulty (easy vs. difficult), and Task 2 Emotion (angry vs. happy). Again, we report only the effects that are critical for our study. The complete summary of the ANOVA is given in Appendix B. Table 3 shows the N400 effect as a function of Task 1 difficulty, Task 2 emotion, and Lag at the central and parietal electrode sites. Figures 5 and 6 show the N400 effect for those conditions at the central and parietal electrode sites, respectively.

The main effect of Task 2 emotion was significant, $F(1, 25) = 4.48$, $p = .044$, suggesting that a normal N400 effect was observed for Task 2 happy face (-.368 μV) but the effect was reversed for Task 2 angry face (.430 μV). Although the main effect of Lag was not significant, $F < 1.0$, its interaction with Electrode site (Central or Parietal) was significant, $F(2, 50) = 4.60$, $p = .015$. For central electrode site, the N400 effect was -.056μV, -.465μV, and .387μV at the Lag 1, 3, and 7, respectively. For parietal electrode site, the N400 effect was -.076μV, .243μV, and .153μV at the Lag 1, 3, and 7, respectively. Nevertheless, further data analyses for each electrode site revealed that the main effect of Lag was not significant for the central electrode site, $F(2, 50) = 1.39$, $p = .2572$, or the parietal electrode site, $F<1.0$. Pairwise comparisons also showed no difference in N400 effects between every two lags, $Fs(1, 25) \leq 2.09$, $ps \geq .1611$.

Finally, the 3-way interaction of Task 1 difficulty, lag, and Task 2 emotion approached to be significant, $F(2, 50) = 2.82$, $p = .069$. When Task 1 was easy, Task 2 angry face elicited N400 effects of -.318μV, -.221μV, 1.736μV at Lag 1, 3, and 7, respectively, whereas Task 2 happy face elicited N400 effect of .379μV, -.782μV, .585μV at Lag 1, 3, and 7, respectively. When Task 1 was difficult, Task 2 angry face elicited N400 effects of .385μV, 1.844μV, -.845μV at Lag 1, 3, and 7, respectively, whereas Task 2 happy face elicited N400 effect of -.711μV, -1.285μV, -.396μV at Lag 1, 3, and 7, respectively. To critically determine the presence or absence of the AB effect, we conducted further *t*-test analyses on N400 effects between Lag 3 and Lag 7 for each condition. The only significant difference in N400 effects between Lag 3 and Lag 7 was observed for easy Task 1 followed by Task 2 angry face, $t(25) = -3.18$, $p = .0039$. The difference approached to be significant for difficult Task 1 followed by Task 2 angry face, $t(25) = 1.87$, $p = .0733$.

Discussion

The present study tested the multi-channel hypothesis for face recognition using two emotional tasks that rely on different processing channels – the emotional word task (the featural-based channel) and the emotional face task (the configural channel). The targets for these two tasks (word for Task 1 and face for Task 2) were embedded in a series of distractor stimuli that were presented successively and rapidly at the same location, with the relative position between these two targets being varied as 1, 3, or 7. The emotional congruency between words and facial expressions was either matched (e.g., both angry) or mismatched (e.g., one angry and one happy). Concurrently, we manipulated Task 1 difficulty (of lowercase words vs. mixed-case words) to determine if Task 1 difficulty modulates the processing of subsequent Task 2 facial emotions as suggested by Landau and Bentin (2008). Different from previous studies, that solely relied on behavioral measures (e.g., accuracies; Awh et al., 2004; Bach et al., 2014; Landau & Bentin, 2008), we used both behavioral and ERPs measures.

Critically, our results showed that lag was significant for Task 2 response accuracy; the average Task 2 response accuracies increased from 0.87, 0.89, to 0.91 at Lag 1, 3, and 7, respectively. Further *t*-test analyses for Lag 3 and Lag 7 showed that the difference in Task 2 accuracy was significant, $t(25) = -6.50$, $p < .0001$. Thus, the significant difference in response accuracies, although only .02, indicates an attentional blink effect. These AB effects were primarily driven by Task 2 happy faces (see Table 2). For there was only a 6% decrease at most for Task 2 accuracy response at Lag 3, while past studies with visually rich images showed ABs having a decreased accuracy around 20% depending on the stimuli (Table 2) (Landau & Bentin, 2008). Even with a small decrease, we found that the Task 2 emotional faces were not immune to the AB effect. These findings are consistent with Bach et al.'s (2014) behavioral study, where they found AB effects for all facial emotion combinations.

Our ERP data also revealed an AB effect, but only for Task 2 angry face. This finding is surprising given that negative emotions have been found to have attentional priority (i.e., a negativity bias) and can capture attention involuntarily (e.g. Lien et al., 2013; Shaw et al., 2011). Note that these studies typically presented one negative emotional face along with another emotional face on the screen for 150 ms in a cuing paradigm, or until participants made a response in a dual-task paradigm. In the present study, the negative emotional face was embedded in a series of 14 face distractors that were presented on the screen for only 100 ms. Thus, it is possible that a negative emotion diverts attention to its emotion only when participants had sufficient time to process a few images. According to this hypothesis, one would expect low accuracies for Task 2 angry faces. In contrary to this prediction, we found that Task 2 angry face produced higher accuracies than Task 2 happy face. Thus, further studies are needed to determine the discrepancy in the negativity bias between different paradigms.

Surprisingly, Lag and Task 1 difficulty were had no significant effect on Task 2 accuracy. Table 2 shows the calculated AB Effect (of Task 2's accuracy at Lag 7-Task 2's accuracy at Lag3) between the easy and difficult Task 1 conditions. Both the Easy and Difficult conditions show an average increase in Task 2 response accuracy from Lag 3 to Lag 7 of comparable magnitudes despite the difficult condition consistently having lower Task 2 accuracies at each lag. In fact, Task 1 difficulty (and its interactions with other variables) was only significant for Task 1 accuracy. A difficult Task 1 had lower

Task 1 response accuracies than an easy Task 1, suggesting that our Task 1 difficulty manipulation was successful. However, in contrary to Landau and Bentin (2008), both our behavioral and N400 effect data revealed that Task 1 difficulty did not modulate the processing of facial emotion or produce the attentional blink at Lag 3.

Finally, the congruency effects for the difficult and easy Task 1 conditions had different response accuracies across Lags 1, 3, and 7 when assessing Task 1 and Task 2's response accuracies (Figures 3 and 4). Where Lag x Task 1 Difficulty x Task 1 Emotion x Task 2 Emotion was significant for Task 1 accuracy, but not significant for Task 2 accuracy (Appendix A). In particular, task difficulty effects were larger for an angry than a happy Task 1 word in Task 1 response accuracies, and the congruency effect was minimal. For Task 2 accuracy, however, the congruency effect was a more distinguishing factor than task difficulty effects. Especially when Task 1 was angry, the incongruent condition had reduced Task 2 response accuracies, whereas when Task 1 was happy the incongruent condition had slightly increased response accuracies. This lack of a congruency effect when Task 1 was happy emphasizes the fact that the emotion of Task 2 impacts Task 2 accuracy more so than the congruency effect; in that, regardless of Task 1 word's emotion, an angry Task 2 face will have higher Task 2 response accuracies than a happy Task 2 face.

<u>Challenges for the Multi-Channel Hypothesis</u>

The evidence of ABs, especially from the behavioral data of Task 2 happy faces and the N400 data of Task 2 angry faces, is inconsistent with the multi-channel hypothesis that processing face stimuli can bypass AB when both face and other non-face targets (such as words) rely on different processing channels. Although AB effects were relatively small in behavioral data and were observed in N400 effects only for Task 2 angry faces, they provide evidence that argue against Awh et al.'s (2004) multi-channel model but were consistent with Bach et al.'s (2014) findings. However, there was evidence supporting our second hypothesis that positivity and negativity bias will influence the accuracy of Tasks 1 and Task 2. An angry Task 1 word followed by a happy Task 2 face had the lowest Task 2 response accuracy, while an angry Task 1 word followed by an angry Task 2 was comparable to the other Task 2 accuracies. This verifies the hypothesis' second stipulation- that an angry Task 2 will be detected with greater accuracies than a happy Task 2 face.

Finally, we found that Task 1 difficulty has no effects on AB effects for an emotional face Task 2. We had expected to see a difficult mixed-case Task 1 word use more attentional resources and create an AB for the Task 2 emotional face. Instead, we found small AB effects irrespective of whether Task 1 was easy or difficult. Therefore, this lack of an effect from Task 1 difficulty on attentional blinks weakens Landau and Bentin's (2008) argument of Task 1 difficulty determining the presence or absence of the AB effect for face recognition.

Implications

Our study aligned with Bach et al.'s (2014) study, which used two face identification tasks and found the emotions expressed by Task 1 and Task 2 faces impacted overall response accuracies rather than the AB effect. What this means, is that the particular emotion of a word (or face) can determine how likely someone is to remember that emotion later on, while the emotion doesn't necessarily determine the strength or presence of the AB effect (where there was less than 8% variation in the AB effects of various Task 1 and 2 emotional conditions, calculated in Table 2). So, response accuracies vary across emotions (e.g., where angry emotions will have higher response accuracies than happy emotions), there was just minimal evidence in our study to suggest emotions are a determining factor of ABs. The AB effects for angry Task 2 faces which were calculated to be negative values (or the opposite of an AB- where Lag 3 had higher accuracies than Lag 7), however, may indicate that negative emotions have their own immunity to ABs where negative emotions are more likely to be remembered under times of attentional limitation.

In relation to people processing negative and positive emotions, this study suggests negative emotions are more likely to be remembered, and take away resources for processing incongruent positive emotions. This overall trend of negative emotions requiring more resources while exhibiting typically high response accuracies corresponds with negative emotions being harder to identify and at the same time serving as a crucial element in social interactions and threat detections. Positive emotions, on the other hand, are easier to recognize (as Task 1) under cognitive loads (where happy words retained much higher response accuracies in the difficult condition than angry words maintained), but are also more prone to lower accuracies at the Task 2 position. These results may then tie back into the idea that happy emotions are the quickest to detect and easiest to recognize which allows even happy words in the difficult condition to finish processing before the onset of the Task 2 face (Goren & Wilson, 2006; Grady, Keightley, Hongwanishkul, Lee, & Hasher, 2007; Miyazawa & Iwasaki, 2010; Posamentier & Abdi, 2003). Also, if the happy emotion is in the Task 2 position it may result in lower response accuracies since it is trying to be processed at its regularly fast speed, but the attention may still be processing Task 1's emotion. Either way, this study confirmed there is a negativity bias that causes the negative emotions to be recalled with higher accuracy.

Limitations

A disparity of Task 1's emotion discrimination when manipulating Task 1's difficulty was an unanticipated outcome of this study (Table 1 and Figure 2). Where on average, difficult happy words had a slightly decreased accuracy (1-10%), and angry words underwent a substantial decrease in accuracy (30-40%) reflecting a potential interaction between the Task 1 difficulty and the emotions' required attentional resources. One explanation could be that the difficult mixed-case word adds the same load to a happy or angry word, yet the attentional resources needed to process angry words is greater and causes the load to frequently push past a crucial threshold point in an individual's processing capabilities. Or, according to Tracy and Robins (2008), there may be something unique about happy emotions being identified quicker than angry emotions. They interpreted negative emotions under cognitive loads as taking longer and having decreased accuracies owing to their resources being automatically diverted towards identifying the source of threat for a fight or flight response (Tracy & Robins, 2008). Even the experimental set-up could have resulted in the difficult mixed-case being easier to somehow identify as "happy" (i.e. perhaps participants had a greater chance of identifying it due to the two p's next to each other). To resolve this uncertainty, other methods should be attempted to increase the difficulty and decrease the response accuracies for a Happy Task 1 Word. Then, the impact of difficult happy words could be evaluated in relation to ABs on Task 2 faces. Even if further measures to increase happy words' difficulty doesn't affect angry and happy words equally, it could indicate that there is an attentional advantage for processing challenging happy words.

Another restriction this study encountered was that the majority of the participants consisted of females (18 females: 8 males). Equal proportions of each gender were placed in the Task 2 female target group and the Task 2 male target group, however the fact that there's more female participants could be influencing the results. For there was a significant interaction found between group and Task 2 accuracy (.919 for Task 2 female target group vs. .858 for Task 2 male target group), indicating the gender of the targets or how the participants perceived the targets influence overall Task 2 response accuracy. As such, females might be better at identifying the emotions of female faces. It would be insightful to have a follow-up study that assesses an RSVP where the gender of the distractors and target are of the same gender but expressing different emotions and/or have a study that compares male and female participants' responses to these conditions. Then, it removes the potential that the target gender is having a pop-out effect, and it relies more predominantly on the idea of identifying and correctly remembering an emotion which can be assessed in relation to the participants.

Future Studies

In addition to the Limitations' suggested follow-up studies, there are three natural courses for continuing the assessment of ABs and Emotion. One direction would be to verify the preferential processing for angry emotions across age groups to extend the applicability of this study's outcomes. Its potential significance relies on Grady et al.'s (2007) experiments showing young adults as recognizing negative faces and words better than neutral or happy faces and words, while older adults have no singular advantage towards identifying an angry, happy, or neutral emotion. This idea could potentially explain the negative emotion advantage shown in this study, and a follow-up study would indicate its contribution and if older adults exhibit a bias towards positive emotions during the AB range.

The second line of studies, could switch Tasks 1 and 2 targets to see if emotional faces attentionally blink an emotional Task 2 word. This could further provide evidence to confirm or dispute Awh et al.'s multi-channel model. Although, there seems to be some ambiguity as to how the multi-channel model accounts for faces attentionally blinking Task 2 non-face objects (when those non-face objects cannot attentionally blink a Task 2 face), it would provide further information and research questions around the parameters for an AB to occur.

Lastly, the use of different ERP components and AB Tasks is needed to determine if the AB occurs from a resource limitation at the same processing step each time. Vogel et al. (1998) attempted to do this and surmised that during an AB only the P3 ERP component was fully suppressed compared to P1, N1, and N400. They also suggested that the N400 was still present, despite following the P3 component chronologically, because it utilized more difficult tasks that dealt with words, rather than numbers and letters. But the current RSVP showed the N400 effect only for Task 2 angry faces and not for happy faces where ABs were more pronounced. Does this mean the AB limitation arises at different points for various stimuli? Would P3, or any other components, also be absent during an Emotional Task 1 Word and Task 2 Face AB? These are excellent questions in continuing to understand face recognition and attentional processing.

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Table 1

Mean Accuracy for Task 1 as a Function of Task 1 Difficulty (Easy vs. Difficult), Task 1 Emotion (Angry vs. Happy), Task 2 Emotion (Angry vs. Happy), and Lag (1, 3, and 7).

Task 1 Emotion	Task 2 Emotion	Lag 1	Lag 3	Lag 7	*Mean*
		Easy Task 1			
Angry	Angry	.956 (.008)	.951 (.009)	.947 (.008)	.951
	Happy	.928 (.013)	.952 (.008)	.948 (.008)	.943
Happy	Angry	.964 (.007)	.970 (.007)	.950 (.010)	.961
	Happy	.970 (.006)	.962 (.011)	.958 (.008)	.963
		Difficult Task 1			
Angry	Angry	.660 (.008)	.654 (.006)	.650 (.009)	.655
	Happy	.587 (.009)	.571 (.007)	.577 (.007)	.578
Happy	Angry	.878 (.010)	.870 (.010)	.867 (.012)	.872
	Happy	.954 (.010)	.956 (.012)	.953 (.011)	.954

Note: The standard error of the mean is shown in parentheses.

Table 2

Mean Accuracy for Task 2 as a Function of Task 1 Difficulty (Easy vs. Difficult), Task 1 Emotion (Angry vs. Happy), Task 2 Emotion (Angry vs. Happy), and Lag (1, 3, and 7). The Attentional Blink (AB) Effect was Calculated by Subtracting Accuracy for Lag 3 from Accuracy for Lag 7.

Task 1 Emotion	Task 2 Emotion	Lag 1	Lag 3	Lag 7	*AB Effect (Lag7 – Lag3)*
		Easy Task 1			
Angry	Angry	.945 (.013)	.949 (.012)	.931 (.013)	−.018
	Happy	.771 (.026)	.839 (.025)	.888 (.023)	.049
Happy	Angry	.912 (.013)	.897 (.019)	.905 (.021)	.008
	Happy	.867 (.017)	.894 (.019)	.908 (.017)	.014
		Difficult Task 1			
Angry	Angry	.943 (.010)	.933 (.015)	.924 (.016)	−.009
	Happy	.747 (.027)	.823 (.027)	.880 (.025)	.057
Happy	Angry	.915 (.016)	.917 (.013)	.894 (.027)	−.023
	Happy	.862 (.020)	.877 (.022)	.909 (.016)	.032

Note: The standard error of the mean is shown in parentheses.

Table 3

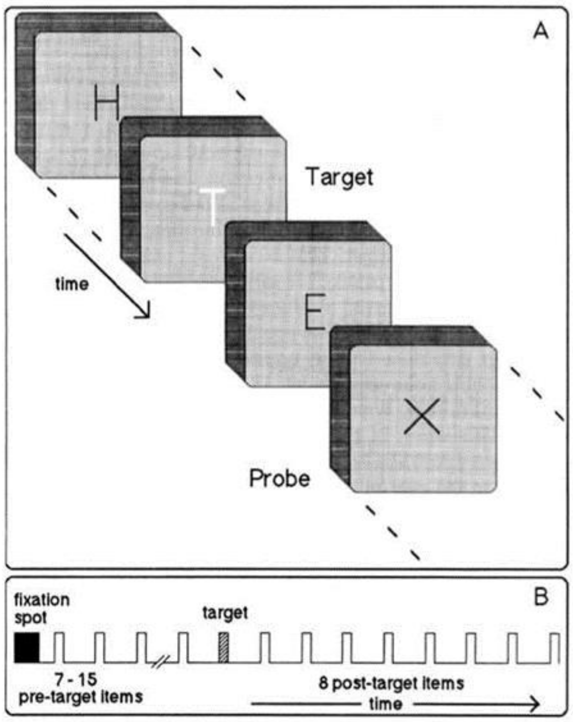
Grand Average Difference in Event−Related Brain Potentials on Task 2 (in μV), formed by Subtracting Emotion Congruent Trials from Emotion Incongruent Trials (i.e., the N400 Effect), as a Function of Task 1 Difficulty (Easy vs. Difficult), Task 2 Emotion (Angry vs. Happy), and Lag (1, 3, and 7) at the Central Electrode Sites (Data Collapsed across C3, C4, and Cz) and Parietal Electrode Sites (Data Collapsed across P3, P4, and Pz).

Task 1	Task 2	Lag		
Difficulty	Emotion	1	3	7
		Central		
Easy	Angry	−.353 (.723)	−.304 (.462)	1.12 (.563)
	Happy	.228 (.844)	-.598 (.823)	.484 (.405)
Difficult	Angry	.073 (.469)	.681 (.978)	.177 (.874)
	Happy	−.173 (.712)	−1.64 (1.48)	−.236 (.600)
		Parietal		
Easy	Angry	−.282 (.664)	−.138 (.826)	2.35 (1.50)
	Happy	.530 (.803)	−.965 (1.04)	.686 (.444)
Difficult	Angry	.696 (.558)	3.01 (1.13)	−1.87 (1.59)
	Happy	−1.25 (.891)	−.930 (1.46)	−.556 (.737)

Note: The standard error of the mean is shown in parentheses.

<u>Figure 1.</u> Panel A shows Raymond, Shapiro, and Arnell's (1992) example of rapid serial visual presentation. Panel B shows an example of attentional blink effect in Raymond et al.'s study.

Panel A



Panel B

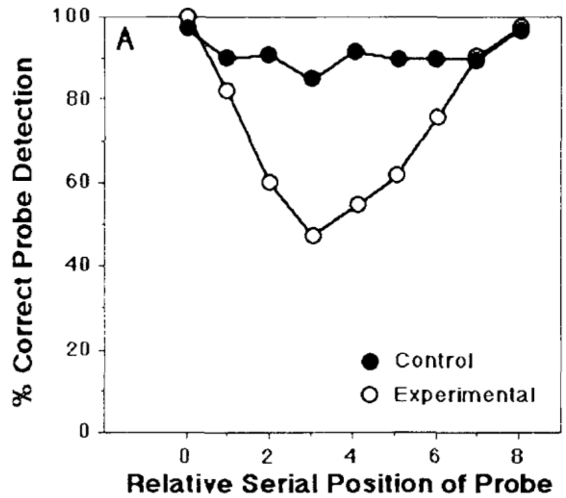
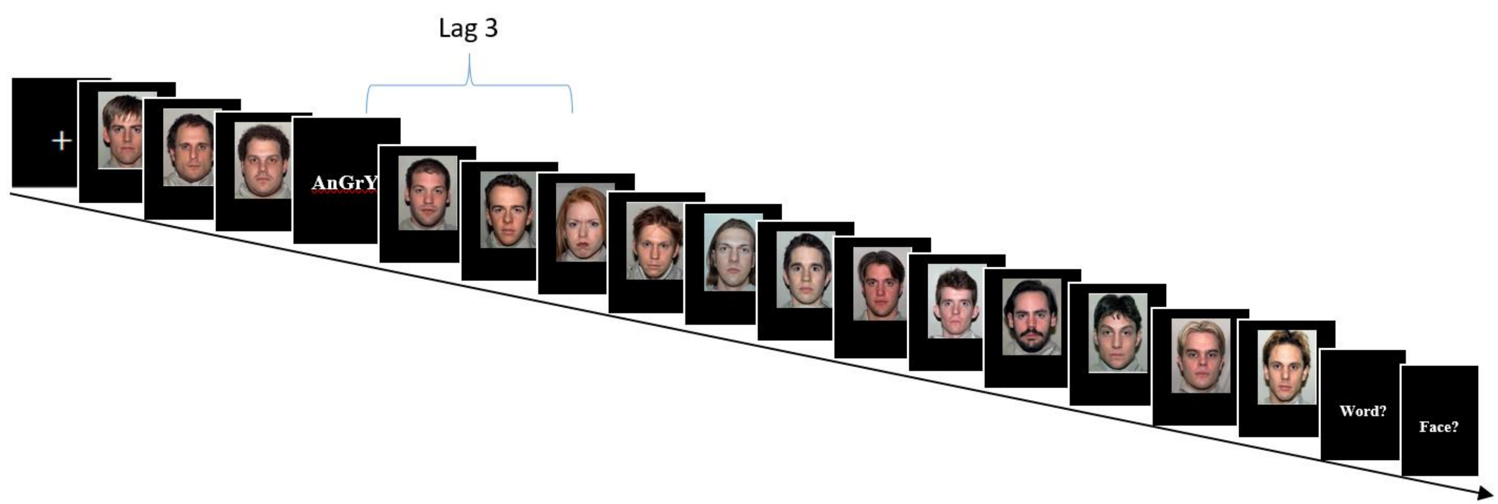
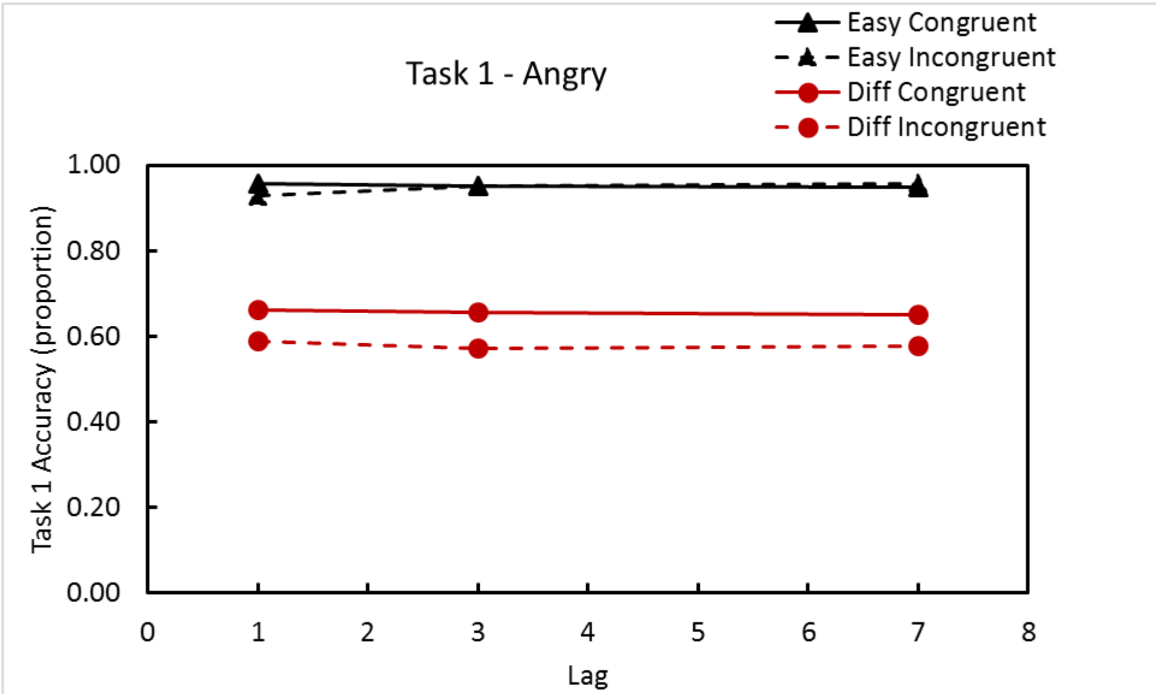


Figure 2 An example of event sequence



<u>Figure 3</u> Mean accuracy for Task 1 as a function of Task 1 difficulty (easy [consistent lower case] vs. difficult [mixed case]), Task 1-Task 2 emotional congruency (congruent vs. incongruent), and Lag (1, 3, and 7) for Task 1 word "angry" and Task 1 word "happy"



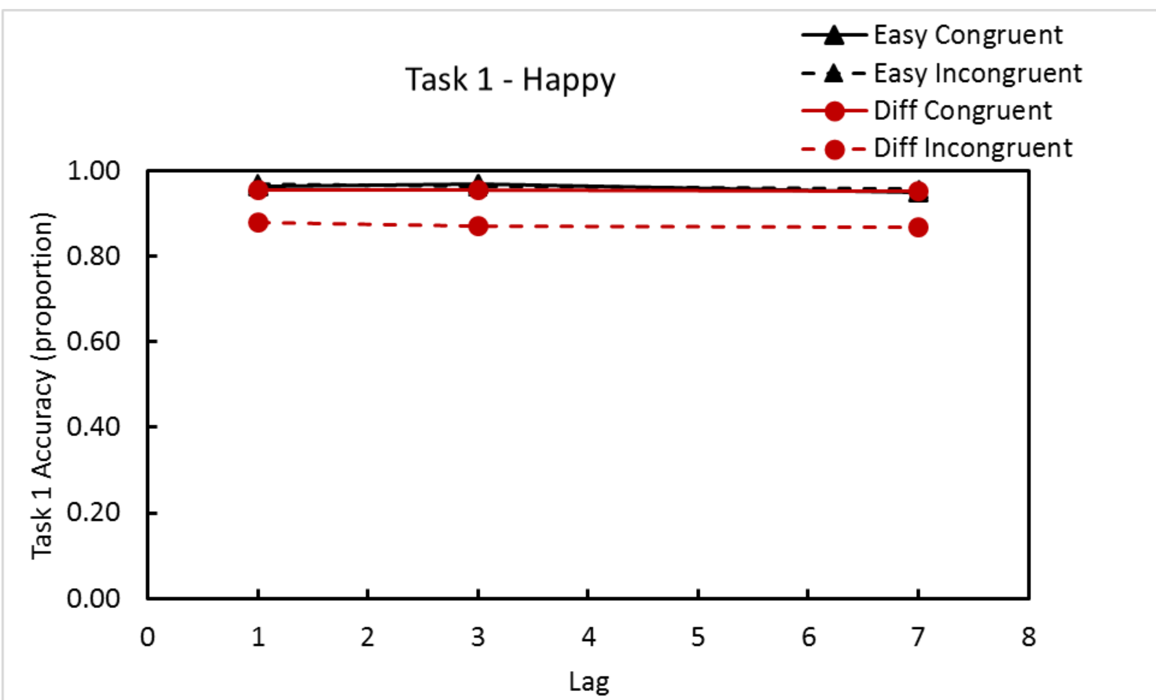
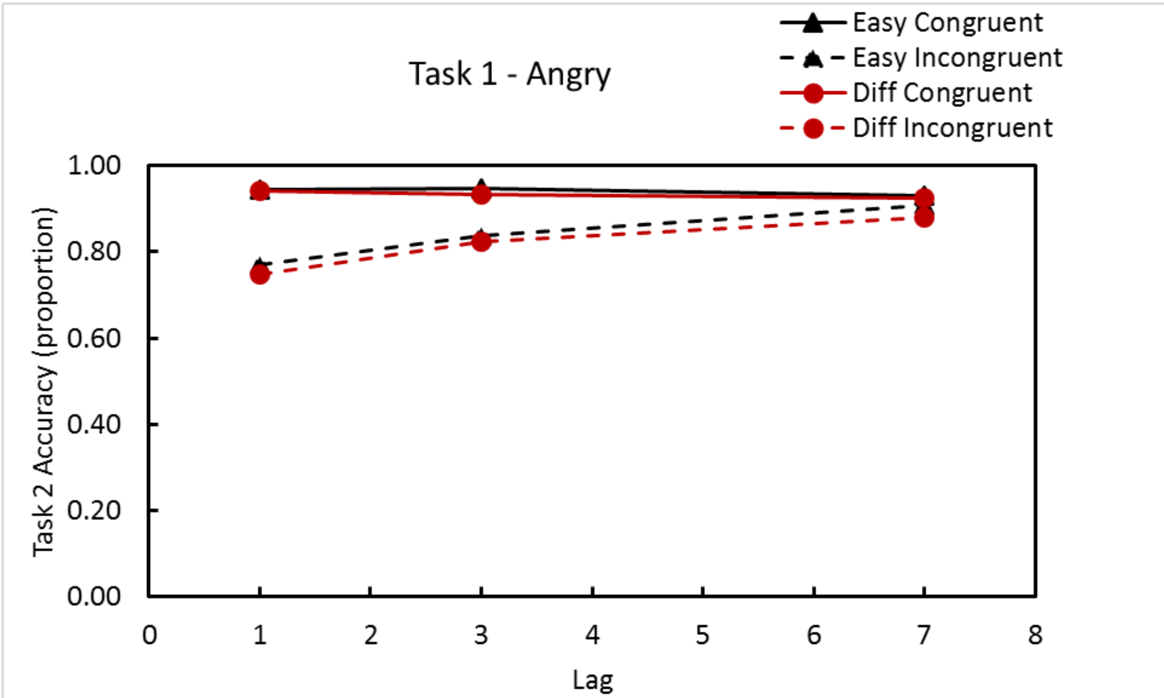


Figure 4 Mean accuracy for Task 2 as a function of Task 1 difficulty (easy [consistent lower case] vs. difficult [mixed case]), Task 1-Task 2 emotional congruency (congruent vs. incongruent), and Lag (1, 3, and 7) for Task 1 word “angry” and Task 1 word “happy”



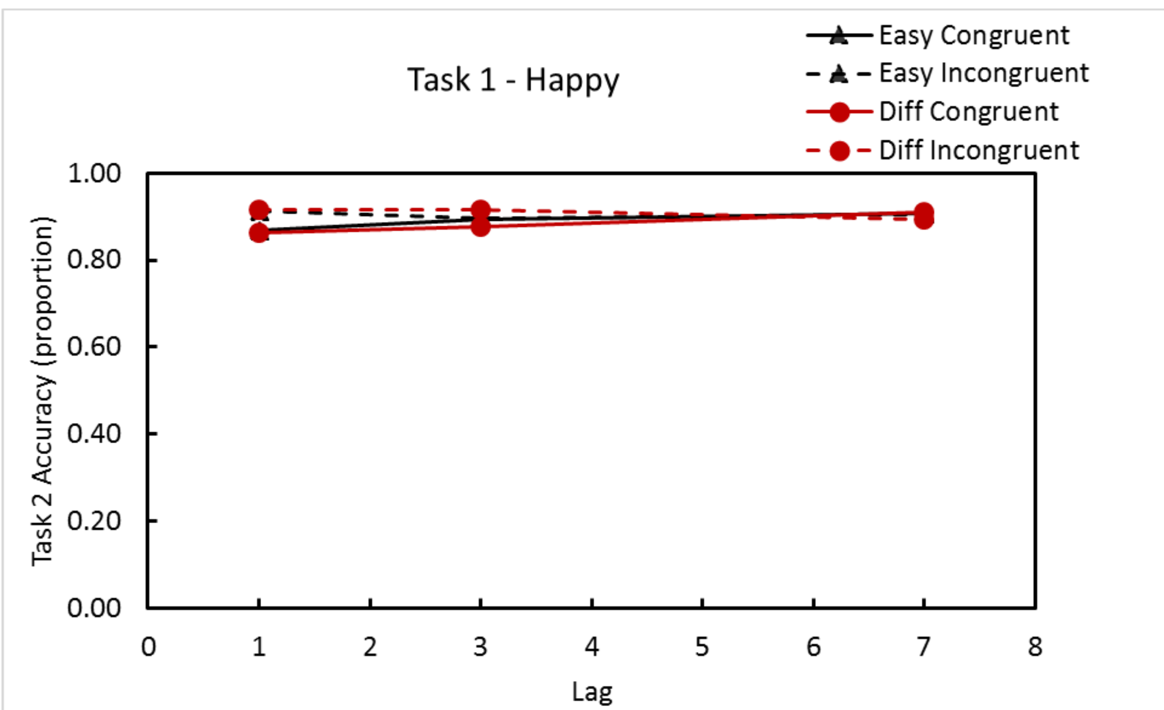


Figure 5 N400: Central (C3, Cz, and C4)

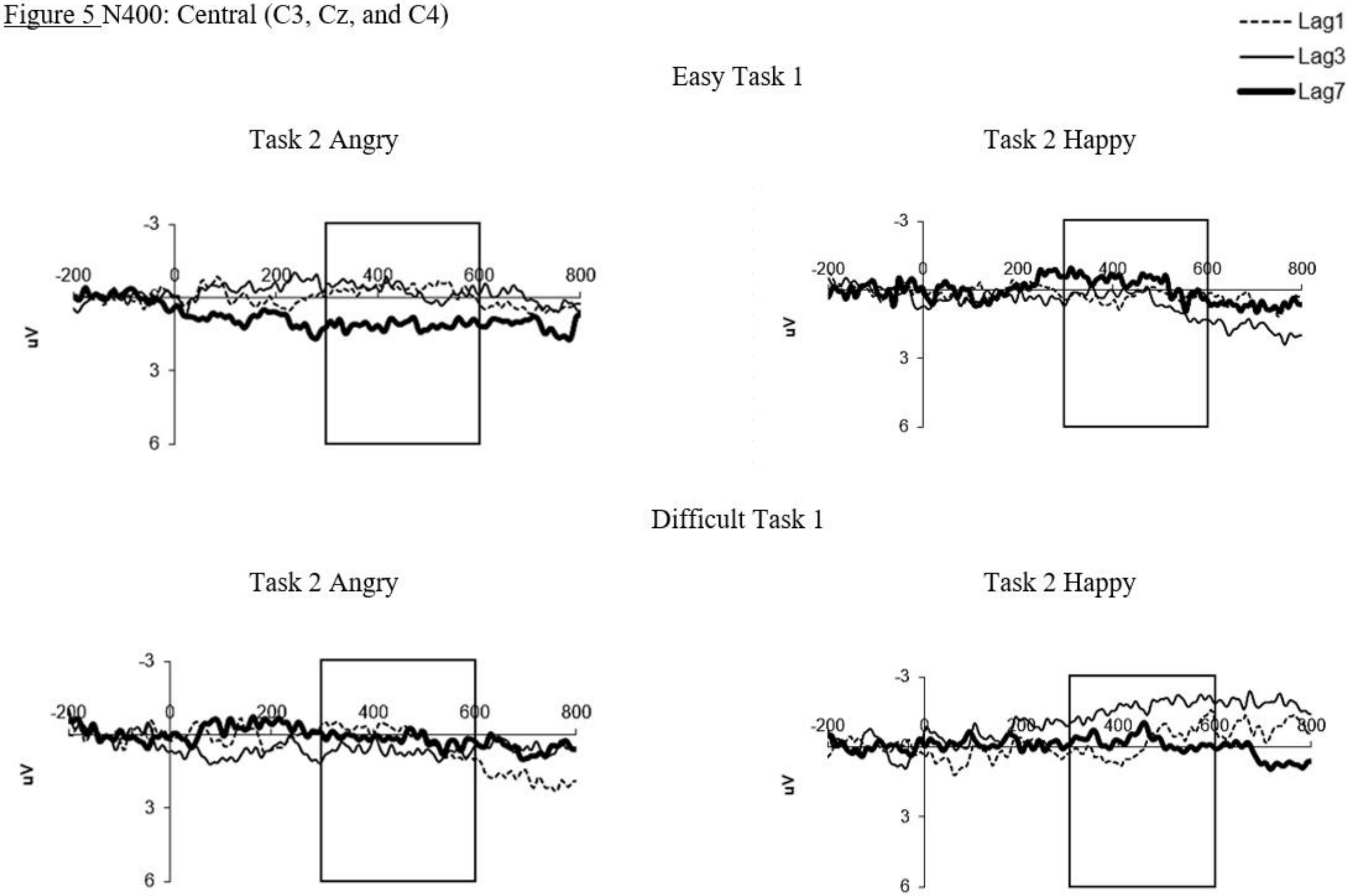
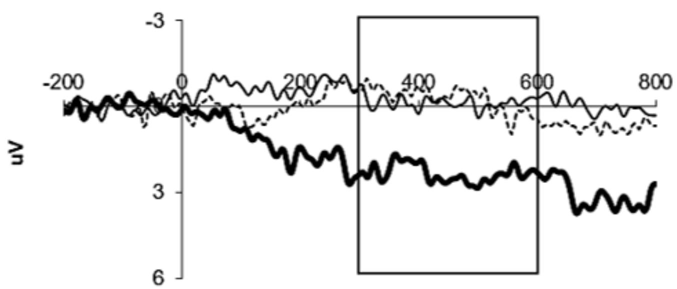


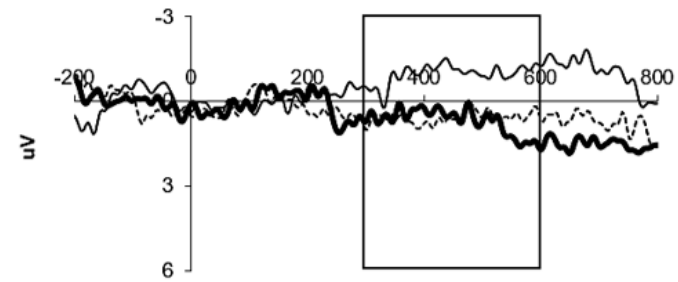
Figure 6 N400: Parietal (P3, Pz, P4)

Easy Task 1

Task 2 Angry

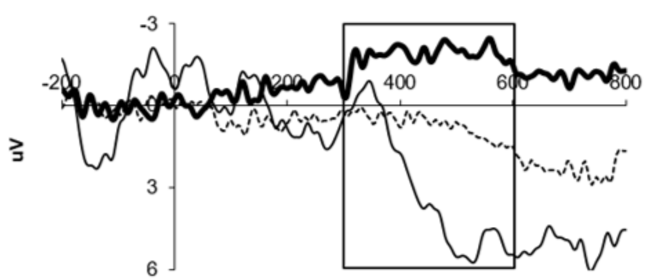


Task 2 Happy

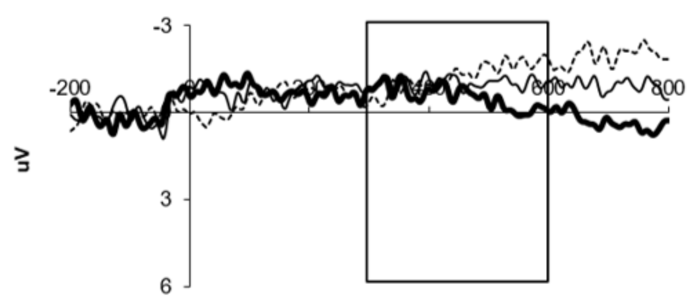


Difficult Task 1

Task 2 Angry



Task 2 Happy



Appendix A

A summary table for ANOVA on the accuracy for Task 1 and Task 2 as a function of group (T2 male face vs. female face), Lag (1, 3, and 7), Task 1 difficulty (easy vs. difficulty), T1 emotion type (angry vs. happy), and T2 emotion type (angry vs. Happy). T1: Task 1; T2: Task 2; T1 Diff: Task 1 difficulty; T1 Emot: Task 1 emotion; T2 Emot: Task 2 emotion.

Effects	*df*	Accuracy of T1		Accuracy of T2	
		F	*p*	*F*	*P*
Group	1,24	<1	___	5.39	.029
Lag	2,48	1.32	.274	9.30	<.001
T1 Diff	1,24	4055.90	<.0001	2.96	.098
T1 Emot	1,24	530.90	<.0001	12.56	.002
T2 Emot	1,24	<1	___	20.52	<.001
Group × Lag	2,48	<1	___	<1	___
Group × T1 Diff	1,24	<1	___	<1	___
Group × T1 Emot	1,24	5.03	.034	<1	___
Group × T2 Emot	1,24	1.36	.255	<1	___
Lag × T1 Diff	2,48	2.70	.077	<1	___
Lag × T1 Emot	2,48	<1	___	9.59	<.001
Lag × T2 Emot	2,48	1.37	.264	39.23	<.0001
T1 Diff × T1 Emot	1,24	590.59	<.0001	2.48	.128
T1 Diff × T2 Emot	1,24	1.58	.221	1.70	.204
T1 Emot × T2 Emot	1,24	232.98	<.0001	17.80	<.001

Group × Lag × T1 Diff	2,48	1.25	.296	<1	___
Group × Lag × T1 Emot	2,48	1.83	.171	<1	___
Group × Lag × T2 Emot	2,48	<1	___	3.46	.039
Group × T1 Diff × T1 Emot	1,24	1.56	.224	2.29	.144
Group × T1 Diff × T2 Emot	1,24	<1	___	<1	___
Group × T1 Emot × T2 Emot	1,24	<1	___	2.52	.126
Lag × T1 Diff × T1 Emot	2,48	1.96	.152	<1	___
Lag × T1 Diff × T2 Emot	2,48	<1	___	<1	___
Lag × T1 Emot × T2 Emot	2,48	<1	___	6.24	.004
T1 Diff × T1 Emot × T2 Emot	1,24	236.09	<.0001	<1	___
Group × Lag × T1 Diff × T1 Emot	2,48	<1	___	2.55	.088
Group × Lag × T1 Diff × T2 Emot	2,48	1.57	.220	1.05	.359
Group × Lag × T1 Emot × T2 Emot	2,48	<1	___	<1	___
Group × T1 Diff × T1 Emot × T2 Emot	1,24	<1	___	<1	___
Lag × T1 Diff × T1 Emot × T2 Emot	2,48	3.95	.026	1.54	.224
Group × Lag × T1 Diff × T1 Emot × T2 Emot	2,48	<1	___	1.35	.269

Appendix B

A summary table for ANOVA on the N400 effect for Task 2 as a function of electrode site (central vs. parietal), Lag (1, 3, and 7), Task 1 difficulty (easy vs. difficulty), and Task 2 emotion type (angry vs. happy). T1 Diff: Task 1 difficulty; T2 Emot: Task 2 emotion.

Effects	*df*	*F*	*p*
Site	1,25	*1.17*	*.289*
Lag	2,50	*<1*	___
T1 Diff	1,25	*<1*	___
T2 Emot	1,25	*4.48*	*.044*
Site x Lag	2,50	*4.60*	*.015*
Site x T1 Diff	1,25	*<1*	___
Site x T2 Emot	1,25	*<1*	___
Lag x T1 Diff	2,50	*2.69*	*.078*
Lag x T2 Emot	2,50	*<1*	___
T1 Diff x T2 Emot	1,25	*<1*	___
Site x Lag x T1 Diff	2,50	*2.22*	*.120*
Site x Lag x T2 Emot	2,50	*1.01*	*.373*
Site x T1 Diff x T2 Emot	1,25	*<1*	___
Lag x T1 Diff x T2 Emot	2,50	*2.82*	*.069*
Site x Lag x T1 Diff x T2 Emot	2,50	*1.66*	*.200*