VISUAL ATTENTION MECHANISMS UNDERLYING THE EMOTIONAL DOT PROBE TASK

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Thesis

Submitted to the faculty of the

Graduate School of Vanderbilt University

in partial fulfillment of requirements

for the degree of

MASTER OF ARTS

in

Psychology

May, 2010

Nashville, Tennessee

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TABLE OF CONTENTS

Page

VII. GENERAL DISCUSSION

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The emotional dot probe task is implemented to study attentional biases elicited by emotional stimuli. Reaction time measures are the predominant dependent variables in this paradigm, and responses to probes after emotional stimuli are usually faster than those after neutral stimuli. However, reaction time is a coarse measure representing the sum of a number of processes that occur to both initial stimuli and the probe itself, and it is unclear whether it is necessary to be highly anxious to show these effects. ERPs allow these processes to be parsed during both emotional and probe stimuli. We used an emotional dot probe paradigm to investigate these effects behaviorally and with ERPs, and we also investigated the degree to which anxiety is necessary to demonstrate these effects.

The Emotional Dot Probe Task

The visual cueing task was originally inspired by the work of cognitive psychologists interested in understanding the influence of expectancy of cues by the visual system. Posner, Snyder, and Davidson (1980) developed a visual cueing paradigm that tested a variety of different task parameters. One of the most important findings from Posner et al. (1980) was that individuals were more likely to respond faster to targets that appeared in attended visual areas than targets that appeared in unattended visual areas. Though this task was originally designed to assess covert visual attention, it has been successfully applied to both covert and overt visual attention processes, as covert attention precedes overt orientation and detection (Weierich, Treat & Hollingworth, 2008).

The world of clinical research has since capitalized on this cueing paradigm to examine attentional biases. Instead of varying expectancy, the spatial cues were changed to carry emotional weight. One way clinical research has explored the influence of emotional context on attentional capabilities is through a modified version of such a visual cueing task, known as an emotional cueing task or emotional dot probe task, where emotional stimuli are used as cues prior to probe detection (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Frewen, Joanisse, & Neufeld 2007, Mogg & Bradley, 1998). Instead of providing spatial and orienting information, the cues are emotional stimuli and neutral stimuli that are displayed briefly and simultaneously. After the offset of the cues, a target probe appears in one of the two regions that was cued. The rationale is that probes that are cued by emotional stimuli will elicit faster reaction time responses than probes that are cued by neutral stimuli. Emotional information, especially threatening information, presumably is more salient than neutral stimuli, and so should be processed more rapidly (Öhman, Flykt & Lundqvist, 2000).

It was thought that emotional content would drive biases and play into the hypersensitivity that some people experience in the face of emotionally salient information. MacLeod, Mathews, & Tata (1986) used this paradigm to test attentional bias towards threatening information in individuals suffering from clinical levels of anxiety. In a number of experiments (see Bar-Haim et al., 2007 and Mogg & Bradley 1998, for reviews), it was found that individuals high in trait anxiety were faster to respond to target probes when preceded by threatening stimuli. Using behavioral reaction time measures, it was inferred that these high trait anxiety individuals were more sensitive to threatening information. This bias captured their attention over the neutral words and primed them to be quicker to respond to probes when their attention was captured by the threatening information. Other research has addressed other kinds of attentional biases utilizing this paradigm, including research aimed at understanding addictions (Loeber, Vollstädt-Klein, von der Goltz, Flor, Mann, & Kiefer), trouble with food cravings for both obese and other disordered populations (Johansson, Ghaderi, & Andersson), biases of children suffering from recurrent abdominal pain (Boyer, Compas, Stanger, Colletti, Konik, Morrow, & Thomsen, 2006), and the emotional biases and aggressive tendencies of children and adolescents (Kimonis, Frick, Fazekas, & Loney, 2006; Kimonis, Frick, Munoz, & Aucoin, 2007).

While some researchers posit that such a threat bias can only be found in clinically anxious samples (see Bar-Haim et al., 2007), others have taken a stance of evolutionary salience to argue that this bias should be present in normal people as well. An evolutionary perspective regarding threat cues proposes that humans should be vigilant towards threat as a necessary means of survival (Öhman et al., 2000). Based on such an assumption, research has shown that as the perceived threat of stimuli increases, non-clinical groups do in fact show attentional biases towards threatening cues in the emotional probe task (Mogg & Bradley, 1998, Stormark, Nordby, & Hugdahl, 1995).

Event-Related Potentials as Measures of Attention in the Emotional Dot Probe Task

One of the biggest unvoiced criticisms plaguing research involving the emotional dot probe task is the amount of variation that exists between experiments. But the other reason for such equivocal results may lie in the outcome measures of the task itself. All the studies considered thus far have used behavioral reaction time (RT) measures to interpret their findings. However, the dot probe task is complex, and RTs represent the summation of activity across numerous components of the task: the initial cue, the probe, the decision to execute a response, and the motor response itself. The measure of RT is far removed from the onset of the trial, and it may be influenced by a number of different processes. It is useful to explore those preceding influences to understand the behavioral response. In an attempt to disentangle such matters, researchers have utilized more temporally sensitive methods, such as neural event-related potentials (ERPs).

Examining attentional processing via ERPs during different stages of the task may help to clarify between the contribution of attentional engagement versus problems with disengagement in attentional biases. As a purely behavioral task, the dot probe paradigm yields a behavioral measure of RT, which is an indirect measure of attentional bias. As stated previously, this may be problematic for interpretation of the overall task. By looking at brain activity associated with processing of emotional cues, and also separately looking at processing occurring at probe presentation, it may be possible to observe and track shifts in attentional resources prior to the execution of a behavioral response. This technique provides a more direct measure of attentional processing resources during the task.

The literature of ERPs and the emotional dot probe task is a burgeoning one. The focus of these studies has been placed on early visual processing components (Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Pourtois & Vuilleumier, 2006; Santesso, Meuret, Hofmann, Mueller, Ratner, Roesch, & Pizzagalli, 2008), as well as later visual components (Eimer & Kiss, 2007; Fox, Derakshan, & Shoker, 2008; Holmes, Bradley, Nielsen & Mogg, 2009), all of which are locked to stimulus onset. Thus, they complement behavioral RT measures and can be used along side them in interpreting emotional dot probe effects.

One component of interest is the very early occurring C1. It is elicited by the onset of visual stimuli, peaking approximately 90ms and is usually maximal at midline posterior/occipital electrode sites. Because of its automaticity and sensitivity to incoming visual stimuli, the C1 may be useful in indicating greater allocation of initial visual attention resources during the initial display of emotional stimuli in the dot probe task. Because the polarity of the C1 changes with respect to stimulus orientation, Pourtois et al. (2004) presented all stimuli to the upper visual field to isolate a negative C1 waveform in their emotional dot probe task. They found increased C1 amplitudes to fear/neutral face pairs versus happy/neutral faces pairs, suggesting emotional modulation of the C1 component. In contrast, Santesso et al. (2008) did not find a modulation of the C1 component, though they used angry faces instead of fearful faces.

P1 is another early visual component that may be useful in interpreting processing during this experimental task. The P1 component is also maximal at posterior-occipital electrodes sites, but it is usually maximal in lateral electrodes, peaking around 130ms. The P1 component has been linked to attentional gating, and larger amplitudes suggest increased attentional processing of incoming visual information (Hillyard, Vogel, & Luck, 1998). Pourtois et al. (2004) found significantly larger P1 amplitudes to probes cued by fear faces as compared to probed cued by happy faces. Similarly, Santesso et al. (2008) found larger P1 amplitudes to probes cued by angry faces, but also found larger P1 amplitudes to probes cued by neutral faces displayed alongside happy faces, concluding that increased spatial attention was allocated towards the more threatening stimuli during that condition.

Because emotional stimuli are presented as pairs simultaneously displayed, it is still impossible to discern which of the pair is eliciting the recruitment of processing resources without making inferences about patterns of activity. Another component, the N2pc, may be able to shed some light on this issue, as it is related to visual spatial attention selection (Eimer 1996; Woodman & Luck, 1999).

The N2pc is elicited in lateral posterior electrode sites by visual stimuli in the electrode contralateral to the attended visual stimulus. The waveform is typically confined to between 170 and 300 ms, though an earlier portion and a later portion of the component are frequently obtained (Eimer & Kiss, 2007; Holmes et al., 2009) and can provide information about the time course of attentional processing. Holmes et al. (2009) found angry faces revealed larger contralateral N2pc means detected within the early time window and sustained throughout the later time window, while happy faces only elicited larger contralateral N2pc means in the later time window, suggesting a more rapid capture of selective attention for angry faces, and a delayed allocation of selective attention for happy faces.

Current Study

The goal of the current study is to systematically examine the influence of different emotional faces on processing and performance in the emotional dot probe paradigm utilizing a multimodal approach. In addition to measures of behavioral RT to measure the influence of emotional context on performance, ERPs will be collected to assess different stages of processing throughout the task.

The current study takes into account other important aspects of using such sensitive psychophysiological measures, namely placement of stimuli in the visual field. All the previous studies reported their parameters regarding stimuli display in the visual field, including visual angle of stimuli on the screen. But none of the studies have confined the presentation of their stimuli to the region of optimal foveation (Calvo & Lang, 2005). Because ERPs require the minimization of eye movement to prevent eye movement artifacts, this task requires that participants fixated throughout the task. This study presented as much of the visual stimuli (fixation, cues and probes) as possible within this optimal foveal area.

Though both renditions of the experimental task will be identical in procedure, experiment 1 employed fear faces, while experiment 2 employed angry faces. An important difference between fear and angry faces is the emphasis or directionality of the threat. A fearful expression may imply there is a present threat, but it is indirect in its nature, while an angry face conveys a direct threat, and a sense that the viewer is the target of the emotion (Whalen, 1998). In each case, aversive emotional faces were paired with neutral faces, and happy/neutral face pairs were also displayed for half the trials.

Hypotheses

The participants in this experiment are “controls” and so are not expected to show significant differences in reaction times measures between emotional and neutral conditions. Nevertheless, personality traits associated with anxiety may correlate with these differences, particularly for aversive vs. neutral faces.

In line with findings by Pourtois et al. (2004), the C1 is expected to be modulated by fear/neutral face pairs as an indicator of increased attentional resources over the happy/neutral condition. It is unclear what to expect for angry/neutral face pairs, as Santesso et al. (2008) did not find emotional modulation of the C1 for angry/neutral pairs, and prior work has not demonstrated C1 modulation of visual attention (e.g., Clark & Hillyard, 1996). However, prior work has indicated with consistency that P1 is expected to be larger for probes following aversive emotional cues for both fear and angry faces compared to happy faces, and the component may be indicative of increased perceptual processing.

The contralateral N2pc is predicted to support prior work such that larger and earlier amplitudes should correspond to negative emotional face presentations while later portions of the component should be linked to positive (happy) emotional faces. Such a pattern of activity would suggest that negative emotional information indeed captures attention more rapidly than positive emotional information. It is also expected that angry faces will elicit enhanced negativities over fearful faces, as the directionality of the threat will be more personalized via an angry expression.

Finally, ERPs elicited by the dot probes will be examined to investigate the degree to which attentional processes present at the time of face onset persist during the brain's processing of the imperative stimulus. Previous studies have not examined, though they should yield important information regarding how attention may continue to be captured by emotional stimuli or attention may instead disengage from emotional stimuli before a response is made. The relationships of these ERP measures of attention with personality traits associated with anxiety were also examined to determine whether these effects are more pronounced for individuals high in anxious features.

CHAPTER II

METHOD – EXPERIMENT 1

Participants

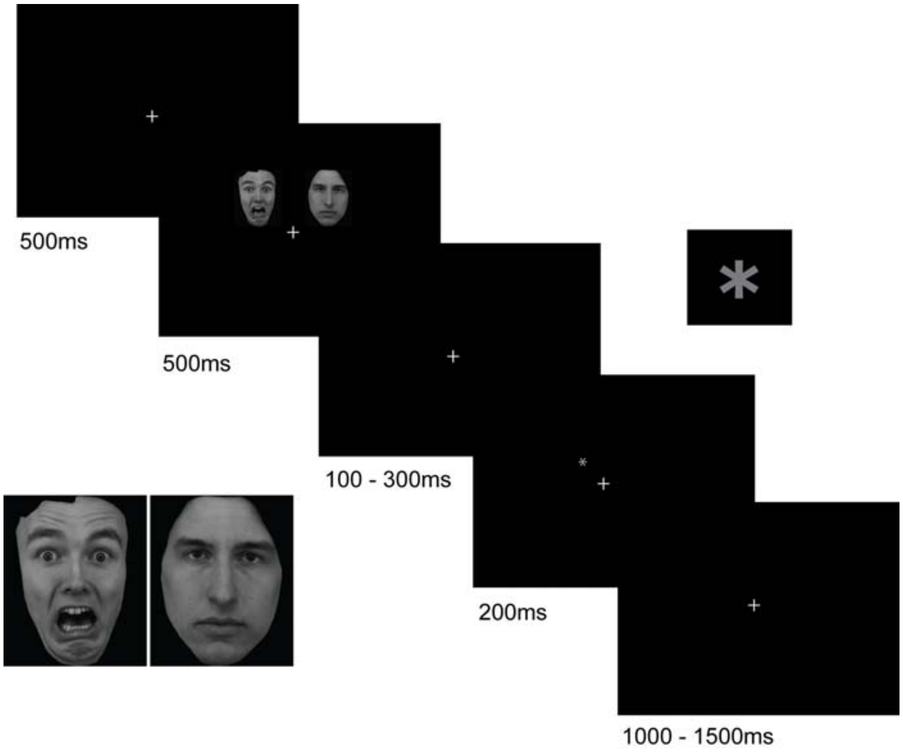
Fourteen healthy volunteers (7 females, mean age = 20.38 yrs) participated in this experiment. Vanderbilt undergraduates were granted course credit for their participation. All participants had normal or corrected-to-normal vision. A number of normal range personality dimensions, including Stress Reaction, were assessed via the Multidimensional Personality Questionnaire (MPQ; Tellegen & Waller, 2008).

Stimuli

16 male and 16 female actors were selected from the Karolinska Directed Emotional Faces (KDEF; Lundqvist, Flykt, & Öhman, 1998). For each actor that was selected, fear, neutral and happy expressions were used of the same actor, half male, and half female for a total of 96 unique stimuli displayed in the task. Faces were in gray scale, and cropped to remove hair and to enclose a rectangular space of close to 4x3cm, creating a visual angle of 2.3˚x 1.8˚ (26.4 pixels/cm) at a 100 cm viewing distance. All stimuli were presented on a black background.

Previous studies have presented the emotional stimuli in visual periphery, and outside the range of covert visual processing (> 2˚ of visual angle; see Calvo & Lang 2005 for further explanation). Calvo and Lang (2005) argue that that outside of a visual angle of between 2 and 2.5 degrees of visual angle, visual acuity decreases, and it becomes increasing difficult to process incoming stimuli. To ensure the face centers were presented within 2˚ of visual angle in the current study, the center of each face was approximately 3.6cm from the center of the fixation cross, and was placed so that the center of each face and the center of the fixation formed a right angle. Emotional faces had approximately 5 cm between their centers. These parameters allowed participants' eyes to remain fixated on a central point on the screen. The dot probe target was a grey asterisk presented at the central location following face offset. The fixation cross was a white cross approximately 1.2 x 1.3 cm and presented centrally on the screen throughout the task. Images were presented on a 19 inch flat screen LCD monitor using E-Prime software. (See Figure 1.)

Figure1. Experimental Procedure



Procedure

After obtaining informed consent, participants were seated in the experiment room and began responding to a computerized version of the MPQ. While participants completed the MPQ, a 64 channel Neuroscan Quik-Cap was fitted to the participant's head.

The experiment consisted of six blocks of 128 trials, for a total of 768 trials. A fixation cross was displayed continuously throughout the task, and participants were instructed to keep their gaze directed at the fixation throughout the task. Each trial began with the fixation cross at the center of the screen alone for 500 ms, followed by an emotional face pair displayed for 500 ms. After a random jitter of 100-300ms (in 50ms increments) the asterisk appeared for a duration of 200 ms, after which time participants were instructed to press “1” if they perceived the asterisk to the left of the fixation, and “9” if they perceived it to the right of the fixation. The trial continued for another 1000-1500ms. Fear-neutral and happy-neutral face pairs were presented with equal probability, and presentation was random. Emotional faces were also equally as likely to appear on the left and right side of the screen, and the presentation of the probe appeared with equal probability on either side following emotional and neutral faces.

The task was presented in a dark room. Instructions were read aloud to participants by experimenter, and the experimenter remained present for a short practice block of eight trials. The experimental task lasted approximately 35-40 minutes, and participants were allowed to rest between blocks. After the task, participants were also asked to rate the valence and arousal of each face presented during the task using Self

Assessment Manikin rating scale (SAM; Bradley & Lang, 1994). Participants were then thanked and debriefed at the end of the experiment.

Electroencephalogram

EEG was recorded using Neuroscan Acquire software version 4.4 from 32 Ag/AgCl scalp electrodes: FP1, FPZ, FP2, F3, FZ, F4, FC3, FCZ, FC4, C3, CZ, C4, CP3, CPZ, CP4, P7, P3, PZ, P4, P8, PO7, PO3, POZ, PO4, PO8, O1, OZ, O2, and mastoids. Horizontal electroculogram (HEOG) was monitored by electrodes placed laterally on the outer canthi of the eyes, and vertical electroculogram (VEOG) electrodes were placed above and below the left eye. Impedances were kept below 10 kΩ. All electrode sites were referenced to a reference electrode near the vertex then re-referenced offline to averaged mastoids. EEG was bandpass filtered online between 0.05-200 Hz and sampled at a rate of 1000 Hz. The signal was subsequently lowpass filtered offline with a cutoff frequency of 30 Hz.

Prior to offline filtering, the continuous EEG record was epoched to 1250 ms windows circumscribing the onset of face and probe stimuli and including a 250 ms pre-stimulus baseline. A correction was applied offline to reduce blink artifacts (Semlitch et al., 1986). Epochs containing amplitudes exceeding ±70 μV after blink correction were excluded from further processing and analysis (Pourtois et al., 2004).

Data Analysis

Components were defined as a baseline-to-peak amplitude within an established time window based on visual inspection of the grand average waveforms with respect to a

200ms pre-stimulus baseline. The time windows and electrode sites chosen were based on visual inspection of waveforms that confirmed windows used in prior work (Pourtois et al., 2004; Holmes et al., 2009). Thus, analyses are reported for midline and lateral parietal occipital electrodes (namely, PO7, POZ, and PO8).

Several components time locked to the onset of the face pairs were analyzed. The C1 was measured at the midline electrode POZ within a time window of 80-100ms. To examine the influence of the emotional face type on processing, a 2 (Emotion: fear vs. happy) x 2 (emotional face Location: left vs. right) repeated measures ANOVA was performed. P1 was measured at electrodes PO7 and PO8 with a time window of 110-190ms. A 2 (Emotion: fear vs. happy) x 2 (emotional face Location: left vs. right) ANOVA was performed to further examine sensitivity of spatial attention to faces. The N2pc was also time-locked to face pair onset and measured at PO7 and PO8 in two time windows; 1) early N2pc between 170-220ms, and 2) late N2pc between 250-330ms. A 2 (Emotion: fear vs. happy) x 2 (electrode Laterality: contralateral vs. ipsilateral) repeated measures ANOVA was performed on these components' amplitudes time-locked to the face display. Additional a priori paired *t* tests for contralateral versus ipsilateral waveforms were conducted separately for happy and fear conditions.

For probe-locked P1 waveforms, analyses included lateral parietal-occipital electrodes PO7 and PO8 and was measured between 100-190 ms following the onset of the probe display. To examine the influence of validity of the emotional face as a cue for spatial attention, a 2 (Emotion) x 2 (emotional face Location) x 2 (Validity: probe appeared after an emotional or neutral face) within-subject ANOVA was performed. N2pc early and late components were also examined to confirm that participants were attending to the probe. A 2(Emotion: fear vs. happy) x 2 (electrode Laterality: contralateral vs. ipsilateral to the emotional face) x 2 (Validity: probe appeared after an emotional or neutral face) repeated measured ANOVA was performed.

To explore the influence of individual differences of anxiety on attentional processing, Stress Reaction (SR) scores, as measured via the MPQ, were correlated with both behavioral RT and with cortical activity from ERP components of interest.

CHAPTER III

RESULTS – EXPERIMENT 1

Behavioral Results

While accuracy was very high for the task (*M* = .96, *SD* = .04), incorrect trials were not included in the initial inspection of the data regarding the dot probe effect. Reaction times (RTs) faster than 200ms and slower than 3 *SD*s above the sample's mean were excluded.

Mean RTs for emotional face type (cue type) for fear/neutral and happy/neutral face pair conditions and are shown in Table 1. Paired samples *t*-tests of these mean RTs did not yield any significant differences. Solely based on behavioral RTs, this would suggest no emotional bias in the task, as emotional information (negative or positive) did not influence behavioral responses measured by RTs.

For other analyses, RT difference scores were calculated as mean RTs of Emotional Cue – Neutral Cue for both fear and happy conditions.

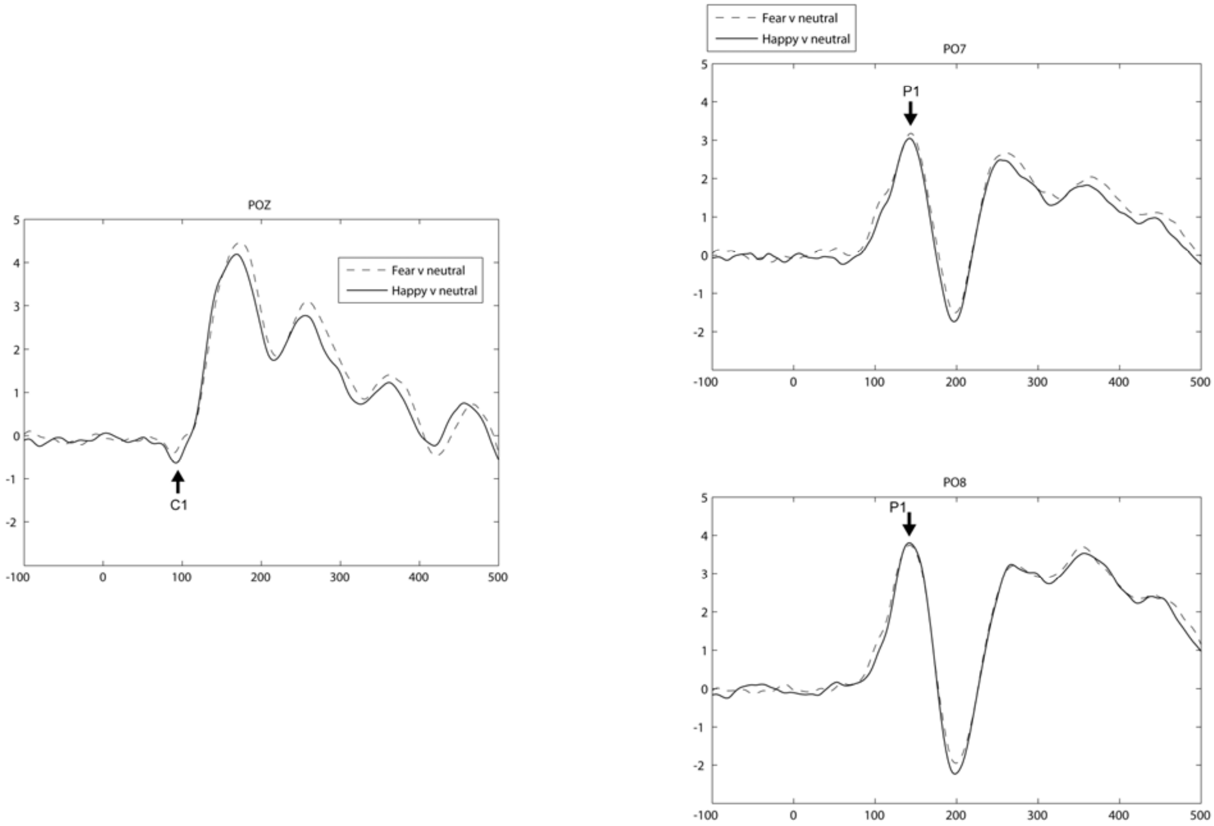
Table 1. Mean Reaction Times (RTs) and Standard Deviations for Emotional Cue and Neutral Cue Trials.

	Fear/Neutral face pairs	Happy/Neutral face pairs
	M (SD)	*M (SD)*
Emotional cues	407 (39)	407 (36)
Neutral cues	407 (37)	406 (37)

Face-Locked Activity

Contrary to findings by Pourtois et al. (2004), no emotional modulation of the C1 wave was found for either emotional face condition, as no main effects or interactions for face-locked C1 activity at POZ were found. There were also no significant effects on face-locked P1 or early or late N2pc amplitudes (see Figure 2 for waveforms).

Figure 2. Face-locked Waveforms for Fear and Happy Face Pair Conditions.



Probe-Locked Activity

As depicted in Figure 3, probes occurring after fear faces tended to evoke greater probe-locked P1 amplitudes than those after happy faces, *F*(1,13) = 3.13, *p* = .10. This effect was confined to the right hemisphere as demonstrated by a trend toward a face Location x Emotion interaction, *F*(1,13) = 3.74, *p* = .08. Similar effects were not found at PO7. This trend toward greater processing of the probe stimuli in the right posterior electrode is generally consistent with prior findings (e.g., Pourtois et al., 2004; Santesso et al. 2008). Probe-locked P1 did not exhibit a significant Validity x Emotion interaction as expected.

Probe-locked N2pc was again split into an early and late N2pc. Late probe-locked N2pc was significant for electrode Laterality, *F*(1,14) = 35.6, *p* < .01, confirming that participants perceived the probes, as covert attention was directed to probe locations as indexed by the contralateral electrode. A curious result emerged for early probe-locked N2pc, which showed a strong effect for electrode Laterality, *F*(1,14) = 21.9, *p* < .01, but with greater amplitudes at the ipsilateral electrode than the contralateral electrode for this time window (see Figure 4 for waveforms).

Figure 3. Probe-locked P1 Activity for Fear and Happy Face Conditions.

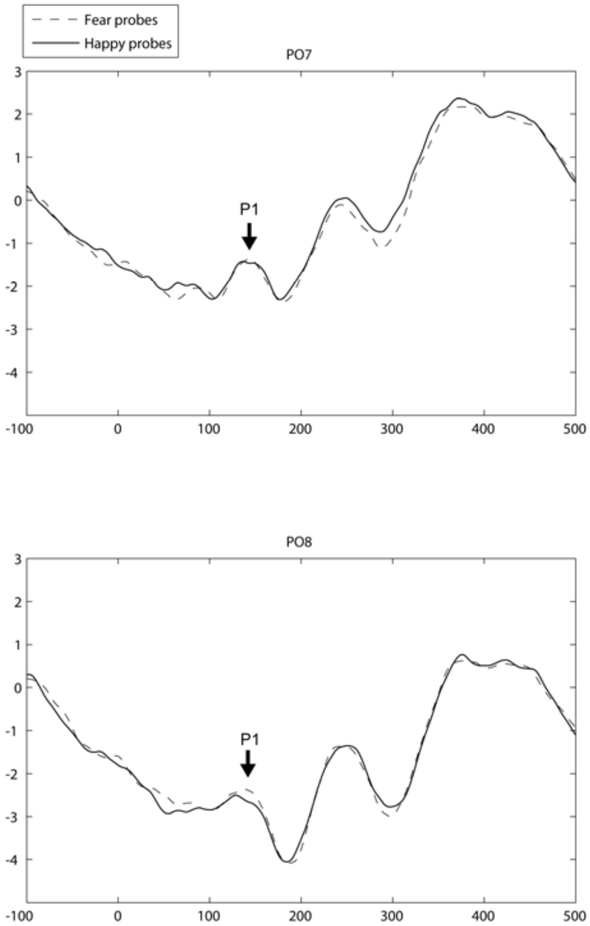
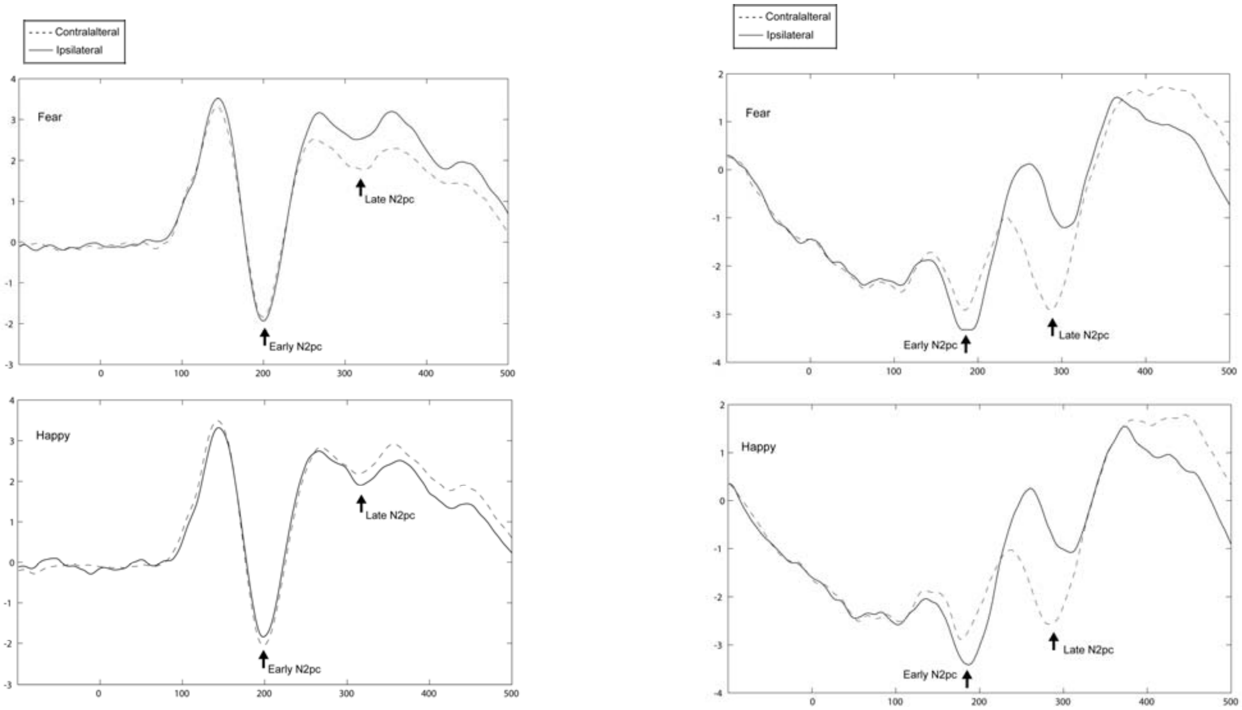


Figure 4. Face-locked and Probe-locked N2pc Waveforms for Contralateral and Ipsilateral Activity.



Correlations of Brain Activity

Table 2 displays the correlation matrix between face-locked C1 and face-locked P1 components, including difference scores and averages between electrodes. There was a trend for the face-locked C1 fear-happy difference and face-locked P1 fear-happy difference to be related at both PO7 and PO8. A significant relationship was found between face-locked C1 for fear/neutral pairs and averaged (PO7 and PO8) face-locked P1 activity during the fear and happy conditions. The same relationship was found between C1 for happy/neutral pairs and averaged face-locked P1 activity during the happy condition; this relationship approached significance in the fear condition.

Table 2. Correlation Matrix for Face-locked C1 Activity and Face-locked P1 Activity Between Conditions.

	C1 at POZ (Fear)	C1 at POZ (Happy)	C1 difference (Fear-Happy)
P1 at PO7 difference (Fear-Happy)	.33	.11	.51†
P1 at PO8 difference (Fear-Happy)	-.15	-.35	.47†
P1 average (PO7/PO8) Fear	.54*	.54*	.01
P1 average (PO7/PO8) Happy	.52†	-.58*	-.12

Note. * $p < .05$, † $p < .10$

Contrary to Pourtois et al. (2004), there was no significant correlation between face-locked C1 activity at POZ with probe-locked P1 activity for both fear and happy conditions. Thus, there was no evidence of sustained attention to emotional faces from face onset to probe onset.

Correlations of RT and ERP Components

C1 amplitude was not correlated with RTs across conditions. Face-locked P1 amplitude as measured by PO8 was positively correlated with RT measures from all conditions (*r*s range from .57 to .65, *p*s < .05). This relationship did not hold up when RT difference score was calculated. This may indicate early selective attention to the face pairs as indexed by the P1 component and lateralized to the right posterior hemisphere is linked with slowed RTs. The average P1 activity across PO7 and PO8 during the fear/neutral face pair condition also showed a positive correlation with RTs across all conditions (rs > .57, $p < .05$). Thus, in these analyses, it appears that when the faces are perceived more strongly early on, they may contribute to slowed behavioral responses. Face-locked N2pc was not related to RT differences, and probe-locked P1 and probe-locked N2pc did not correlate with RTs.

Personality Traits and Brain Activity

Face-locked C1 amplitudes in the fear/neutral face pair condition were correlated with MPQ behavioral constraint scores, such that larger C1 amplitudes were related to higher scores on Behavioral Constraint ($r = -.55$, $p < .05$). No measures of anxiety were correlated with the face-locked C1 or P1 amplitude. Probe-locked P1 was not correlated with measures of anxiety.

Results from the correlation between N2pc and personality measures of interest are listed in Table 3. Face-locked Late N2pc amplitudes were correlated with higher scores of SR (rs < -.51, $p < .05$), where greater N2pc amplitudes and higher scores on Stress Reactivity (SR) are correlated. Interestingly, face-locked early N2pc difference (contralateral-ipsilateral) correlated negatively with Behavioral Constraint (CO), for fear/neutral pairs and positively for happy/neutral pairs. In other words, greater N2pc differences between contralateral and ipsilateral electrodes for fear correlated with higher scores of Behavioral Constraint, whereas greater N2pc differences for happy correlated with lower Behavioral Constraint scores. This pattern suggests that Behavioral Constraint may be related to increases in attention allocation in the context of negative, specifically fear, emotional stimuli.

Table 3. Correlations Between N2pc Mean Peak Amplitudes for Face-locked Activity and Personality Dimensions as Measured by the MPQ

	Stress Reactivity	Negative Emotionality	Positive Emotionality	Behavioral Constraint
Face-Locked N2pc				
Early				
Fear	-.43	-.31	-.17	-.19
Happy	-.45	-.30	-.26	-.05
Fear Difference (Contra-Ipsi)	.14	.01	.41	-.60*
Happy Difference (Contra-Ipsi)	-.04	.10	-.52†	.59*
Late				
Fear	-.59*	-.37	.16	-.37
Happy	-.51†	-.27	-.01	-.10
Fear Difference (Contra-Ipsi)	.11	.01	.32	-.28
Happy Difference (Contra-Ipsi)	-.11	.05	-.24	.27

Note. * $p < .05$, † $p < .10$.

CHAPTER IV

DISCUSSION

As expected, results from experiment 1 did not show any differences between conditions regarding behavioral reaction time. Contrary to Pourtois et al. (2004), none of the early visual components' amplitudes were modulated by emotional faces. Furthermore, face-locked activity was not related to probe-locked activity to show attentional effects of fear faces, and N2pc effects are also not in line with prior work. In experiment 2, fear faces are replaced with angry face expressions in an attempt to increase the saliency of the negative emotional face for participants, as angry face expressions are thought to be less ambiguous regarding the source of the threat (Whalen, 1998).

CHAPTER V

METHOD – EXPERIMENT 2

Fifteen healthy volunteers (12 females, mean age = 19.27yrs) participated in this experiment. All procedures were identical to those listed for Experiment 1. Fear face expressions were replaced with angry face expression by the same actors chosen for Experiment 1 from the KDEFs (Lundqvist, Flykt, & Öhman, 1998). All other procedures and plans for analysis are identical to those outlined in Experiment 1.

CHAPTER VI

RESULTS – EXPERIMENT 2

Behavioral Results

While accuracy was again very high for this task (M = 96%, SD = .03), incorrect trials were not included in the initial inspection of the data regarding the dot probe effect. As per procedures in experiment 1, RTs were converted to z scores, and RTs faster than 200ms and 3 z scores above each participant's mean were excluded from analyses.

Mean RTs were calculated for emotional face type (cue type) for angry/neutral and happy/neutral face pair conditions and are shown in Table 4. Similar to experiment 1, paired samples *t*-tests of these mean RTs did not yield any significant differences. This might again suggest no emotional bias, as emotional information (negative or positive) did not influence behavioral responses as measured by RTs. Negative emotional faces were changed from fear, in experiment 1, to angry, in experiment 2, yet this did not produce a difference in behavioral RT between conditions in this task.

Table 4. Mean Reaction Times (RTs) and Standard Deviations for Emotional Cue and Neutral Cue Trials.

	Angry/Neutral face pairs	Happy/Neutral face pairs
	M (SD)	*M (SD)*
Emotional cues	410 (37)	411 (37)
Neutral cues	409 (37)	411 (38)

Face-Locked Activity

As depicted in Figure 5, the C1 component was not modulated by emotion. It is worth noting, however, that main effect for Emotion almost reached trend levels, such that a more negative C1 can be seen for angry face pairs relative to happy face pairs, $F(1,14) = 2.99$, $p = .106$). Paired samples *t*-test of C1 for angry condition versus C1 for happy condition did not yield significance ($t = -1.18$, n.s.) Face-locked P1 did not yield any significant effects, as diagrammed in Figure 5.

Face-locked early N2pc showed no significant effects. However, the late N2pc yielded a significant main effect for electrode Laterality, indicating greater negativity for contralateral electrodes, $F(1,14) = 5.04$, $p < .05$. Paired samples *t*-test revealed a significant difference between contralateral and ipsilateral electrodes in the angry condition, $t(14) = -2.48$, $p < .05$, but not for the happy condition, $t(14) = .37$, $p = .72$. The late face-locked N2pc thus confirms an attentional bias for angry faces, as angry faces are selectively attended to over neutral faces, and also compared to happy/neutral pairs (see Figure 6 for waveforms).

Figure 5. Face-locked Waveforms for Angry and Happy Face Pair Conditions.

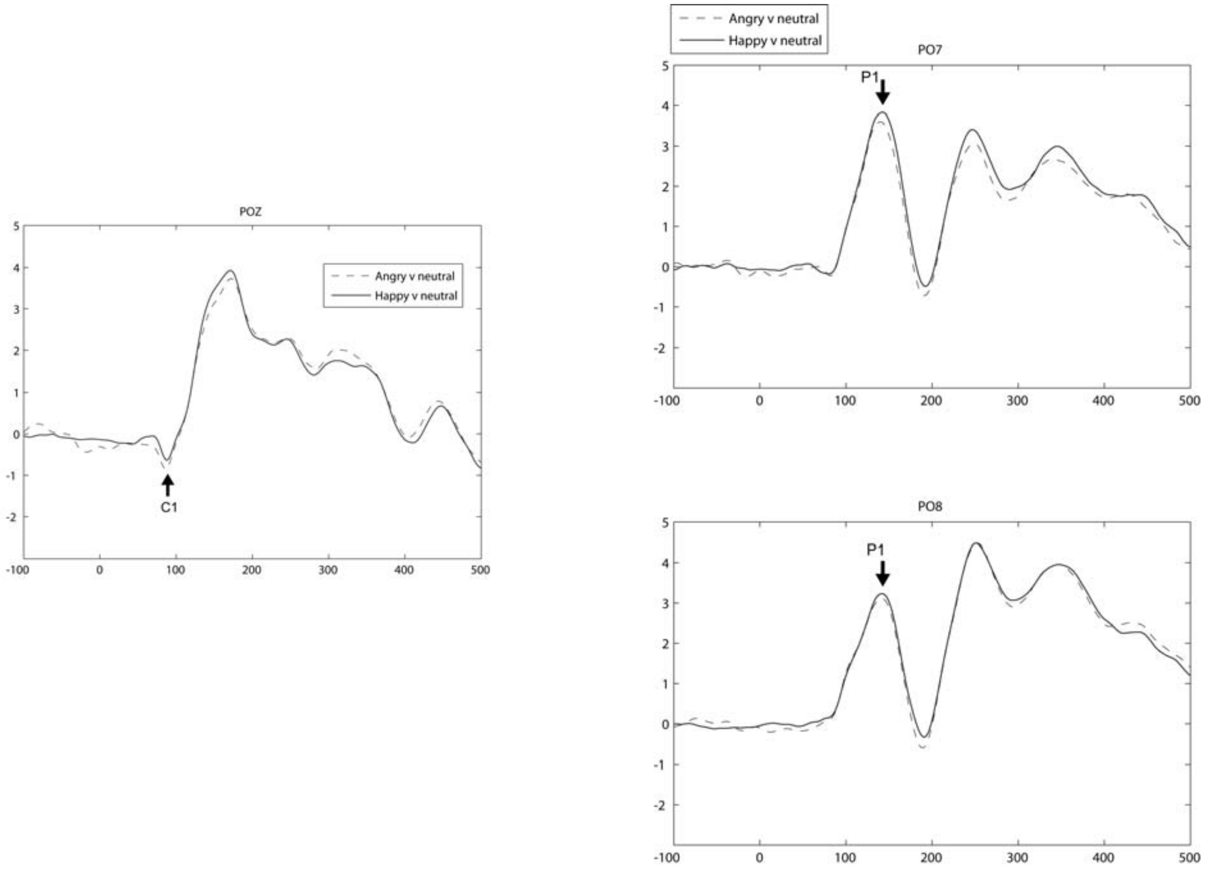
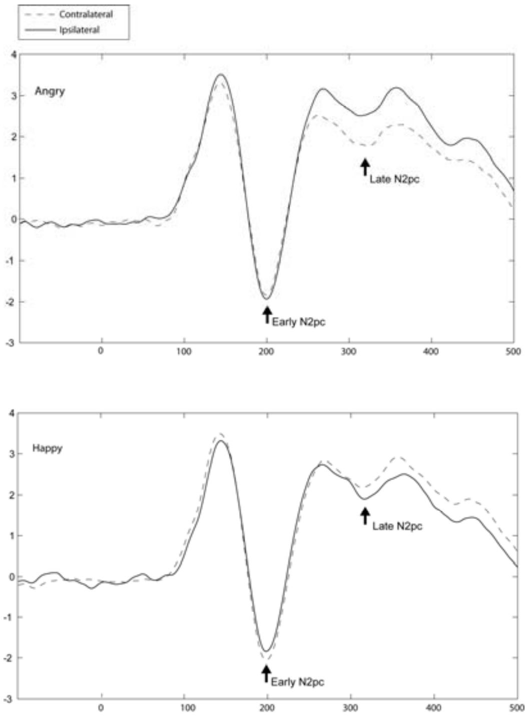


Figure 6. N2pc Face-locked Activity.



Probe-Locked Activity

As shown in Figure 7, for the probe-locked P1 at PO7, there was significant interaction of face Location x Emotion, $F(1,14) = 15.5$, $p < .01$. There was also a significant interaction of face Location x Validity $F(1,14) = 6.55$, $p < .05$.

Probe-locked Early N2pc yielded a similarly curious result for main effect of electrode Laterality as seen in experiment 1, in that greater negativities in this time window were associated with ipsilateral electrode activity, $F(1,14) = 16.6$, $p < .01$. It is still not clear how to interpret this result, but further examination is warranted into the nature of the early versus late N2pc component.

As shown in Figure 8, probe-locked late N2pc also yielded a significant main effect of Laterality, such that contralateral electrodes generated more negative N2pc amplitudes than ipsilateral electrodes, $F(1,14) = 6.68$, $p < .05$. This portion of the component also showed significant interactions of Emotion x electrode Laterality, $F(1,14) = 7.54$, $p < .05$, where greater negativity was found in the difference of activity between contralateral and ipsilateral in the happy condition. The most interesting result was a significant interaction between Emotion x Validity, $F(1,14) = 6.71$, $p < .05$, such that for the angry/neutral condition the negativity was greater for probes following neutral face cues, whereas for the happy/neutral condition the negativity was greater for probes following happy face cues. The magnitude of the happy/neutral N2pc was also less negative than the angry/neutral N2pc. This suggests greater resources were recruited to process probes following neutral faces when paired with angry faces. This pattern of activity for probes occurs on the heels of a significant finding for initial capture of attention being greater for angry faces. This pattern of activity for face-locked compared to probe-locked N2pc activity illustrates the flexibility of attentional resources exhibited by participants' performance in this task. It suggests that attentional capture has distinct brain activity patterns for different components of the emotional dot probe task.

Figure 7. Probe-locked P1 Activity.

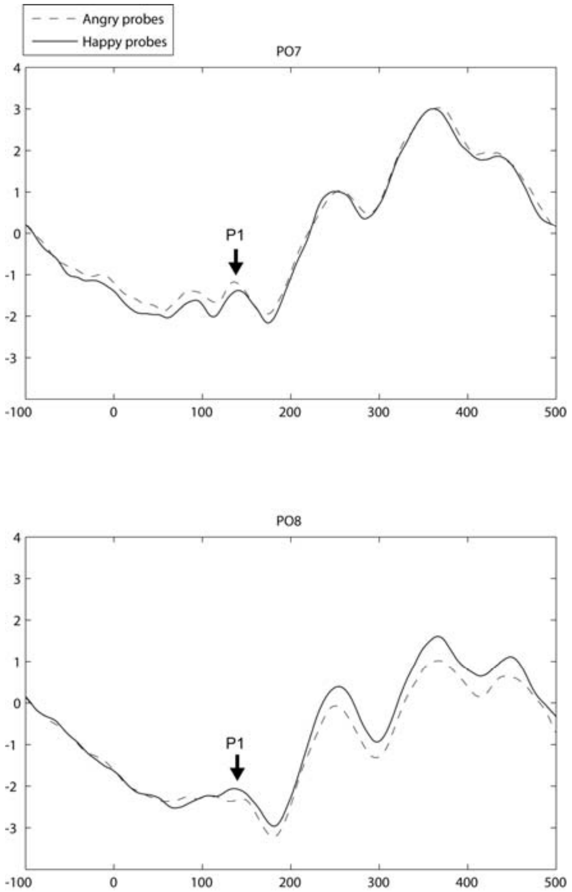
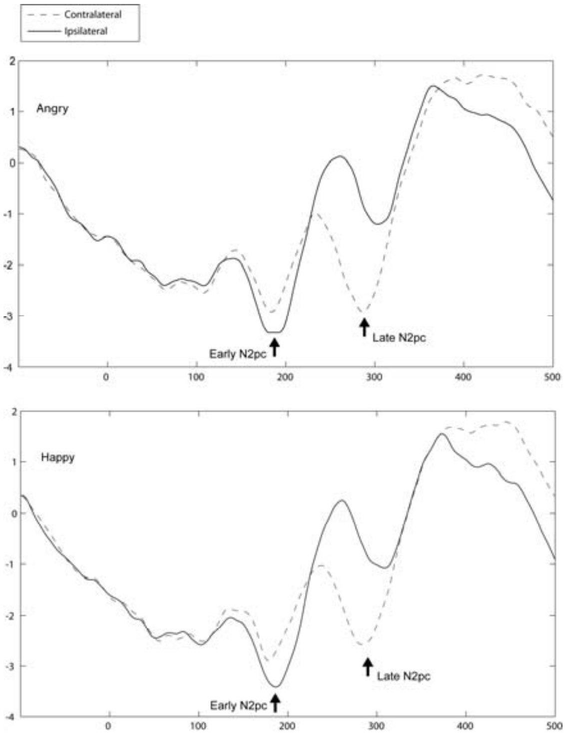


Figure 8. Face-locked and Probe –locked N2pc Activity.



Correlations of Brain Activity

Table 5 shows the correlations between face-locked C1 and face-locked P1 activity. A significant positive correlation between C1 angry – happy difference and angry – happy difference for P1 at both PO7 and PO8 was found. This correlation is stronger than the correlation for experiment 1 and may indicate angry faces did influence an increase in these automatic visual processing components.

Table 5. Correlation Matrix for Face-locked C1 Activity and Face-locked P1 Activity Between Conditions.

	C1 at POZ Angry	C1 at POZ Happy	C1 difference (Angry-Happy)
P1 at PO7 difference (Angry-Happy)	-.18	-.39	.53*
P1 at PO8 difference (Angry-Happy)	.11	-.12	.53*
P1 average (PO7/PO8) Angry	-.20	-.04	-.34
P1 average (PO7/PO8) Happy	-.18	.02	-.43

Note. * *p* < .05.

To test for sustained attention between emotional faces and later probe onset (see Pourtois et al., 2004), face-locked C1 was correlated with probe-locked P1, but even with the change to angry faces, results were not significant.

Correlations of RT and ERP components

There were no correlations found between C1, or face-locked or probe-locked P1 with RT measures. The face-locked early N2pc contralateral - ipsilateral difference for angry face pairs correlated positively with mean RTs across conditions, whereas the contralateral – ipsilateral difference for happy face pairs correlated negatively across condition (see Table 6). Face-locked late N2pc, and probe-locked N2pc did not correlate with RTs. In other words, faster RTs were associated with larger N2pc for angry face pairs, while slower RTs were associated with happy face pairs.

Table 6. Face-Locked N2pc Difference (Contralateral-Ipsilateral) and Mean RTs

	Mean RTs			
	Angry	Happy	NeutralAngry	NeutralHappy
Face-Locked N2pc				
Early				
Angry difference	.54*	.56*	.49†	.51†
Happy difference	-.59*	-.63*	-.62*	-.59*
Late				
Angry difference	.35	.33	.25	.26
Happy difference	-.39	-.42	-.36	-.35

**p* < .05, †*p* < .10

Personality Traits and Brain Activity

The contralateral – ipsilateral difference for the probe-locked N2pc during happy faces during congruent trials tended to correlate with Negative Emotionality as measured by the MPQ, $r = .50$, $p = .06$. Also, the contralateral - ipsilateral difference for early and late face-locked N2pc during happy faces negatively correlated with Stress Reactivity, such that higher Stress Reaction scores were related to larger N2pc amplitudes. The face-locked correlations are displayed in Table 7.

Table 7. Correlations Between N2pc Mean Peak Amplitudes for Face-locked Activity and Personality Dimensions as Measured by the MPQ

	Stress Reactivity	Negative Emotionality	Positive Emotionality	Behavioral Constraint
Face-Locked N2pc				
Early				
Angry	-.24	-.04	.03	.07
Happy	-.42	-.14	.09	.04
Angry Difference (Contra-Ipsi)	.46†	.19	-.07	.24
Happy Difference (Contra-Ipsi)	-.65**	-.31	.27	.18
Late				
Angry	.30	.35	-.07	-.08
Happy	.08	.20	-.15	-.14
Angry Difference (Contra-Ipsi)	.28	.07	.18	.38
Happy Difference (Contra-Ipsi)	-.57*	-.28	-.07	.03

Note. ** $p < .01$, * $p < .05$, †$p < .10$.

CHAPTER VII

GENERAL DISCUSSION

The emotional dot probe task is commonly used as a behavioral task to confirm attentional biases based on measures of RT. By adding the psychophysiological measure of cortical brain activity via ERPs, the task can measure more than just behavioral reaction time and provide information about processing during different time points throughout the task by assessing attention engagement and resource recruitment. In both experiment 1 and 2, RTs were not significantly different across conditions. This might lead to an interpretation of this version of the task being unable to tap attentional biases, but when considering the ERP data, a different story emerges.

Early Visual ERP Components

Prior work has examined early automatic visual components as a way to index selective attention to emotional face pairs presented at the beginning of this task (see Pourtois et al., 2004; Santesso et al., 2008). Our results cannot confirm emotional modulation of the C1 component. In the cognitive literature, C1 has not been found to be modulated by selective attention (Clark & Hillyard, 1996; Di Russo, Martinez, & Hillyard, 2003; Gomez Gonzalez, Clark, Fan, Luck, Hillyard, 1994; Fu, Fan, Chen, Zhuo, 2001; Martinez, Anllo-Vento, Sereno, Frank, Buxton, Dubowitz, Wong, Hinrichs, Heinze, & Hillyard, 1999), and the results for emotional modulation may have been spurious. It is interesting to note that although no significant effects were found for fear faces, angry face pairs approached a trend for a main effect of emotion. Perhaps with increased power this result could reach statistical significance, thought it would also need to be replicated.

Another very early visual component that was examined and that can be influenced by selective attention is the P1 (Hillyard, et al., 1998; Martinez, DiRusso, Anllo-Vento, Sereno, Buxton, & Hillyard, 2001). In both experiments, the face-locked P1 was not significantly affected by emotion. Instead, it was the probe-locked P1 that was related to attentional modulation. For experiment 1, which contrasted fear and happy faces, probe-locked P1 showed greater activity in the right hemisphere, consistent with what was found for face-locked P1 activity in Pourtois et al. (2004). However, in experiment 2, which contrasted angry and happy faces, P1 showed greater activity in the left hemisphere. These inconsistent results make it difficult to interpret.

Difference in C1 activity and P1 activity time-locked to face presentations were related at trend levels in experiment 1, but reached significance in experiment 2. This supports the notion that these very rapid visual components are related to one another, and that the emotional negative and positive conditions were being distinguished by participants, but at very low levels of awareness.

The N2pc as a Measure of Emotional Dot Probe Attentional Processes

The N2pc component, although a rapid component, is not usually referred to as “automatic visual component” in the same way the C1 and P1 are thought of in the ERP literature. Nevertheless, the N2pc is also indicative of selective attentional processing (Eimer 1996; Woodman & Luck, 1999) and so is appropriate for examination of processing in this task. The N2pc waveforms highlighted a flexibility of attentional mechanisms in this task, particularly in experiment 2, where angry faces where displayed. Individuals tended to process the angry faces faster and with more resources than the happy faces, but then showed a shift in attentional resources for the processing of the probe when it was preceded by a neutral or happy face. This suggests the imperative stimulus was more salient and subsequently won over attentional resources from any influence the angry emotional faces had initially. The same pattern was not seen for fear faces, and so there is support of the angry faces having a greater impact on participants, perhaps because they represented a more direct threat to participants (Whalen, 1998). This also demonstrates the utility of using ERPs in this task as a more direct measure of attentional biases, as the shifts in attentional resources can be observed throughout the task procedure.

Emotional Dot Probe Effects and Personality

There is a long history of the emotional dot probe task being associated with examination of attentional biases in anxious populations. Some would argue that attentional biases in this task can only be detected in clinically anxious samples (see Bar-Haim et al., 2007). Unlike other emotional dot probe studies in non-clinical samples (Pourtois et al., 2004; Holmes et al., 2009; Brosch, Sander, Pourtois, & Scherer, 2008), RT measures neither showed the expected effects nor did they correlate with personality dimensions in the current study. But further examination of the ERP data and personality dimensions yielded interesting results. In experiment 1, C1 activity to fear faces correlated with Behavioral Constraint (CON), while this result did not hold up in experiment 2. P1 did not show any pattern of correlation with personality dimensions. Greater face-locked early N2pc difference (contralateral – ipsilateral) for fear faces was related to increased CON, while the difference for happy faces was related to decreased CON. Since CON is related to measures of control, these findings suggest that those with greater self-reported behavioral constraint also seem to show a greater ability to maintain control over their attentional resources, and can do so very quickly in the context of emotional stimuli.

Also, greater late face-locked N2pc for both fear and happy conditions was correlated with higher Stress Reactivity scores. In experiment 2, only the difference between contralateral and ipsilateral N2pc for happy faces was correlated with lower Stress Reactivity scores. Also in experiment 2, probe-locked late N2pc difference for happy was related to lower scores on Negative Emotionality. Thus, the N2pc was associated with theoretically relevant personality dimensions, certainly as compared to the earlier visual components C1 and P1. In the current study Stress Reactivity is being used as a proxy for a measure of trait anxiety. In prior work, trait anxiety has been implicated in increased vigilance of emotional information, so for the face-locked activity to be linked with increased SR makes sense. It also makes sense, that lower scores of Negative Emotionality would be linked with greater probe-locked activity, as this indicates an ability to flexibly disengage from emotional stimuli.

Limitations and Future Directions

Our version of the emotional dot probe task is different than others in the literature, and the differences and limitations should be noted. The paradigm needed to be adjusted to allow for the optimal recording of EEG and the reduction of ERPs. This included increasing the number of total trials to ensure a proper signal to noise ratio. The increased number of trials could have contributed to the task becoming tedious, and may have induced fatigue. For this reason, participants were given frequent breaks and encouraged to take as much time as they needed to prepare for subsequent blocks.

Another important change in the task related to collecting good ERP data was the instruction to maintain a steady gaze on a central fixation throughout the task to minimize eye movement artifacts. Having gaze restricted to a central fixation cross throughout the experiment may have further impacted the influence of irrelevant and non-spatially valid cues such that no differences in RT for emotional cues were established. In other words, participants may have been doing an excellent job maintaining their gaze and attention on the central fixation to such a degree that the emotional cues were not salient enough to influence behavioral changes. Restriction of eye movement is an unfortunate compromise as it is required for the collection of usable ERP data. It also may have been the case that participants who may have been getting tired towards the end of the task may have been focusing very intently on the fixation cross, and may not have had adequate resources to fully perceive and distinguish between the emotional faces. The task was rather easy compared to other versions of the dot probe, as participants only had to report on which side of the screen the dot probe occurred. Participants were notably faster in mean RT compared to other reports in the literature, which may have restricted the range of behavioral facilitation effects that could be observed for probes congruent with emotional faces in the RT measures.

Emotional faces were chosen as the emotional cues for this paradigm as faces are processed rapidly, and have high ecological validity. Future work will employ emotional words, as words may be processed even faster than faces, and also emotional scenes to test the boundaries of this experimental paradigm. Emotional Scenes may have the greatest ecological validity, but may be difficult to process when presented in pairs due to their increased complexity. Since emotional cues are presented so rapidly, it may be difficult to capture attentional bias mechanisms over simple complexity issues.

The task required a button press on every trial, and this may have introduced motor artifact into the probe-locked waveforms. Two alterations may help to remedy this problem. First, performing a Principal Components Analysis (PCA) on the data during this epoch may distinguish between the ERP components, allowing for greater precision when analyzing and interpreting results. Second, altering the task so that motor responses are less frequent (such as employing a go/no-go version of the task) would result in less overt motor activity and reduce motor artifact noise overall. Embedding a go/no-go task (see Pourtois et al., 2004 for details) may also increase the difficulty, as mentioned as another possible limitation of the current study.

Despite its limitations, the current study highlights the utility of ERPs as a measure of attentional allocation driven by emotion. It also provides a spring board for further examination of cortical brain activity in this task, namely in teasing apart the question of attentional capture versus problems with disengagement of emotional cues and non-emotional targets. These results bear replication in clinical samples to examine whether the N2pc is a sensitive measure of sustained attention capture in the emotional dot probe, particularly by depictions of direct threat.

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