

9-2017

ERP and Theta Activity Associated with Facial Emotion Memory

Shaina Roxanne Herman

Follow this and additional works at: <http://scholarsrepository.llu.edu/etd>

 Part of the [Clinical Psychology Commons](#)

Recommended Citation

Herman, Shaina Roxanne, "ERP and Theta Activity Associated with Facial Emotion Memory" (2017). *Loma Linda University Electronic Theses, Dissertations & Projects*. 472.
<http://scholarsrepository.llu.edu/etd/472>

This Thesis is brought to you for free and open access by TheScholarsRepository@LLU: Digital Archive of Research, Scholarship & Creative Works. It has been accepted for inclusion in Loma Linda University Electronic Theses, Dissertations & Projects by an authorized administrator of TheScholarsRepository@LLU: Digital Archive of Research, Scholarship & Creative Works. For more information, please contact scholarsrepository@llu.edu.

LOMA LINDA UNIVERSITY
School of Behavioral Health
in conjunction with the
Faculty of Graduate Studies

ERP and Theta Activity Associated with Facial Emotion Memory

by

Shaina Roxanne Herman

A Thesis submitted in partial satisfaction of
the requirements for the degree
Doctor of Philosophy in Clinical Psychology

September 2017

© 2017

Shaina Roxanne Herman
All Rights Reserved

Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Doctor of Philosophy.

_____, Chairperson
Colleen A. Brenner, Associate Professor of Psychology

Richard E. Hartman, Professor of Psychology

Grace J. Lee, Assistant Professor of Psychology

ACKNOWLEDGEMENTS

I would like to acknowledge and thank Britan Moore and Dr. Colleen Brenner for their help in completing and editing this project. I would also like to thank other members of Brain Potential Laboratory who provided feedback, support, and discussions of the literature reviewed for the completion of this project. Finally, I would not be able to complete this work without support from my family members, friends, professors, and colleagues.

CONTENT

Approval Page.....	iii
Acknowledgements.....	iv
List of Figures	vii
List of Tables	viii
List of Abbreviations	x
Abstract.....	xiii
Chapter	
1. Background and Significance	1
Face Recognition	3
Neuroanatomy of Face Processing.....	5
Time Sequence of Face Processing.....	9
ERP Components Related to Face Processing.....	10
Facial Emotion Processing.....	13
2. Specific Aims and Hypotheses	22
Aim 1	22
Aim 2	22
Aim 3	23
Aim 4	23
Aim 5	24
3. Methods.....	25
Participants.....	25
Procedure	25
EEG Data Acquisition.....	26
ERP Amplitudes.....	27
Delay Interval Theta Power	27
Statistical Analysis.....	29
4. Results.....	31
Event-Related Component Analyses	31

P1 at the Left Occipital Electrode Site.....	31
P1 at the Right Occipital Electrode site	31
N170 at the Left Parietal Electrode Site	31
N170 at the Right Parietal Electrode Site	32
Theta Power Analyses.....	34
Left Parietal Electrode Site	34
Right Parietal Electrode site.....	37
Left Occipital Electrode Site.....	40
Right Occipital Electrode Site	43
ERP and Theta Power Regression Analyses.....	46
Left Parietal Electrode Site	46
Right Parietal Electrode site.....	48
Left Occipital Electrode Site.....	50
Right Occipital Electrode Site	52
5. Discussion.....	54
References.....	72

FIGURES

Figures	Page
1. Presentation of stimuli during the emotion memory task	26
2. Sequence of events for the 500 ms Delay Condition of the emotion memory task	28
3. Sequence of events for the 1000 ms Delay Condition of the emotion memory task	29
4. Sequence of events for the 2000 ms Delay Condition of the emotion memory task	29
5. Differences in N170 amplitude for each emotion at electrode site P7	32
6. Differences in N170 amplitude for each emotion at electrode site P8	33
7. Differences in Theta power magnitudes at electrode site P7 for the 500 ms, 1000 ms, and 2000 ms Delay intervals	35
8. Differences in Theta power magnitudes at electrode site P7 for the Early, Middle, and Late latencies	36
9. Differences in Theta power magnitudes at electrode site P8 for the 500 ms, 1000 ms, and 2000 ms Delay intervals	38
10. Differences in Theta power magnitudes at electrode site P8 for the Early, Middle, and Late latencies	39
11. Differences in Theta power magnitudes at electrode site O1 for the 500 ms, 1000 ms, and 2000 ms Delay intervals	41
12. Differences in Theta power magnitudes at electrode site O1 for the Early, Middle, and Late latencies	42
13. Differences in Theta power magnitudes at electrode site O2 for the 500 ms, 1000 ms, and 2000 ms Delay intervals	44
14. Differences in Theta power magnitudes at electrode site O2 for the Early, Middle, and Late latencies	45

TABLES

Tables	Page
1. Segmentation of Time Intervals for each Delay Condition	28
2. Repeated Measures ANOVA on Theta power at electrode site P7 with within-subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000).....	34
3. Six (one for each emotion) repeated measures ANOVAs on Theta power at the P7 electrode site with Latency & Delay as within-subjects effects was conducted to interpret the Emotion X Latency and Delay X Latency interactions	37
4. A repeated measures ANOVA on Theta power at electrode site P8 was conducted, with within-subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000)	38
5. Three (one for each Delay condition) repeated measures ANOVAs with Latency as a within-subjects effect for each delay condition (500 ms, 1000 ms, 2000 ms) was conducted to interpret the interaction effect of Delay X Latency ($F(4,84)= 25.628, p < 0.001$) at electrode site P8	40
6. A repeated measures ANOVA on Theta power at electrode site O1 was conducted, with within-subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000)	40
7. Three (one for each Delay condition) repeated measures ANOVAs with Latency as a within-subjects effect for each delay condition (500 ms, 1000 ms, 2000 ms) was conducted to interpret the interaction effect of Delay X Latency ($F(4,84)= 32.260, p < 0.001$) at the O1 electrode site.....	43
8. A repeated measures ANOVA on Theta power at electrode site O2 was conducted, with within-subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000)	43
9. Three (one for each Delay condition) repeated measures ANOVAs with Latency as a within-subjects effect for each delay condition (500 ms, 1000 ms, 2000 ms) was conducted to interpret the interaction effect of Delay X Latency ($F(4,80)= 31.428, p < 0.001$) at the O2 electrode site.....	46
10. Regression of P1 and N170 Event-Related Potential Amplitudes and Total Theta Power Throughout Delay Conditions Predict Correct Identification of Emotions at the P7 Electrode Site.....	47

11. Regression of P1 and N170 Event-Related Potential Amplitudes and Total Theta Power Throughout Delay Conditions Predict Correct Identification of Emotions at the P8 Electrode Site.....	49
12. Regression of P1 and N170 Event-Related Potential Amplitudes and Total Theta Power Throughout Delay Conditions Predict Correct Identification of Emotions at the O1 Electrode Site	51
13. Regression of P1 and N170 Event-Related Potential Amplitudes and Total Theta Power Throughout Delay Conditions Predict Correct Identification of Emotions at the O2 Electrode Site	52

ABBREVIATIONS

EEG	Electroencephalography
ERP	Event-related Potential
fMRI	Functional Magnetic Resonance Image
PET	Positron Emission Tomography
MEG	Magnetoencephalography
ERS	Event-related Synchronization
ERD	Event-related Desynchronization
HC	Healthy Control

ABSTRACT OF THE THESIS

ERP and Theta Activity Associated with Facial Emotion Memory

by

Shaina Roxanne Herman

Doctor of Philosophy, Graduate Program in Psychology

Loma Linda University, September 2017

Dr. Colleen A. Brenner, Chairperson

Facial emotion recognition is an important component of daily functioning and is highly connected to the social element of human interaction. At present, it is not clear whether initial stimulus encoding or memory maintenance of the face promotes accurate facial emotion memory. The purpose of this study was to explore the mechanisms of facial affect memory. Specifically, we aimed to compare whether type of emotion, length of delay interval, or robustness of encoding the initial stimulus were associated with accurate facial emotion recognition and memory. A task of explicit emotion memory was given to 30 participants. A visual stimulus of a face expressing one of 6 emotions (Very Happy, Happy, Neutral, Sad, Fear, Anger) was presented for 200ms. After a delay of either 500ms, 1000ms, or 2000ms participants were presented with another facial stimulus (with a different identity than the first stimulus) displaying either a matched or mismatched emotional expression. Participants indicated whether or not the second emotion matched the first by pressing a button with their dominant hand.

Electroencephalography (EEG) was recorded from 32 channels during the entire task. A repeated measures ANOVA was used to determine if there were significant within-subject differences in event-related potential (ERP) amplitudes based on Facial Emotion,

Delay Condition, and Time Interval. Finally, regression analyses were used to test whether the relationship between ERP amplitude and Theta Power predict behavioral performance. P1 amplitudes at occipital electrode sites and N170 amplitudes at parietal sites differed by emotional expression. Increased P1 at occipital sites was the best predictor of correct matching of positive emotions whereas N170 amplitudes at parietal sites predicted correct identification of negative emotions. Correct matching of faces expressing Fear was predicted by ERPs and Theta Power more than any other emotion. Theta Power was greatest in shorter delay intervals and declined throughout all delay intervals, but was not associated with behavioral performance. Emotions influence how well stimuli are perceived and encoded. Increased robustness of encoding of emotional visual stimuli predicts correct identification of emotions more than emotion maintenance during the delay.

CHAPTER ONE

BACKGROUND AND SIGNIFICANCE

Facial emotion recognition is a vital part of daily human interaction. Emotions expressed by others are used to inform thoughts, attitudes and actions. This learned behavior is highly connected to the social element of human interaction (Adolphs, 2003). Like many animals, humans communicate through a variety of means, including visual messages. Gestures provide information about situations, events, ideas, and objects. Facial emotion expression provides additional information about the internal experience of the individual and helps regulate how we behave in response to the social environment. Deficits in facial emotion memory make it difficult for individuals to behave in accordance with appropriate social norms as seen in individuals with schizophrenia (Csukly, Stefanics, Komlósi, Czigler, & Czobor, 2014; Herrmann, Ehlis, Ellgring, & Fallgatter, 2005; D.-W. Kim, Shim, Song, Im, & Lee, 2015; Morrison, Bellack, & Mueser, 1988; Streit, Wölwer, Brinkmeyer, Ihl, & Gaebel, 2001). Research has found that there are structures within the brain, such as the fusiform gyrus and superior temporal gyrus and sulcus that are involved in processing facial expressions (Adolphs, 2003; George et al., 1999; Eric Halgren et al., 1999; James V. Haxby, Hoffman, & Gobbini, 2000; James V Haxby et al., 1996; Kanwisher, McDermott, & Chun, 1997; J. J. Kim et al., 1999; Sams, Hietanen, Hari, Ilmoniemi, & Lounasmaa, 1997). While these structures are important for identification of faces, facial emotion processing relies on a complex neural network that extends beyond the process of basic structural encoding. It is unclear whether facial emotion memory deficits, such as those

seen in patients with schizophrenia, are associated with face structure encoding, short-term emotion memory maintenance, or both.

Facial emotion recognition is so important to human social development and evolution that learning to mirror facial emotion is seen in infancy. Babies spend more time looking at images of faces when the emotion is changed and even mimic the expressions of others (Field, Woodson, Greenberg, & Cohen, 1982). Throughout the lifespan, individual emotional development progresses through stages. In childhood, emotions are perceived as external and physical events that can be controlled through the help of others. In later stages of development, emotions are understood as objective and subjective experiences that are “controlled” by uniting feelings with logical thinking (Labouvie-Vief, DeVoe, & Bulka, 1989). Such emotional development compliments the development of social skills and behaviors that influence how the individual interacts with their social environment (Morton et al., 2000).

Although there are many ways of studying face emotion recognition, understanding how facial affect is processed requires the ability to accurately measure changes that occur extremely quickly. Facial expressions change within milliseconds; thus, in order to accurately perceive and interpret another’s emotional experiences the brain must be able to detect differences as they occur within millionths of a second. In fact, Edwards (1998) found that correct identification of time-lapsed photos of an emotional expression improved when there was less time to complete the task. In this study participants were asked to arrange segmented clips of an emotion from onset to offset (neutral facial expression through emotional response to a return to neutral). The images were taken from a video that captured the entire expression of one emotion

segmented into recognizably different phases. Participants were able to complete the task more accurately when given 38 seconds as opposed to 3 minutes. This suggests that subtle changes in facial emotion expression are detected automatically rather than requiring lengthy application of conscious thought. What is not clearly understood is what happens when these subtle cues are detected and how they are maintained to accurately remember and identify facial emotion expressions. The general hypothesis of visual facial emotion processing indicates that first the facial expression is perceived and encoded, and while the emotion expression is being maintained the significance of the expression and its interpretation in relation to the environment are processed (Bruce & Young, 1986; E Halgren, Baudena, Heit, Clarke, & Marinkovic, 1994). Yet, whether it is the initial stimulus encoding or memory maintenance of the face (or both) that promotes accurate facial emotion memory is not clearly understood.

Face Recognition

Interest in facial recognition began as a response to prosopagnosia, a condition in which patients are unable to recognize faces of relatives after sustaining brain injuries. Such patients were able to recognize and name objects and their features as well as familiar sounds and even the voices of relatives, but specific deficits were seen in visually recognizing faces. As Meadows (1974) points out, a unique feature of prosopagnosia is that deficits are associated more closely with memory than recognition of facial features since patients with this disorder are able to match and discriminate faces, but cannot identify familiar faces. In attempting to understand prosopagnosia, research has identified specific areas in the brain that are responsible for face recognition.

Early studies of prosopagnosic patients identified visual field deficits in the upper left quadrant suggesting damage to the posterior right cerebral hemisphere (Hecaen et al., 1962; Meadows, 1974). More recent studies have specified that prosopagnosia is associated with damage to the right occipitotemporal cortex (Benton, 1980; Meadows, 1974). Research of prosopagnosia has not only provided answers about the disorder itself, it has also provided details about which neuroanatomical features are involved in facial encoding, and has highlighted the effects that memory has on face recognition.

Face processing involves various steps or phases of brain activity that may provide a basis for understanding how facial emotion memory occurs. According to Bruce & Young (1986), face processing begins with perceiving the visual stimulus and encoding the structural code of a face. Next, recognition of the face stimulates the retrieval of specific semantic representations of identity. Finally, a name or identification of the individual is recalled. Similarly, Halgren et al. (1994) proposed that visual stimulus processing (of words and faces) starts with encoding of sensory information and then the information is integrated using cognitive mechanisms. Facial emotion memory likely follows similar steps as described by Graham & LaBar (2012). First, the movement of facial features must be visually perceived and encoded. Next, emotion recognition units are stimulated which leads to the identity of specific semantic and emotional representations of the expression (Graham & LaBar, 2012). Finally, an interpretation of the emotional expression is recalled associated with activity in the amygdala (Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004). This model implicitly underlies the nature of most research investigating face processing, as inferred from the methodological design of studies investigating facial emotion processing and memory.

These studies involve visual presentation of facial stimuli, recording of neural activity (fMRI, PET, MEG, or EEG), and a behavioral task that tests the participants' accuracy for identifying emotions (L.I. Aftanas, Varlamov, Reva, & Pavlov, 2003; Brenner, Rumak, & Burns, 2016; Brenner, Rumak, Burns, & Kieffaber, 2014; Knyazev, Slobodskoj-Plusnin, & Bocharov, 2009; Krolak-Salmon, Fischer, Vighetto, & Mauguiere, 2001; Sato, Kochiyama, Yoshikawa, & Matsumura, 2001). The individual components of this process (encoding, maintenance, and memory recall of emotions) have not been independently evaluated within the same study to determine their contributions to facial emotion processing and memory.

Neuroanatomy of Face Processing

Following findings of prosopagnosia research, further investigation has identified neuroanatomical areas associated with face processing in humans. Studies have found that rhesus and macaque monkeys respond to faces (of humans and other monkeys) differently than other visual stimuli (Pascalis & Bachevalier, 1998; Perrett, Rolls, & Caan, 1982; Rolls, 1984). A single-cell recording study by Perrett et al. (1985) examined the activity of neurons in the brains of macaque monkeys in response to stimuli of human and monkey faces. The cells recorded in this study exhibited increased activity to faces rather than other stimuli, with fewer cells responding to pictures of faces compared to real faces and selective cells responding differently in response to familiar faces.

Additional findings indicated that these cells were also sensitive to head orientation and eye gaze with decreased activation as the head and eyes rotated away from either full-face or profile views and direct gaze. Not only did this study provide detailed information

about face processing within the macaque brain, it also demonstrated that cells within neural structures have significantly different functions for processing visual stimuli (Perrett, Smith, & Potter, 1985).

In human subjects, additional methods for identifying the structures involved in face-processing and distinguishing their specificity for human faces include observing cerebral blood flow using functional magnetic resonance imaging (fMRI) and molecular activity using positron emission tomography (PET) scans, or magneto-encephalography (MEG). The area of the brain that has been consistently associated with visual face-specific activity using these methods is located in the inferior occipitotemporal cortex, specifically in the fusiform gyrus (George et al., 1999; Eric Halgren et al., 1999; James V. Haxby et al., 2000; James V Haxby et al., 1996; Kanwisher et al., 1997; J. J. Kim et al., 1999; A Puce, Allison, Bentin, Gore, & McCarthy, 1998; Sams et al., 1997). This area of the brain shows greater activity in response to visual stimuli of faces than to other visual stimuli including: words, buildings, and other objects (Allison et al., 1994; Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eric Halgren et al., 1999; J V Haxby et al., 2001; Kanwisher et al., 1997; McCarthy, Puce, Gore, & Allison, 1997; Aina Puce, Allison, Asgari, Gore, & McCarthy, 1996; Sams et al., 1997; Sergent, Ohta, & MacDonald, 1992); familiar faces (Bentin et al., 1996; Kanwisher et al., 1997; Linkenkaer-Hansen et al., 1998); blurred or otherwise distorted images of faces (Bentin et al., 1996; George, Evans, Fiori, Davidoff, & Renault, 1996; Kanwisher et al., 1997; Linkenkaer-Hansen et al., 1998); and separated components of the face or other body parts (Bentin et al., 1996; Kanwisher et al., 1997).

A series of neuroimaging (fMRI) studies by Kanwisher and colleagues (1997) provides a step-down demonstration of the right fusiform gyrus's (or fusiform face area's) specificity to faces. Throughout this series of tests, activity in the fusiform face area distinguished responses to faces from responses to various other visual stimuli and from activity related to other neurological processes. For the first part of the series, Kanwisher and colleagues presented subjects with images of faces and objects and found that faces were associated with consistent activation of the right fusiform gyrus for all participants whereas other objects were associated with activation of bilateral and more medial (parahippocampal) areas. The next part of the series tested two hypotheses: whether the low-level features of a face (scrambled image of a face that is unrecognizable) are also processed by the fusiform face area, and whether activity in this area is used to process visual stimuli of "exemplars" of a category (front-views of faces were compared to front-views of houses). Activity in the right fusiform gyrus was significantly stronger to face stimuli than front-views of houses and scrambled images of faces, suggesting that this area is not where low-level features nor category exemplars (unrelated to faces) are processed. The final part of the series investigated whether activation of the fusiform face area was generalized to different view-points of faces (three-quarter view of face), if this area responded to the face itself or external features of the head (hair and neck were not included in the images), if other human body parts stimulated activity in this area (face stimuli were compared to images of human hands), and if activity in this area was the result of general attentional mechanisms (through a 1-back memory task). Again, results supported the hypothesis that activity in the right fusiform gyrus was specific to faces, including different view-points of faces, rather than

the external features of the head and other human body parts and that it was not associated with general attentional mechanisms (Kanwisher et al., 1997).

Findings from Bernstein et al. (2014) confirm that the fusiform face area is involved specifically in the processing of faces. In this study, fMRI data was used to compare neural activity in response to pairs of faces and bodies positioned one above the other. Their findings suggest that the fusiform face area recognizes faces associated with a complete person and is not specific to processing faces detached from the human body, an indication that two individuals are being represented (Bernstein, Oron, Sadeh, & Yovel, 2014). More precisely, it appears that structural and static facial characteristics that provide information about personal identity are processed in the fusiform face area (Adolphs, 2003). Facial expressions that involve movement of facial structures are processed in different areas of the brain including the superior temporal gyrus and sulcus (Eimer & McCarthy, 1999; James V. Haxby et al., 2000). As Graham (2012) discussed in his review of hypothesized models for face processing, it is likely that eye gaze and emotion expression are processed in a complex, interactive system that includes the superior temporal sulcus (Engell & Haxby, 2007; James V. Haxby et al., 2000; James V. Haxby, Hoffman, & Gobbini, 2002; Pourtois et al., 2004), the intraparietal sulcus (George, Driver, & Dolan, 2001; A Puce et al., 1998), and the amygdala and limbic structures (Hoffman, Gothard, Schmid, & Logothetis, 2007; Straube, Langohr, Schmidt, Mentzel, & Miltner, 2010). Regarding the procedure for face processing, Streit et al (1999) found that neuroanatomical structures are activated in the following order: right superior temporal cortex (at about 140-170ms after stimulus onset), middle right temporal cortex (with a first activation at 180-210ms and a second at 210-240ms), right amygdala,

posterior right superior temporal cortex, left inferior frontal cortex, and a final reactivation of the temporal and left inferior frontal structures. The specific contributions of each of these neuroanatomical regions and how they interact to process early expression, and later memory of that expression, are yet to be supported through research.

Time Sequence of Face Processing

Understanding how faces are processed also requires an understanding of the order of operations involved. Brain processes occur quicker than can be observed by conscious attention and must be evaluated through methods that can make precise measurements at very small time intervals. Electroencephalography (EEG) is a method used to measure electrical signals in the brain and accurately measures changes on a millisecond timescale. This method allows measurements of subconscious neural processes while an individual observes and processes visual images.

Electroencephalography that involves depth electrodes, or devices that measure electrical signals when placed directly onto neural structures, has been used to support findings that the fusiform gyrus is a face-specific neural structure (Allison et al., 1994; Seeck et al., 1993). Yet, depth recordings can only be taken when medically necessary, such as epilepsy patients undergoing surgery. Studies that use non-invasive EEG measurements have found that visual processing of faces yields a consistent pattern of neural activity. A measurement of brain activity from the time a stimulus is presented (stimulus onset) until the brain activity returns to baseline is considered an event-related potential (ERP). ERPs reflect synchronous firing of large populations of neurons and, when averaged across multiple trials, are represented as positive and negative deflections at specific time points

after the stimulus onset (Sur & Sinha, 2009). Non-invasive EEG cannot provide detailed information about the neural generators of neural activity, but it does provide information about the strength of the neural response (represented by the amplitude of the deflection) and the latency of the neural response, on a millisecond time scale.

ERP Components Related to Face Processing

The P1 ERP is associated with early attention processing and has been found to have a unique association with face processing. The positive peak appears between 80 and 130ms after a visual stimulus is presented. Originally, this peak was called P100 for the positive peak with an average latency at 100ms post stimulus onset. It is more accurately distinguished as P1 to indicate the first obvious positive peak after stimulus onset with a latency that differs with the type of stimulus presented. This component represents attention-based early visual processing (Heinze et al., 1994; Mangun, 1995; B Rossion et al., 1999). P1 amplitudes have been found to be greater for attended compared to unattended stimuli which suggests that this component marks activity related to selective attention or directing one's attention to a particular stimulus (Clark & Hillyard, 1996). The P1 component is also associated with spatial attention, such that its amplitude is larger in response to visual stimuli presented in spatial locations that are attended to (Mangun, 1995; McCarthy & Nobre, 1993; Salillas, El Yagoubi, & Semenza, 2008). A study by Eimer, Holmes, and McGlone (2003) found that the P1 also represents transient attention or attending to a stimulus that draws attention for a short time.

Studies have also found that the P1 component demonstrates unique responses to face processing. Hermann et al. (2005) found that the P1 amplitude is larger in response

to visual stimuli of faces compared to other objects such as buildings, yet, no significant differences in P1 amplitude or latency were found between face and scrambled face stimuli. Developmental studies of the P1 component (in response to visual stimuli) throughout childhood and adolescence indicate that the location of the P1 response changes and that its latency and amplitude decrease with age, yet Kuefner et al. (2009) found that these changes are not specific to faces. Although the P1 component does not necessarily indicate that a visual stimulus of a face is being processed, it provides helpful information about the attentional resources dedicated to a visual stimulus, including that of a face. In fact, the P1 response appears to be greatest to low-level features that are critical for face processing such as contrast, brightness, color, and frequency (E. Halgren, 2000; Jemel et al., 2003; Rousselet et al., 2005; Tanskanen, Näsänen, Montez, Päälyssaho, & Hari, 2005). Recognizing the apparent conflict in literature regarding the relationship between P1 and face processing, Rossion and Caharel (2011) measured ERP responses to images of faces and cars and scrambled images of faces and cars that maintained the same low-level characteristics. Results indicated that the P1 amplitude and latency were larger to face *and* scrambled face stimuli than to those of cars. In other words, the P1 amplitude and latency were not specific to faces, since the response was no different for images of faces that were indistinguishably scrambled (with low-level features maintained).

The event-related potential component that has been identified as a specific response to faces is the N170 peak. This negative peak approximately 170ms after stimulus onset has been consistently found to be associated with face processing and activity in the fusiform gyrus (Allison et al., 1994; Bentin et al., 1996; Eimer &

McCarthy, 1999; Herrmann et al., 2005; Linkenkaer-Hansen et al., 1998; Seeck et al., 1993). The N170 response to human faces is unique in that it is differentiated from responses to other objects (Bentin et al., 1996; Herrmann et al., 2005), scrambled faces (George et al., 1996; Herrmann et al., 2005), inverted faces (Bentin et al., 1996; Linkenkaer-Hansen et al., 1998), face components (Bentin et al., 1996), pointillized faces (Linkenkaer-Hansen et al., 1998), and unfamiliar faces (Seeck et al., 1993).

Although the N170 response is specific to intact faces which elicit large amplitudes, it does have a smaller response to other stimuli. Bentin et al. (1996) compared N170 for faces to N170 of other stimuli through a series of tests. First, the N170 response to faces was compared to the response to scrambled images of faces that were of equal luminance. Although the N170 component existed for both stimuli, the amplitude of N170 to faces was larger indicating that, unlike P1, N170 does not represent attention to low-level visual features. Next, Bentin et al. found that the N170 response to faces compared to images of animal faces, human hands, and furniture had a larger amplitude suggesting that the N170 component is strongest for faces. Another experiment compared images of faces, cars, and butterflies to inverted versions of the images and found that the N170 response to cars, butterflies, and their inverted versions were smaller than the responses to faces and inverted faces. They also found that the response to faces and inverted faces was similar, indicating that the N170 response to faces is not dependent on the position of the face. In the next experiment ERPs to butterflies, human faces, eyes, lips, and noses were compared. The N170 to faces was similar to those seen in the previous experiments. Of note, the N170 for eyes was later and larger than that to faces. The responses to human lips and noses were later and smaller than the N170s in

response to faces and eyes. These findings suggest that the N170 component may be specific to eyes as indicators that a face is present. Finally, stimuli of distorted faces with components of the inner face dislocated were compared to stimuli of isolated eyes, lips, and noses to examine the importance of eye location. N170 were larger for distorted faces and eyes than those for lips and noses. A slightly, yet not significantly, larger N170 was observed for eyes than for distorted faces possibly indicating that the spatial integrity of facial components did not greatly influence N170 amplitude or latency. In all of these studies, the N170 was either trending toward significance or significantly larger on the right hemisphere over the posterior lateral scalp, a region proximal to the right fusiform gyrus or fusiform face area (Bentin et al., 1996).

Facial Emotion Processing

As noted above, facial emotion processing involves perception and encoding, identity of semantic and emotional representations, and an interpretation of the expressed emotion. The P1 component of ERPs to visual stimuli is a relative measure of neurological resources attending to a visual presentation of a face. A higher P1 amplitude suggests better perception and encoding of low-level features of the visual stimulus (E. Halgren, 2000). The P1 appears to have higher amplitudes for faces than for other visual stimuli suggesting that the low-level features of faces prompt increased attention to visual presentations of faces (Herrmann et al., 2005; Bruno Rossion & Caharel, 2011). A low P1 amplitude measured following presentation of a facial emotion might suggest that the emotion is not being perceived and encoded optimally.

The N170 component has been found to have a specifically strong response to visual stimuli of faces, yet there is conflicting evidence as to whether its amplitude is a relative measurement of arousal, attention, or distinct emotion identification. As discussed previously, the negative ERP peak at about 170ms after stimulus onset represents perception of the static, structural features of a visually presented face. Yet the amplitude of the N170 does not seem to indicate the strength of the perception or encoding of the stimulus. Schyns, Petro, & Smith (2007) traced the time course of the N170 at 4ms intervals to map the wave form associated with emotion expression that surrounds this negative peak. From their results, Schyns et. al. proposed that the N170 represents integration of facial features over time starting about 50ms before the N170 peak beginning with visual cues from around the eyes and then proceeding down the face (regardless of the expression). Once information critical for behavior is integrated the process is stopped, represented by the N170 peak. The results of the study by Schyns and colleagues suggest that the N170 peak amplitude represents the culmination of integrated information associated with emotional expression. Consistent with this hypothesis, some studies that sought to determine if emotions are differentiated within the early stages of facial emotion processing have found that N170 amplitude distinguishes between different emotions (Batty & Taylor, 2003; Blau et al., 2007; Brenner et al., 2016, 2014; Caharel, Courtney, Bernard, Lalonde, & Rebaï, 2005; Krombholz, Schaefer, & Boucsein, 2007; Streit et al., 1999, 2001).

Visual stimuli of faces expressing emotions have been found to be associated with larger N170 amplitudes than neutral emotions (Streit et al., 1999, 2001), and negative emotions such as fear, anger, and disgust seem to have the greatest amplitudes (Batty &

Taylor, 2003; Blau et al., 2007; Brenner et al., 2016, 2014; Caharel et al., 2005; Krombholz et al., 2007). Many of these studies have also found a relationship between amplitude and behavioral performance (Brenner et al., 2014; Streit et al., 1999, 2001). Streit et al. (1999) compared N170 in response to visual stimuli of faces with emotional expressions (happiness, fear, anger, surprise, disgust, and sadness) to blurred images of faces. In addition to finding that the N170 amplitude was larger for faces with emotional expressions, larger amplitudes were also associated with increased expression recognition (Streit et al., 1999). Caharel et al. (2005) compared N170 amplitudes and button press response times in tasks of familiarity and expression identification. In the familiarity task, participants were asked to indicate whether the facial image presented was a familiar face. In the expression identification, participants indicated if the face was expressing an emotion. The images in this study had four levels of familiarity to the participant (participant's mother, their own face, celebrities, and unknown individuals) and three expressions (smiling, neutral, and disgust). Consistent with previous research, the N170 amplitude was larger for familiar faces and for emotions compared to neutral expressions (disgust was associated with the largest amplitudes). Response times were faster for images of the participant's mother's face and their own and were slower for emotion compared to familiarity identification. For familiar faces higher N170 amplitude was associated with faster identification (Caharel et al., 2005).

There have been some studies that offer evidence for alternative explanations for N170 amplitude differences for emotions. Krombholz et al. (2007) found that N170 amplitudes to visual stimuli of hand-drawn faces when primed by a semantic cue ("happy" and "angry") were higher for angry compared to happy faces, but did not find

evidence of semantic priming effects. In the discussion of their findings, Krombholz and colleagues argue that tasks that require the participant to focus explicitly on the emotions of the face will produce the differences in N170 amplitude for different emotions. Rellecke et. al. (2012) presented participants with images of faces expressing angry, happy, and neutral expressions, but used a comparison of average reference to average mastoid reference and found that using a mastoid reference eliminated the N170 amplitude differences for the different emotions. A study by Ashley et al. (2004) found that while face inversion was associated with N170 amplitude, emotional expression (happy and disgust) did not influence N170 amplitude. Together, these studies suggest that differences in N170 amplitude in response to emotions can be influenced by study design, but a clear explanation for the differences is still lacking. One hypothesis that offers an explanation for the apparently conflicting evidence of N170 amplitude associations was tested by Almeida et al. (2016). Almeida and colleagues, in addition to previous studies that compare N170 amplitude for facial stimuli with different emotional expressions, measured the effects of perceived arousal of the facial expression on N170 amplitudes. Regardless of emotional category, N170 amplitudes were found to be significantly influenced by perceived arousal. In conclusion, although N170 amplitudes may differ by emotion presented, more research is needed to clarify what is being measured by N170 amplitude and how it is related to facial emotion memory.

Although the P1 and N170 ERP amplitudes may not distinguish emotional expressions, other, later EEG components as well as frequency oscillations have been found to be associated with different emotional expressions. Many studies have found that positive and negative expressions can be distinguished from neutral facial

expressions based on waveform peak amplitudes after about 250 ms post stimulus onset with negative emotions having generally greater amplitudes (Balconi & Pozzoli, 2003; Batty & Taylor, 2003; Krolak-Salmon et al., 2001; Münte et al., 1998). The theory suggested by many of these studies proposes that emotional expressions boost or improve early visual processing of faces and that the emotional expression itself is interpreted in later visual processing (Sato et al., 2001). As early ERP components provide information about the strength or robustness of facial emotion expression encoding, later ERP components may provide information about identification of the facial emotion expression.

EEG oscillations can also be assessed as the amount of synchronous activity within a specific frequency band. The amount of synchronous activity is reflected in “power” or the magnitude of the response within that frequency band. Similar to event-related potentials, the synchronization (or desynchronization) of specific frequency bands can be time locked to a specific event to form event-related synchronization (ERS) or desynchronization (ERD). Synchronization indicates coordinated neural activity while desynchronization indicates sporadic activity. ERS in the theta frequency band (4-7 Hz) in frontal and central brain areas has been found to be associated with orienting and selective attention (Başar, Schürmann, & Sakowitz, 2001; Chang & Huang, 2012; Deiber et al., 2007; Missonnier et al., 2006), yet theta activity in parietal and occipital areas appears to be related to working memory (Sarnthein, Petsche, Rappelsberger, Shaw, & von Stein, 1998; Sauseng, Griesmayr, Freunberger, & Klimesch, 2010). Klimesch et al. (2001) found that greater theta power in parietal and occipital areas was associated with memory compared to knowledge on a semantic task in which participants were presented

with words from a previously presented list and asked to indicate whether they consciously remembered the word or “knew” the word, but did not recollect seeing it on the list. Studies have also found that theta power in parietal and occipital regions is associated with retention of information rather than perception (Sarnthein et al., 1998), working memory execution and speed (Tsoneva, Baldo, Lema, & Garcia-Molina, 2011), and higher memory load on working memory tasks (Deiber et al., 2007). Additionally, studies that analyze theta activity associated with working memory demonstrate that increased memory load is associated with increased theta activity (Deiber et al., 2007; Jensen & Tesche, 2002). A study by Lee et al. (2005) found that theta power in the occipital cortex of monkeys increased during the delay interval of a working memory task indicating that theta power is associated with memory maintenance over a delay interval. This finding was supported by Klimesch et al. (2006) in a sample of human participants, such that desynchronization of theta activity during delay intervals was associated with episodic trace decay or difficulty maintaining memory during delay periods (Klimesch et al., 2006). The relationship between theta activity in parietal and occipital areas and emotion memory maintenance during a delay period is of particular interest for this study.

Previous studies that have investigated theta power associated with emotion memory maintenance have found a relationship between theta synchronization and emotional valence in early facial emotion processing. In a series of studies by Aftanas et al. (2001, 2002, & 2003) theta ERS was found to be greater in the right hemisphere for negative emotions and greater in the left hemisphere for positive emotions and greater for emotional stimuli compared to neutral (for healthy controls and patients with

alexithymia) (L.I. Aftanas, Varlamov, Pavlov, Makhnev, & Reva, 2001; L.I. Aftanas et al., 2003; Ljubomir I Aftanas, Varlamov, Pavlov, Makhnev, & Reva, 2002). In support of these findings, many studies have confirmed that theta synchronization in response to visual stimuli of emotional expressions occurs between about 100-400 ms post stimulus onset (Balconi & Lucchiari, 2006; Balconi & Pozzoli, 2009; González-Roldan et al., 2011; Güntekin & Başar, 2009; Zhang et al., 2012) and is stronger in the right compared to left hemisphere (Balconi & Lucchiari, 2006; Güntekin & Başar, 2009; Zhang et al., 2012). Theta synchronization has also been found to discriminate emotional expressions from neutral facial expressions, such that emotional expressions are associated with increased theta synchrony (Balconi & Lucchiari, 2006; Balconi & Pozzoli, 2009; Zhang et al., 2012). Of note, Gonzalez-Roldan et al. (2011), found that higher intensity images of pain and anger were associated with significantly greater theta synchronization than low intensity images of these facial emotion expressions indicating that theta activity may also be associated with relative arousal of the visual stimulus. Similarly, Knayazev et al. (2009), found that theta synchronization was stronger for emotional compared to neutral stimuli overall, but during tasks of implicit emotional identification appear to be associated with earlier theta synchronization compared to explicit emotion identification. These findings have not yet been replicated so it is important for future research to determine whether arousal and early versus later theta activity influence findings related to theta activity of facial emotion processing.

Few studies have examined theta activity as it relates to both working memory and facial emotion processing. Brenner et al. (2014 & 2016) examined theta activity as it relates to ERP components for explicit memory of emotional expressions. In these

studies, healthy participants (2014) and those with schizophrenia (2016) were required to maintain emotional expressions in memory for a delay of 2000 ms. Findings from these studies indicated that theta power was larger in response to negative compared to positive emotions and that theta power in earlier epochs (500-1000 ms) was larger than in later epochs (1000-2000 ms). In addition, theta power was correlated with N170 amplitude during the delay period for the healthy individuals and that both increased N170 amplitude *and* increased theta power predicted correct identification of affect for the very happy emotional expression. It is unclear from these findings whether theta activity during the delay represents continued oscillations from the N170 response or mechanisms associated with emotion memory maintenance. These previous studies by Brenner et al. (2014 & 2016) do not address the impact of the length of the memory delay on theta oscillatory activity during emotion memory as only a 2000 ms delay interval was used. The current study hopes to further clarify the relationship between theta activity during working memory and explicit facial emotion processing by exploring theta synchronization in response to emotion memory maintenance during delay periods of varying lengths.

In summary, this study aims to further elucidate the mechanisms of facial affect recognition and memory. Facial emotion processing begins with the perception of the low-level features of facial expressions. The amount of attentional resources dedicated to encoding of these low-level features is indicated by the amplitude of the P1 ERP component. Then, as noted by the N170 ERP component, the structures of a face are perceived and identified. Simultaneously, perception and retention of distinct emotions is likely differentiated by the amplitude of the N170 and theta power with negative

emotions (such as fear, anger, and disgust) correlating with larger amplitudes than positive emotions (Batty & Taylor, 2003; Blau et al., 2007; Brenner et al., 2016, 2014; Krombholz et al., 2007). Deficits in facial emotion memory are likely to be associated either with the robustness of encoding the visual representation of emotions or the maintenance of the emotion as neurological resources are dedicated to the interpretation and maintenance of the expression. To make this distinction, the present study will compare encoding of emotions and maintenance of emotional expressions like previous studies by Brenner et al. (2014 & 2016). A unique component of the current study is the analysis of sustained theta activity during varying lengths of the delay interval for the emotion memory task, which will provide additional information about how emotion memory is maintained.

CHAPTER TWO

SPECIFIC AIMS AND HYPOTHESES

This study aims to determine the mechanisms of facial emotion recognition and memory and explore theta activity during delay periods of varying lengths.

Aim 1

To determine whether facial emotional expression and the length of the delay period influence the robustness of facial emotion encoding (represented by P1 and N170 amplitude).

Specific Hypothesis 1: There will be no differences in P1 amplitude for emotional expression, but N170 amplitudes will be greater in response to visual stimuli of negative emotions as compared to stimuli of positive and neutral emotions.

Specific Hypothesis 2: There will be no difference in P1 and N170 amplitudes in response to the to-be-remembered facial emotion for the three delay interval lengths (500 ms, 1000 ms, 2000 ms).

Aim 2

To determine if the length of the delay period and type of emotional expression influence emotion memory maintenance (represented by theta power magnitude).

Specific Hypothesis 1: There will be differences in the magnitude of theta power for the varying time delays such that theta power during the entire delay period will be greater for the shorter intervals (500 ms & 1000 ms) than for the longer interval (2000 ms).

Specific Hypothesis 2: There will be differences in the magnitude of theta power for emotional expressions such that negative emotions (Fear, Sad, and Anger) will be associated with greater theta power than neutral and positive emotions (Happy and Very Happy).

Aim 3

To determine if memory maintenance of emotional expressions (represented by theta power magnitude) is different for the beginning, middle, and end latencies of the emotion working memory delay interval.

Specific Hypothesis 1: Theta power will be stronger for the beginning latencies of the time delays regardless of the length of the delay than for the middle and end latencies.

Aim 4

To explore the relationships between theta oscillations, P1 amplitude, and N170 amplitude.

Specific Hypothesis 1: N170 amplitude and theta power throughout the entire delay period (regardless of length of delay) will be correlated, but P1 amplitude will only be correlated with N170 amplitude and not theta power.

Specific Hypothesis 2: Theta power will mediate the relationship between N170 amplitude and correct emotion identification for emotions that show significant N170 amplitudes.

Aim 5

To determine if length of delay interval affects facial emotion memory.

Specific Hypothesis 1: Length of delay interval will be associated with performance, such that longer delay intervals (1000 ms and 2000 ms) will be associated with fewer correct emotion identification responses throughout the task compared to the shorter delay interval (500ms).

CHAPTER THREE

METHODS

Participants

Thirty healthy persons (HC) free from any Axis I disorders participated in this study. Participants were an average of 20 years old ($SD = 1.4$ years) and 43% (13) were male. Exclusion criteria included head injury resulting in loss of consciousness >10 minutes, learning disability and self-reported hearing impairment. All procedures were approved by the UBC ethics board and participants provided written informed consent.

Procedure

Procedure and EEG acquisition details are similar to those of Brenner et al. (2014) and Brenner, Rumak, & Burns (2016). Participants were seated in a quiet, darkened room and stimuli were presented on a cathode ray tube monitor 110 cm in front of the participant. Facial affect stimuli for the delayed match-to-sample task were taken from the NimStim Face Stimulus Set and consisted of an equal number of Caucasian female and male faces (Tottenham et al., 2009). Six emotions were depicted by 22 different models (Very Happy, Somewhat Happy, Neutral, Sad, Fearful, and Angry) and pictures from every emotional category were selected for each model. The facial stimuli subtended 12.97 degrees of visual angle, and color and contrast of the pictures were not modified. The first face stimulus was presented for 200 ms, followed by a delay interval. The second stimulus was then presented for 200 ms and the participants responded, via button press with their dominant hand (right for all but two participants), whether the affective expression of the second stimulus was the same or different from the first

stimulus (Figure 1). There were 3 blocks of trials presented in random order (one for each delay interval of 500 ms, 1000 ms, or 2000 ms) during which a black fixation cross remained on the screen. The task consisted of 120 trials per block; 60 matched expressions and 60 mismatched expressions, balanced across emotional expression (20 trials per emotion) and blocks were presented in randomized order. The first and second stimuli were always different models of the same sex, and the identity of the models was counterbalanced across matched and mismatched trials.

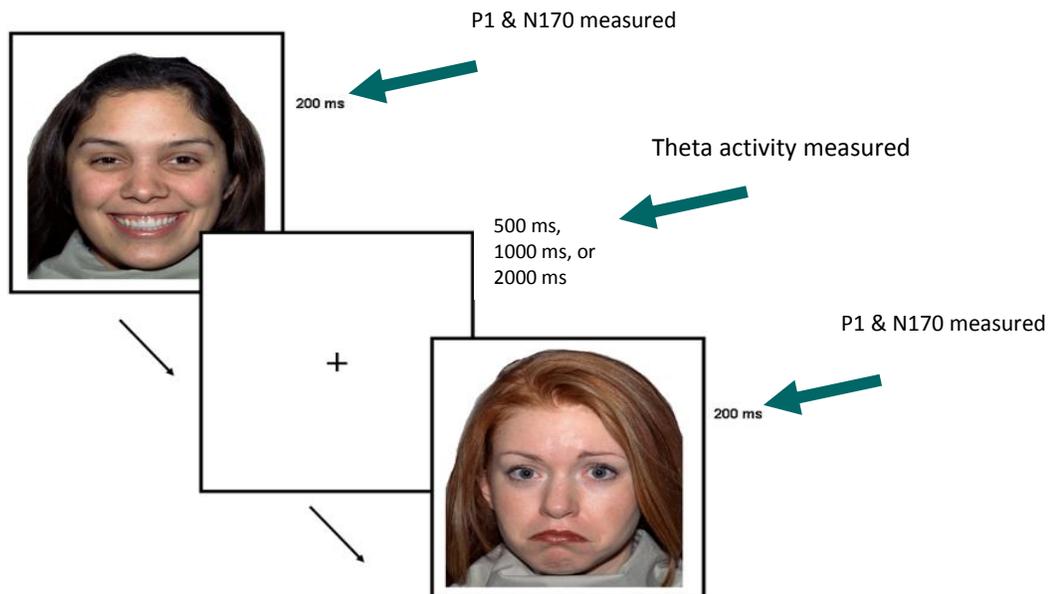


Figure 1. Presentation of stimuli during the emotion memory task. Event related-potential components (P1 and N170) were recording in response to both visual stimuli. Theta activity was measured during the delay interval for each condition of 500 ms, 1000 ms, and 2000 ms.

EEG Data Acquisition

Brainwave activity was recorded from 31 electrode sites using Brain Vision QuickAmps. Data were captured at 1000 Hz using a common average reference and all impedances were kept below 10k Ω . Eye blink activity was recorded using bipolar

electrodes placed above and below the left eye and on each temple for offline eye-blink correction (Gratton, Coles, & Donchin, 1983). Only trials in which participants provided a correct response were analyzed further.

ERP Amplitudes

Data for ERP analyses were filtered between 1-30 Hz and segmented into latencies for each time delay with 200 ms pre-stimulus from the onset of the first face and 100 ms post-stimulus from the onset of the second face. Artefacts greater than +/- 150 μ V were excluded and semi-automated peak-picking of the average waveforms was performed. ERP amplitudes were averaged for the P100 and N170 from parietal (P3, P4, P7, & P8), temporo-parietal (TP7 & TP8), and occipital regions (O1 & O3). Outliers were identified as amplitudes three times the interquartile range and were excluded from analyses.

Delay Interval Theta Power

Raw data were segmented into latencies that varied in length depending on the length of the delay interval, but each had a 200 ms baseline period. For the 500 ms delay, the total epoch measured 3000 ms, for the 1000 ms delay the total epoch was 3500 ms, and for the 2000 ms delay the epoch was 4000 ms (Figures 2, 3, and 4). A Morelet wavelet was run over the entire averaged waveform from 1-60 Hz in 60 steps ($c = 6$) and normalized with respect to sampling rate and baseline activity. Power between 5-8 Hz was averaged and exported for a total epoch interval and a beginning, middle, and end interval for each epoch for the 3 time delays (Table 1 & Figure 2-4). Data will be

transformed to normalize the distribution if it is found to be non-normal (Brenner, Sporns, Lysaker, & O'Donnell, 2003; Nakao, Bai, Nashiwa, & Northoff, 2013).

Table 1. Segmentation of Time Intervals for each Delay Condition.

	Beginning Interval	Middle Interval	End Interval	Full Interval
500 ms Delay	0-167 ms	167-334 ms	334-500 ms	200-700 ms
1000 ms Delay	0-333 ms	333-666 ms	666-1000 ms	200-1200 ms
2000 ms Delay	0-666 ms	666-1334 ms	1334-2000 ms	200-2200 ms

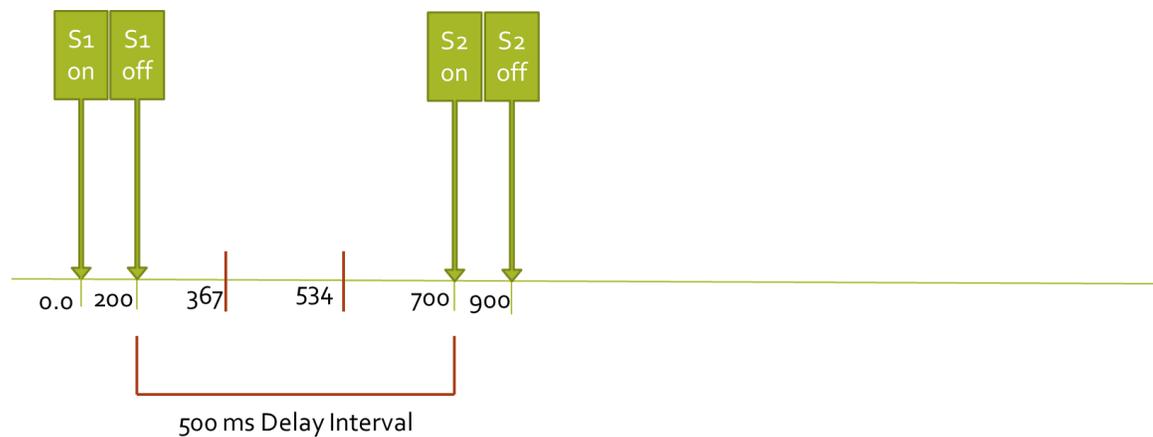


Figure 2. Sequence of events for the 500 ms Delay Condition of the emotion memory task. The delay interval was segmented into 3 time intervals as demonstrated by tic marks on the timeline.

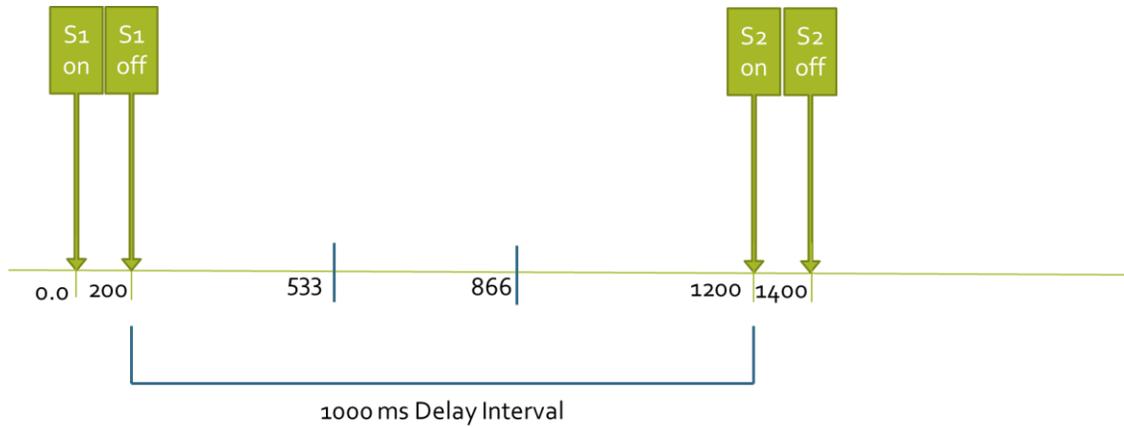


Figure 3. Sequence of events for the 1000 ms Delay Condition of the emotion memory task. The delay interval was segmented into 3 time intervals as demonstrated by tic marks on the timeline.

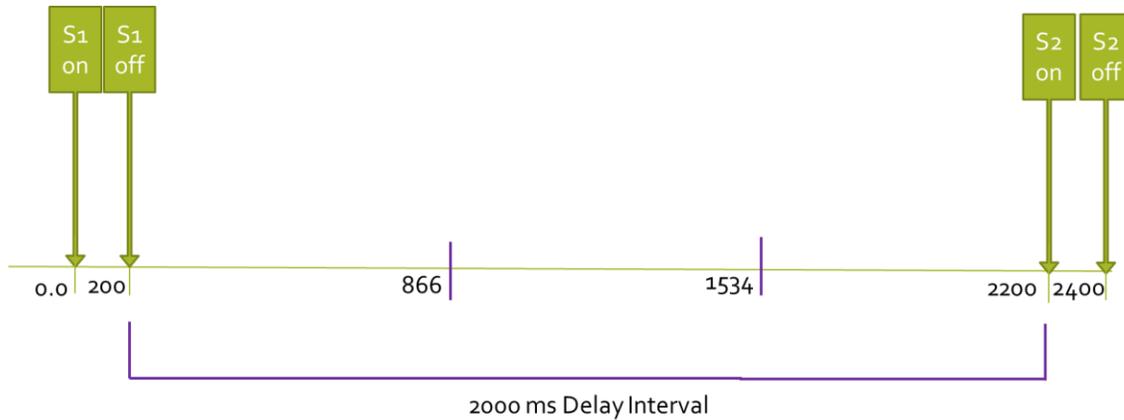


Figure 4. Sequence of events for the 2000 ms Delay Condition of the emotion memory task. The delay interval was segmented into 3 time intervals as demonstrated by tic marks on the timeline.

Statistical Analysis

Repeated Measures ANOVA with 2 within subjects factors of Emotion (very happy, happy, neutral, sad, fear, and anger) and Delay Condition (500 ms, 1000 ms, and 2000 ms) will be used to evaluate P1 and N170 amplitudes from ERPs to Stimulus 1 and

for theta power during the entire delay for each condition. Additional repeated measured with 2 within-subject factors of Emotion (6) and Time Interval (beginning interval, middle interval, and end interval) for each delay condition will be compared to evaluate theta power during the delay intervals. If sphericity is violated, Greenhouse-Geisser corrections will be reported. Finally, mediation analyses using the PROCESS macro from Hayes (2013) will be used to test whether the relationship between N170 amplitude and behavioral performance was mediated by theta power for significant emotions across all delay conditions and delay intervals (Aiken & West, 1991; Hayes, 2013). All statistical analyses will be done in SPSS (version 22.0).

CHAPTER FOUR

RESULTS

Event-Related Potential Component Analyses

P1 at the Left Occipital Electrode Site

A repeated measures ANOVA on P1 ERP amplitude at electrode site O1 was conducted, with within subjects factors of Emotion (6) and Delay (500, 1000, 2000) and revealed a main effect of Emotion ($F(5,140) = 2.917, p = 0.015$). Pairwise comparisons indicated that P1 amplitude to Happy Open was significantly larger than those to Neutral ($p = 0.015$), Fear ($p = 0.006$) and Anger ($p = 0.007$). In addition, P1 amplitude to Happy Closed was significantly larger than that to Neutral ($p = 0.042$) and Fear ($p = 0.027$).

P1 at the Right Occipital Electrode Site

A repeated measures ANOVA on P1 ERP amplitude at electrode site O2 was conducted, with within subjects factors of Emotion (6) and Delay (500, 1000, 2000) and revealed no significant findings.

N170 at the Left Parietal Electrode Site

A repeated measures ANOVA on N170 ERP amplitude at electrode site P7 was conducted, with within subjects factors of Emotion (6) and Delay (500, 1000, 2000) and revealed a main effect of Emotion ($F(5,130) = 4.211, p = 0.001$). Pairwise comparisons (see Figure 5) indicated that N170 amplitude to Fear was significantly larger than those to Happy Open ($p = 0.023$), Happy Closed ($p = 0.005$), and Neutral ($p = 0.009$). N170 amplitude to Anger was also significantly larger than those to Happy Open ($p = 0.005$),

Happy Closed ($p= 0.010$), and Neutral ($p= 0.00$). N170 amplitudes to Fear and Anger did not significantly differ from one another ($p= 0.720$).

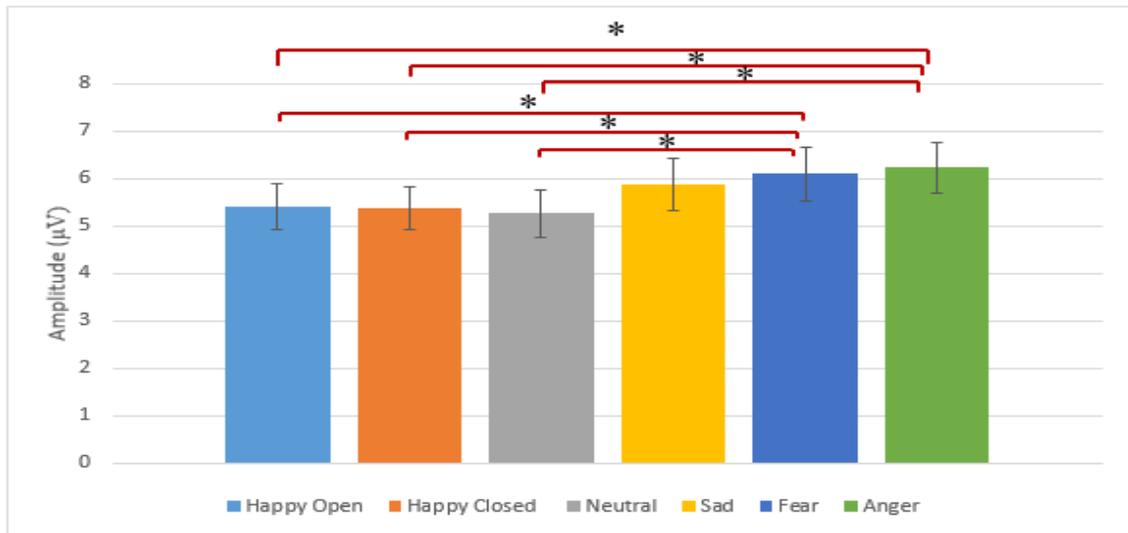


Figure 5. Differences in N170 amplitude for each emotion at electrode site P7. * $p < .01$

There was also a main effect of Delay ($F(2,52)= 4.893$, $p= 0.011$) indicating that N170 amplitudes collected during the 500 ms and 1000 ms delay interval conditions were larger than those collected during the 2000 ms delay interval condition ($p= 0.010$, $p= 0.031$ respectively). Amplitudes collected during the 500 ms and 1000 ms delay interval did not significantly differ from one another ($p= 0.357$).

N170 at the Right Parietal Electrode Site

A repeated measures ANOVA on N170 ERP amplitude at electrode site P8 was conducted, with within subjects factors of Emotion (6) and Delay (500 ms, 1000 ms, 2000 ms) and revealed a main effect of Emotion ($F(5,130) = 4.071$, $p= 0.002$). Pairwise comparisons (see Figure 6) indicated that N170 amplitude to Anger was significantly

larger than those to Happy Open ($p= 0.002$), Happy Closed ($p= 0.033$), Neutral ($p= 0.003$), and Sad ($p= 0.013$). In addition, N170 amplitude to Fear was significantly larger than that to Happy Open ($p= 0.046$) and Neutral ($p= 0.007$). N170 amplitudes to Fear and Anger did not significantly differ from one another ($p= 0.445$).

There was also a main effect of Delay ($F(2,52)= 10.345, p < 0.001$) indicating that N170 amplitudes collected during the 500 ms and 1000 ms delay interval conditions were larger than those collected during the 2000 ms delay interval condition ($p < 0.001, p= 0.005$ respectively). Amplitudes collected during the 500 ms and 1000 ms delay interval did not significantly differ from one another ($p= 0.260$).

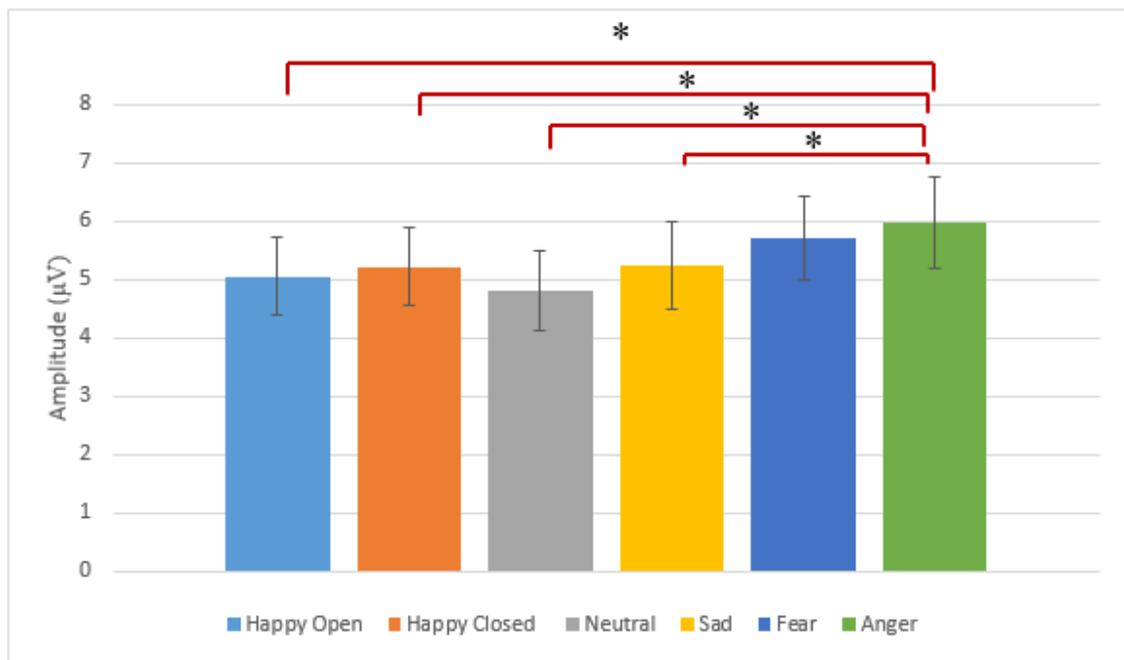


Figure 6. Differences in N170 amplitude for each emotion at electrode site P8. * $p < .01$

Theta Power Analyses

Left Parietal Electrode Site

A repeated measures ANOVA on Theta power at electrode site P7 was conducted, with within subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000) and revealed a main effect of Delay (see Table 2) indicating that Theta power collected during the 500 ms delay interval condition was larger than those collected during the 1000 ms and 2000 ms delay interval conditions. In addition, Theta power collected during the 1000 ms delay interval was larger than that collected during the 2000 delay interval condition (see Figure 7).

Table 2. Repeated Measures ANOVA on Theta power at electrode site P7 with within-subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000).

	df	F	<i>p</i>
Emotion	3.50, 80.49	2.19	.09
Delay	1.28, 29.62	40.55	<.001
Latency	1.10, 25.33	44.36	<.001

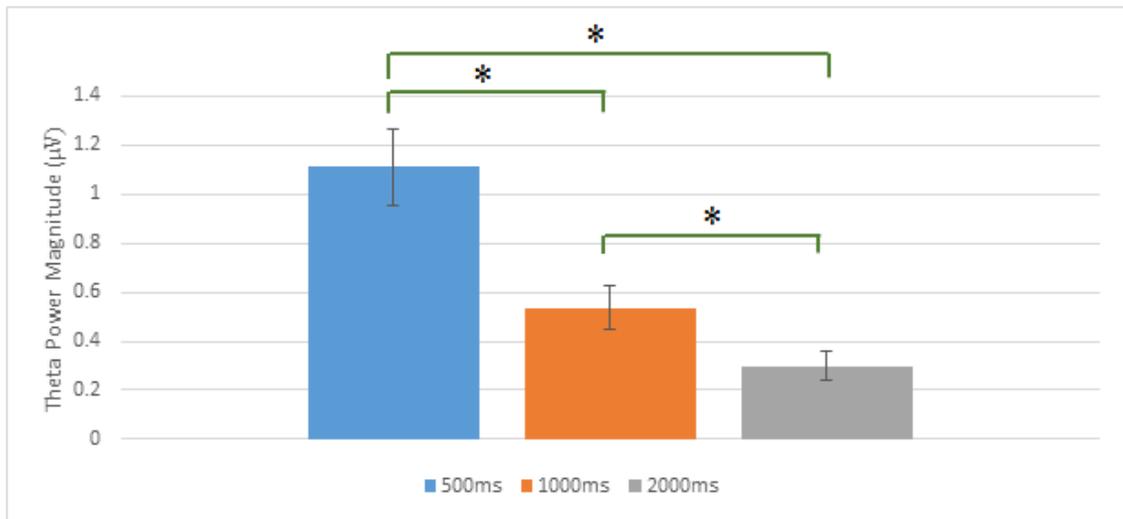


Figure 7. Differences in Theta power magnitudes at electrode site P7 for the 500 ms, 1000 ms, and 2000 ms Delay intervals. * $p < .001$

There was also a main effect of Latency (see Table 2) indicating that Theta power collected during the Early latencies of the delay intervals was larger than those collected during the Middle and Late latencies of the delay intervals. In addition, Theta power collected during the Late latencies was also larger than those collected during the Middle of the delay intervals (see Figure 8).

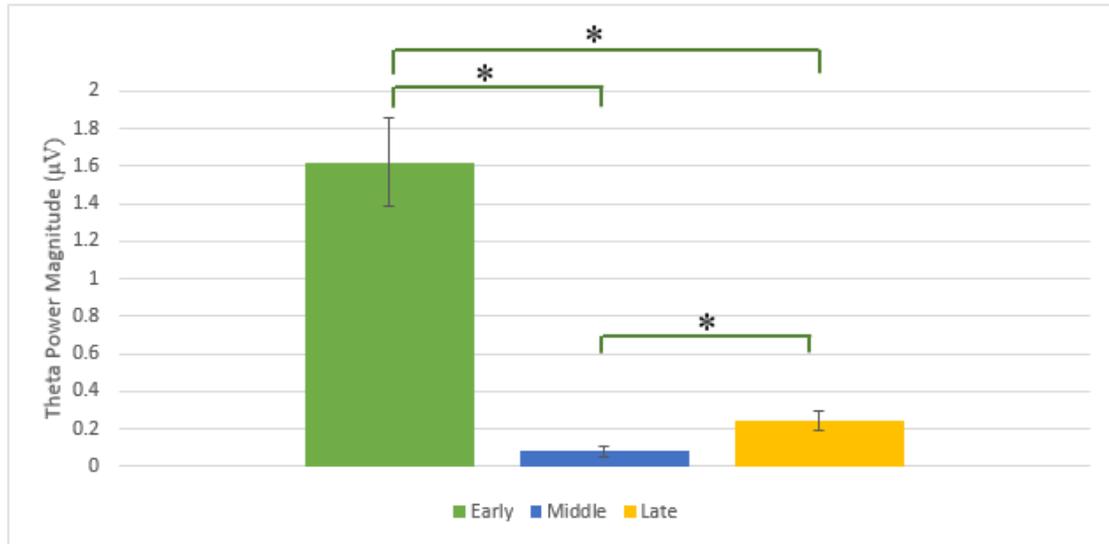


Figure 8. Differences in Theta power magnitudes at electrode site P7 for the Early, Middle, and Late latencies. * $p < .001$

In addition, there were interaction effects of Emotion X Latency ($F(3.692,84.924)= 3.490, p=.013$) and Delay X Latency ($F(2.060,47.383)= 35.402, p < 0.001$). A repeated measures ANOVA with Latency & Delay as within-subjects effects for each emotion was conducted to interpret both of these interactions and results are displayed in Table 3. For all emotions, there was a main effect of Delay such that Theta power collected during the 500 ms delay interval condition was larger than those collected during the 1000 ms and 2000 ms delay interval conditions. Theta power in response to Neutral and Fear expressions was greater during the 2000 ms delay condition than in the 1000 ms condition. Also for all emotions, there was a main effect of Latency such that Theta power during the Early third of the delay intervals was larger than theta power during Middle and Late which did not differ from each other for Happy Open, Happy Closed, and Neutral expressions. Theta power in response to faces expressing Sad, Fear, and Anger was greater in the Middle third of delay intervals than in the Late third

(see Table 3). There was also an interaction of Latency X Delay for all emotions indicating that Theta power during the 500 ms interval was greatest for the Early latency, smaller for the Middle latency, and smallest for the Late latency, but differences between the latencies were not significant during the 1000 ms and 2000 ms delay conditions.

Table 3. Six (one for each emotion) repeated measures ANOVAs on Theta power at the P7 electrode site with Latency & Delay as within-subjects effects was conducted to interpret the Emotion X Latency and Delay X Latency interactions.

		df	F	p	Contrast Effects
Happy Open	Delay	1.7, 26.94	44.60	<.001	500ms > 1000ms > 2000ms
	Latency	2, 46	15.97	<.001	Early > Mid = Late
Happy Closed	Delay	1.22, 27.98	34.04	<.001	500ms > 1000ms > 2000ms
	Latency	1.31, 30.07	14.66	<.001	Early > Mid = Late
Neutral	Delay	1.11, 25.42	31.66	<.001	500ms > 2000ms > 1000ms
	Latency	1.51, 34.79	18.45	<.001	Early > Mid = Late
Sad	Delay	1.08, 24.74	27.68	<.001	500ms > 1000ms = 2000ms
	Latency	1.50, 34.59	15.27	<.001	Early > Mid > Late
Fear	Delay	1.09, 25.08	53.57	<.001	500ms > 2000ms > 1000ms
	Latency	1.47, 33.90	22.36	<.001	Early > Mid = Late
Anger	Delay	1.11, 25.55	51.36	<.001	500ms > 2000ms > 1000ms
	Latency	2, 46	25.06	<.001	Early > Mid = Late

Right Parietal Electrode Site

A repeated measures ANOVA on Theta power at electrode site P8 was conducted, with within subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000) and revealed a main effect of Delay (see Table 4) indicating that Theta power collected during the 500 ms delay interval condition was larger than those collected during the 1000 ms and 2000 ms delay interval conditions. In

addition, Theta power collected during the 1000 delay interval was larger than that collected during the 2000 delay interval condition (see Figure 9).

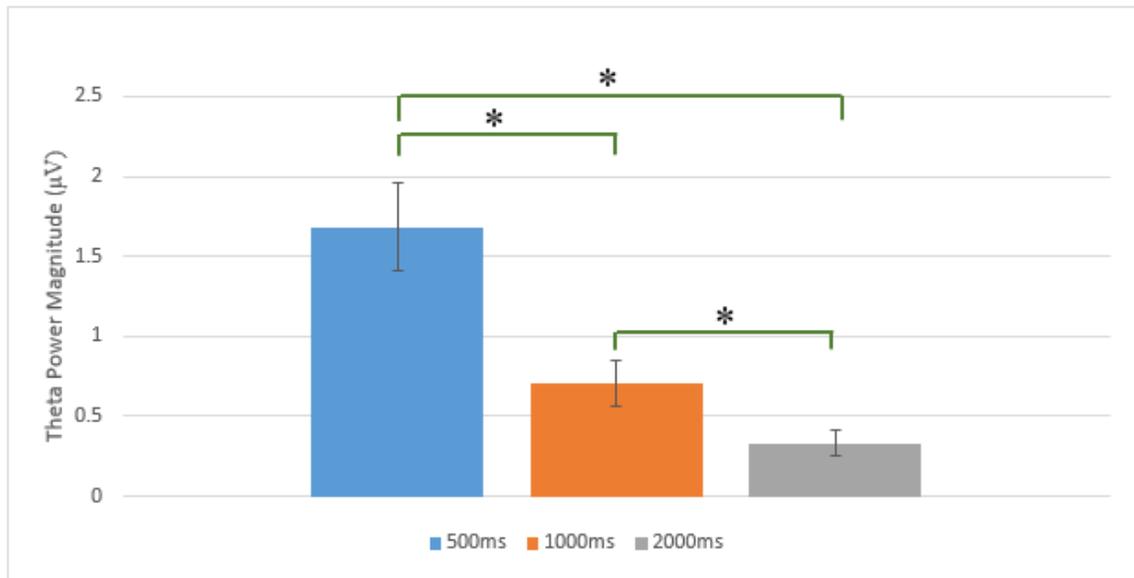


Figure 9. Differences in Theta power magnitudes at electrode site P8 for the 500 ms, 1000 ms, and 2000 ms Delay intervals. * $p < .001$

Table 4. A repeated measures ANOVA on Theta power at electrode site P8 was conducted, with within-subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000).

	df	F	p
Emotion	3.27, 68.57	.23	.89
Delay	1.15, 24.09	31.84	<.001
Latency	1.06, 22.21	37.20	<.001

There was also a main effect of Latency (see Table 4) indicating that Theta power collected during the Early latencies of the delay intervals was larger than those collected during the Middle and Late latencies of the delay intervals. In addition, Theta power

collected during the Late latencies was larger than those collected during the Middle of the delay intervals (see Figure 10).

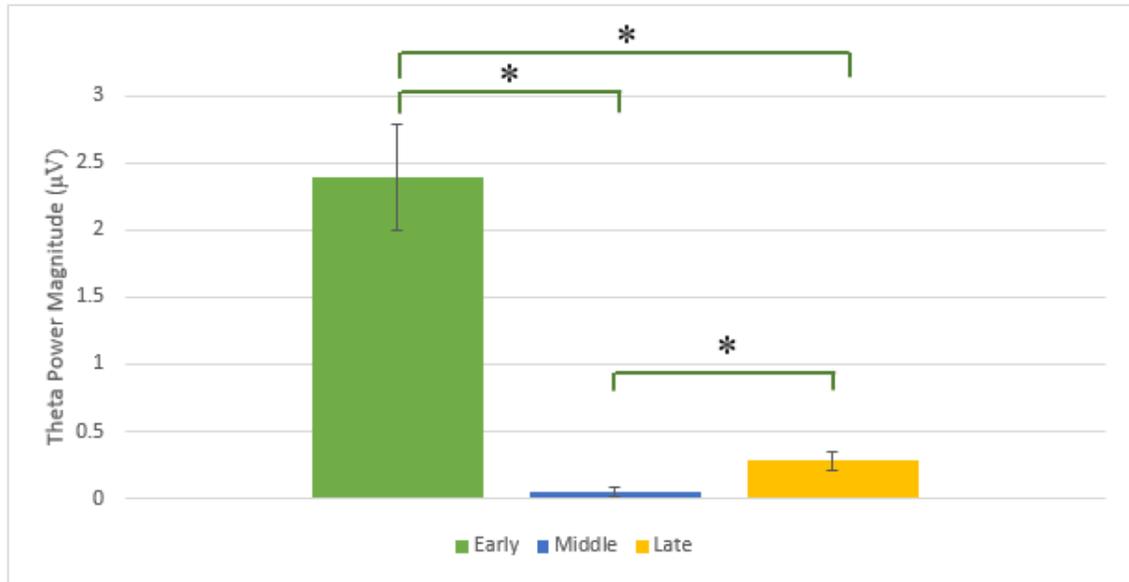


Figure 10. Differences in Theta power magnitudes at electrode site P8 for the Early, Middle, and Late latencies. * $p < .001$

In addition, there was an interaction effect of Delay X Latency ($F(4,84) = 25.628$, $p < 0.001$). A repeated measures ANOVA with Latency as a within-subjects effect for each delay condition (500 ms, 1000 ms, 2000 ms) was conducted to interpret this interaction (see Table 5). For all delay conditions, Theta power collected during the Early latency was larger than in the Middle and Late latencies. For the 1000 ms and 2000 ms delay conditions, Theta power was larger during the Late than in the Middle latencies (see Table 5).

Table 5. Three (one for each Delay condition) repeated measures ANOVAs with Latency as a within-subjects effect for each delay condition (500 ms, 1000 ms, 2000 ms) was conducted to interpret the interaction effect of Delay X Latency ($F(4,84)= 25.628$, $p < 0.001$) at electrode site P8.

	df	F	<i>p</i>	Contrast Effects
500 ms	1.05, 22.05	34.23	<.001	Early > Mid = Late
1000 ms	1.05, 22.01	35.58	<.001	Early > Late > Mid
2000 ms	1.07, 22.5	36.52	<.001	Early > Late > Mid

Left Occipital Electrode Site

A repeated measures ANOVA on Theta power at electrode site O1 was conducted, with within subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000) and revealed a main effect of Delay (see Table 6) indicating that Theta power collected during the 500 ms delay interval condition was larger than those collected during the 1000 and 2000 ms delay interval conditions. In addition, Theta power collected during the 1000 delay interval was larger than that collected during the 2000 delay interval condition (see Figure 11).

Table 6. A repeated measures ANOVA on Theta power at electrode site O1 was conducted, with within-subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000).

	df	F	<i>p</i>
Emotion	5, 105	.23	.95
Delay	2, 42	35.34	<.001
Latency	2,42	79.02	<.001

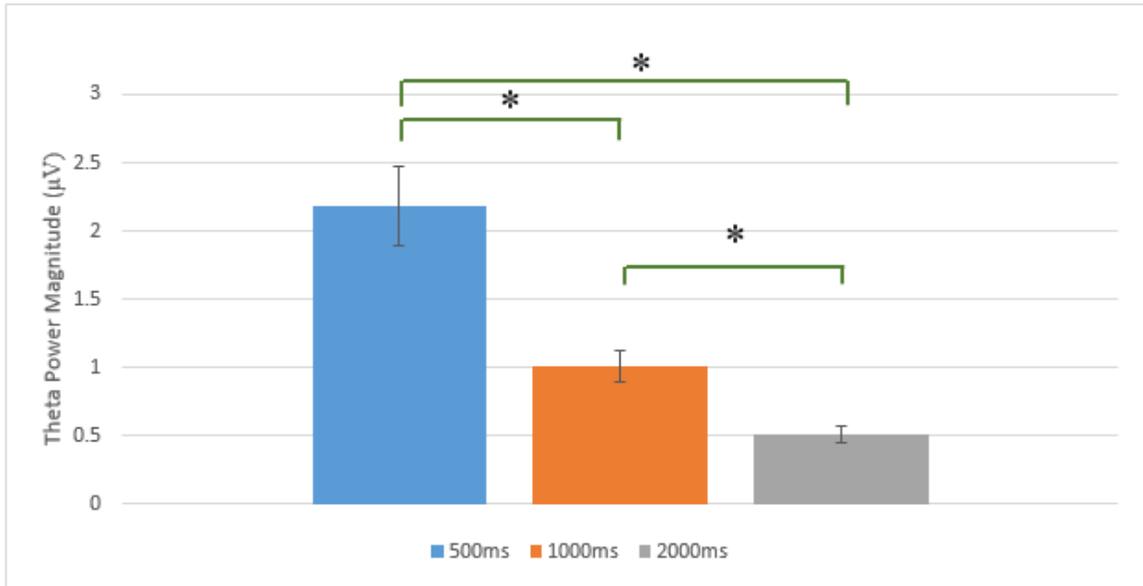


Figure 11. Differences in Theta power magnitudes at electrode site O1 for the 500 ms, 1000 ms, and 2000 ms Delay intervals. * $p < .001$

There was also a main effect of Latency (see Table 6) indicating that Theta power collected during the Early latencies of the delay intervals was larger than those collected during the Middle and Late latencies of the delay intervals. In addition, Theta power collected during the Late latencies was larger than those collected during the Middle of the delay intervals (see Figure 12).

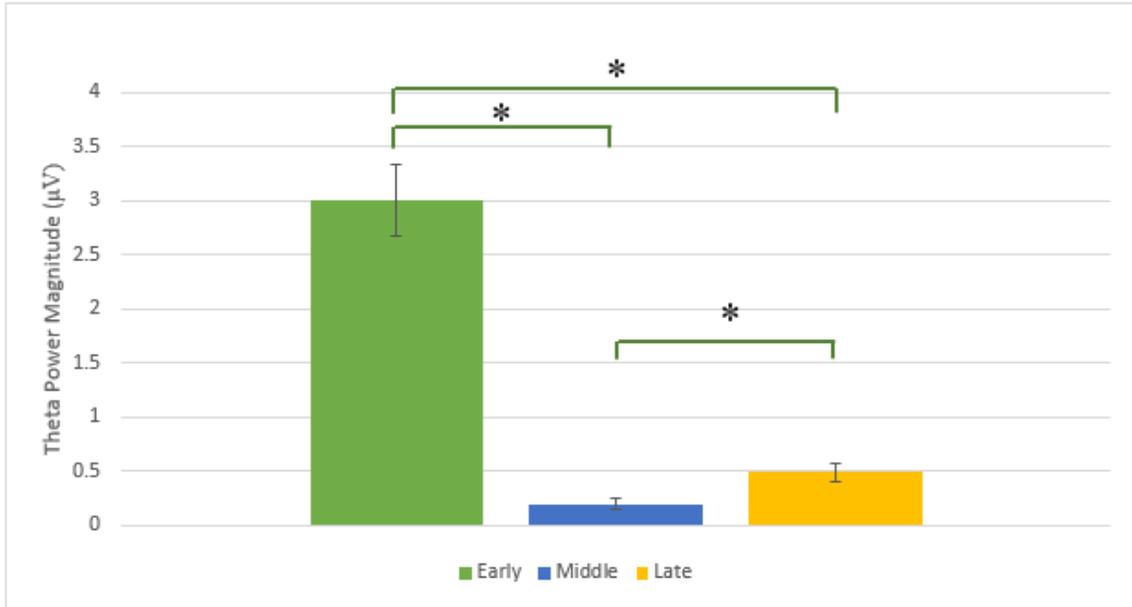


Figure 12. Differences in Theta power magnitudes at electrode site O1 for the Early, Middle, and Late latencies. * $p < .001$

In addition, there was an interaction effect of Delay X Latency ($F(4,84)= 32.260$, $p < 0.001$). A repeated measures ANOVA with Latency as a within-subjects effect for each delay condition (500 ms, 1000 ms, 2000 ms) was conducted to interpret this interaction (see Table 7). In all conditions, Theta power was greatest during the Early latency. In the 1000 ms and 2000 ms delay conditions Theta power was greater in the Late latency than in the Middle latency, but Theta power was not significantly greater during the Late latency than the Middle latency for the 500 ms delay condition (see Table 7).

Table 7. Three (one for each Delay condition) repeated measures ANOVAs with Latency as a within-subjects effect for each delay condition (500 ms, 1000 ms, 2000 ms) was conducted to interpret the interaction effect of Delay X Latency ($F(4,84)= 32.260$, $p< 0.001$) at the O1 electrode site.

	df	F	<i>p</i>	Contrast Effects
Emotion	5, 100	.52	.76	Early > Mid = Late
Delay	2, 40	34.20	<.001	Early > Late > Mid
Latency	2,40	45.38	<.001	Early > Late > Mid

Right Occipital Electrode Site

A repeated measures ANOVA on Theta power at electrode site O2 was conducted, with within subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000) and revealed a main effect of Delay (see Table 8) indicating that Theta power collected during the 500 delay interval condition was larger than those collected during the 1000 and 2000 delay interval conditions. In addition, Theta power collected during the 1000 delay interval was larger than that collected during the 2000 delay interval condition (see Figure 13).

Table 8. A repeated measures ANOVA on Theta power at electrode site O2 was conducted, with within-subjects factors of Emotion (6), Latency (divided into thirds: Early, Middle, Late), and Delay (500, 1000, 2000).

	df	F	<i>p</i>
Emotion	5, 100	.52	.76
Delay	2, 40	34.20	<.001
Latency	2,40	45.38	<.001

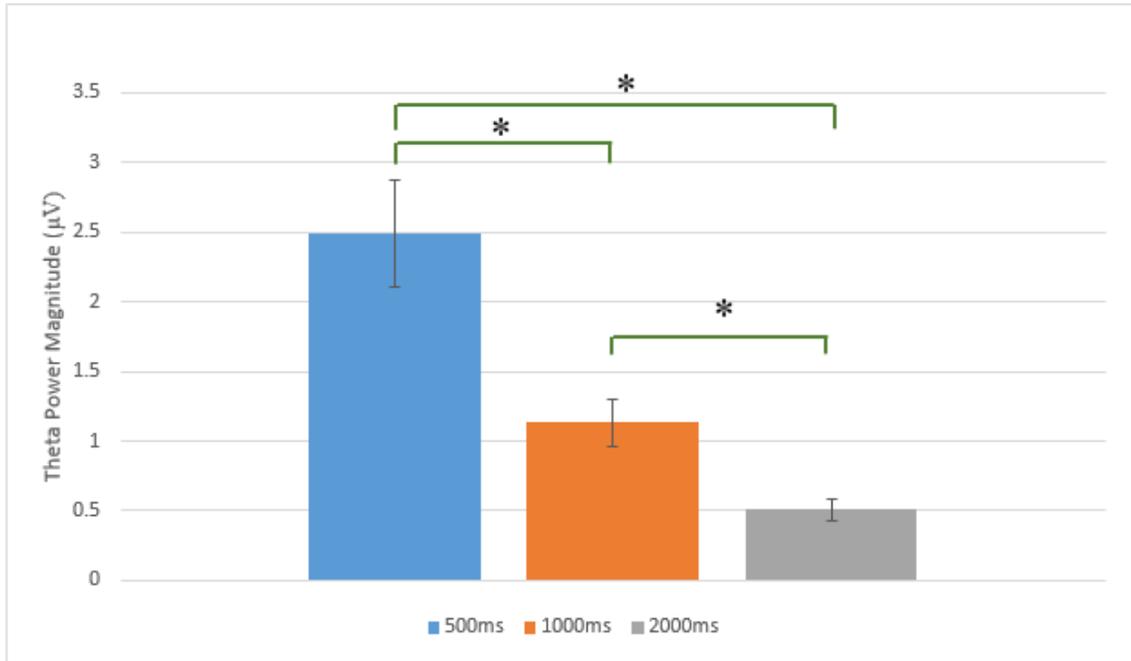


Figure 13. Differences in Theta power magnitudes at electrode site O2 for the 500 ms, 1000 ms, and 2000 ms Delay intervals. * $p < .001$

There was also a main effect of Latency (see Table 8) indicating that Theta power collected during the Early latencies of the delay intervals was larger than those collected during the Middle and Late latencies of the delay intervals. In addition, Theta power collected during the Late latencies was also larger than those collected during the Middle latency of the delay intervals (see Figure 14).

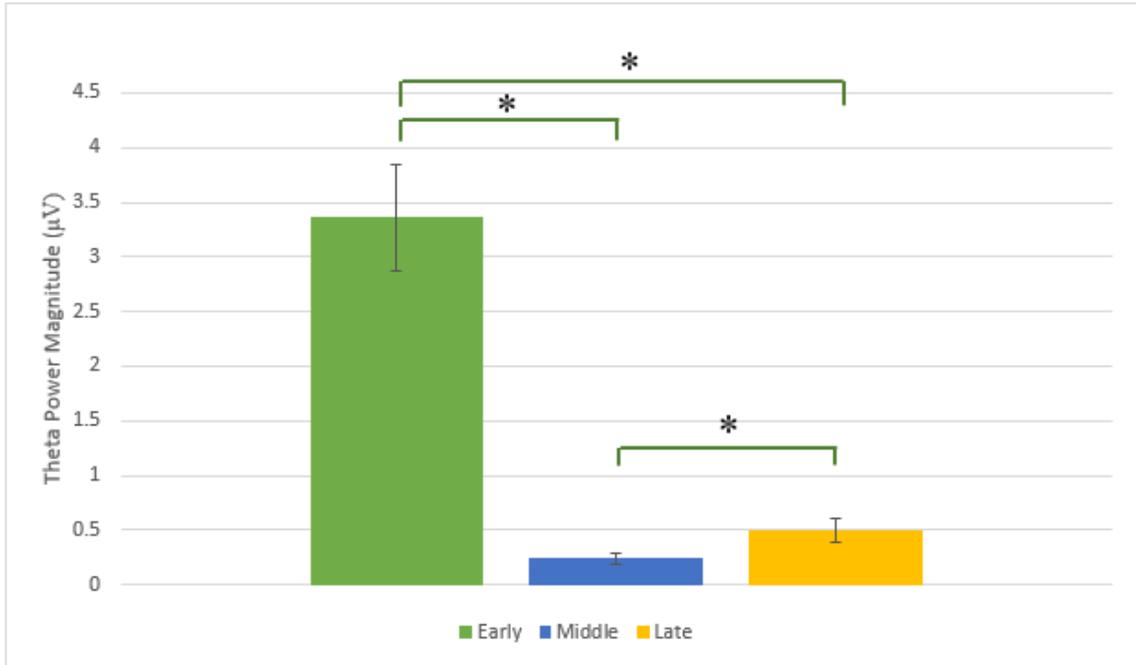


Figure 14. Differences in Theta power magnitudes at electrode site O2 for the Early, Middle, and Late latencies. * $p < .001$

In addition, there was an interaction effect of Delay X Latency ($F(4,80)= 31.428$, $p < 0.001$). A repeated measures ANOVA with Latency as a within-subjects effect for each delay condition (500 ms, 1000 ms, 2000 ms) was conducted to interpret this interaction (see Table 9). For the 1000 ms and 2000 ms delay conditions Theta power collected during the Late latencies was larger than those collected during the Middle latencies, but Theta power was not significantly greater during the Late latency than the Middle latency for the 500 ms delay condition (see Table 9).

Table 9. Three (one for each Delay condition) repeated measures ANOVAs with Latency as a within-subjects effect for each delay condition (500 ms, 1000 ms, 2000 ms) was conducted to interpret the interaction effect of Delay X Latency ($F(4,80)= 31.428, p < 0.001$) at the O2 electrode site.

	df	F	<i>p</i>	Contrast Effects
500 ms	1.10, 22.08	39.60	<.001	Early > Mid = Late
1000 ms	1.08, 21.60	42.10	<.001	Early > Late > Mid
2000 ms	1.12, 22.40	44.77	<.001	Early > Late > Mid

ERP and Theta Power Regression Analyses

Left Parietal Electrode Site

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 500 ms delay condition on behavioral performance (see Table 10). There were no significant effects for P1, N170 and Total Theta power during the 500 ms delay condition in response to Happy Open, Happy Closed, Sad, and Anger. In response to Neutral faces, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^{2\text{adj}} = 0.218, F(3,23) = 3.409, p = 0.035$). N170 amplitude significantly predicted behavioral performance such that as N170 amplitude increased behavioral performance improved ($\beta = 0.640, p = 0.006$). Total Theta power also significantly predicted behavioral performance, such that as Theta power increased, behavioral performance improved ($\beta = .471, p = .042$). In response to faces expressing Fear, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^{2\text{adj}} = 0.258, F(3,24) = 4.122, p = 0.017$). N170 amplitude significantly predicted behavioral performance such that as N170 amplitude increased, behavioral performance improved ($\beta = .597, p =$

0.003). Total Theta power was trending toward significance as a predictor of behavioral performance, such that as Theta power increased, behavioral performance improved ($\beta = 0.403, p = 0.059$).

Table 10. Regression of P1 and N170 Event-Related Potential Amplitudes and Total Theta Power throughout Delay Conditions Predict Correct Identification of Emotions at the P7 Electrode Site.

	Emotion	Variable	<i>F</i>	B	<i>p</i>	
500 Delay Condition	Neutral		3.409		.035	
		N170		0.64		.006
		Total Theta		.471		.042
	Fear		4.122		.017	
		N170		.597		.003
		Total Theta		.403		.059
1000 Delay Condition	Happy Closed		4.505		.013	
		P1		.426		.024

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 1000 ms delay condition on behavioral performance (see Table 10). There were no significant effects for P1, N170 and Total Theta power during the 1000 ms delay condition in response to Happy Open, Sad, Neutral, Fear, and Anger. Overall, in response to Happy Closed faces, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^2_{adj} = 0.288, F(3,23) = 4.505, p = 0.013$). P1 amplitude significantly predicted behavioral performance such that as P1 amplitude increased behavioral performance improved ($\beta = 0.426, p = 0.024$).

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 2000 ms delay condition on behavioral performance and there were no significant findings.

Right Parietal Electrode Site

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 500 ms delay condition on behavioral performance and there were no significant findings.

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 1000 ms delay condition on behavioral performance (see Table 11). There were no significant effects for P1, N170 and Total Theta power during the 1000 ms delay condition in response to Happy Closed, Sad, Neutral, Fear, and Anger. Overall, in response to Happy Open faces, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^2_{\text{adj}} = 0.207$, $F(3,22) = 3.174$, $p = 0.044$). P1 amplitude significantly predicted behavioral performance such that as P1 amplitude decreased, behavioral performance improved ($\beta = -0.502$, $p = .013$).

Table 11. Regression of P1 and N170 Event-Related Potential Amplitudes and Total Theta Power throughout Delay Conditions Predict Correct Identification of Emotions at the P8 Electrode Site.

	Emotion	Variable	<i>F</i>	B	<i>p</i>
1000 Delay Condition	Happy Open		3.174		.044
		P1		-.502	
2000 Delay Condition	Happy Open		3.481		.032
		N170		-.451	
	Neutral		3.055		.049
		P1		.577	
	Fear		4.599		.011
P1		.565		.008	
		Total Theta		-.451	.015

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 2000 ms delay condition on behavioral performance (see Table 11). There were no significant effects for P1, N170 and Total Theta power during the 2000 ms delay condition in response to Happy Closed, Sad, and Anger. Overall, in response to faces expressing Happy Open, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^{2adj} = 0.223$, $F(3,23) = 3.481$, $p = 0.032$). N170 amplitude significantly predicted behavioral performance such that as N170 amplitude increased, behavioral performance improved ($\beta = .451$, $p = 0.003$). Overall, in response to Neutral faces, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^{2adj} = .285$, $F(3,23) = 3.055$, $p = 0.049$). P1 amplitude significantly predicted behavioral performance such that as P1 amplitude increased behavioral performance improved ($\beta = 0.577$, $p = 0.008$). In response to Fear, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^{2adj} = 0.365$, $F(3,24) = 4.599$, $p =$

0.011). P1 amplitude significantly predicted behavioral performance such that as P1 amplitude increased behavioral performance improved ($\beta = .565, p=0.008$). Total theta power also significantly predicted behavioral performance such that as total theta power decreased behavioral performance improved ($\beta = -0.451, p=0.015$).

Left Occipital Electrode Site

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 500 ms delay condition on behavioral performance and there were no significant findings.

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 1000 ms delay condition on behavioral performance (see Table 12). There were no significant effects for P1, N170 and Total Theta power during the 1000 ms delay condition in response to Happy Open, Happy Closed, Neutral, Sad, and Anger. Overall, in response to Fear, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^2_{adj} = 0.447, F(3,22) = 5.918, p = 0.004$). P1 amplitude significantly predicted behavioral performance such that as P1 amplitude increased, behavioral performance improved ($\beta = 0.386, p=.035$). N170 also significantly predicted behavioral performance such that as N170 amplitude decreased, behavioral performance improved ($\beta = 0.589, p=0.01$).

Table 12. Regression of P1 and N170 Event-Related Potential Amplitudes and Total Theta Power throughout Delay Conditions Predict Correct Identification of Emotions at the O1 Electrode Site.

	Emotion	Variable	<i>F</i>	B	<i>p</i>	
1000 Delay Condition	Fear		5.918		.004	
		P1		.386		.035
		N170		.589		.01
2000 Delay Condition	Sad		4.99		.008	
		Total Theta		-.517		.004
	Anger		5.934		.004	
P1	.563	.002				

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 2000 ms delay condition on behavioral performance (see Table 12). There were no significant effects for P1, N170 and Total Theta power during the 2000 ms delay condition in response to Happy Closed, Neutral, Sad, and Fear. Overall, in response to faces expressing Happy Open, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^{2adj} = 0.384$, $F(3,24) = 4.990$, $p = 0.008$). Total theta power significantly predicted behavioral performance such that as theta decreased, behavioral performance improved ($\beta = -0.517$, $p = 0.004$). Overall, in response to Anger, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^{2adj} = .363$, $F(3,23) = 5.934$, $p = 0.004$). P1 amplitude significantly predicted behavioral performance such that as P1 amplitude increased behavioral performance improved ($\beta = 0.563$, $p = 0.002$).

Right Occipital Electrode Site

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 500 ms delay condition on behavioral performance and there were no significant findings.

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 1000 ms delay condition on behavioral performance (see Table 13). There were no significant effects for P1, N170 and Total Theta power during the 1000 ms delay condition in response to Happy Open, Happy Closed, Neutral, Sad, and Anger. Overall, in response to Fear, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^2_{adj} = 0.274$, $F(3,23) = 4.264$, $p = 0.016$). N170 amplitude significantly predicted behavioral performance such that as N170 amplitude increased, behavioral performance improved ($\beta = 0.587$, $p = 0.009$).

Table 13. Regression of P1 and N170 Event Related-Potential Amplitudes and Total Theta Power throughout Delay Conditions Predict Correct Identification of Emotions at the O2 Electrode Site.

	Emotion	Variable	F	B	P
1000 Delay Condition	Fear		4.264		.016
		N170		.587	
2000 Delay Condition	Fear		3.12		.046
		P1		.508	
	Anger		6.55		.002
P1	.39	.034			

A standard multiple linear regression was conducted to determine the influence of P1 and N170 amplitudes and Total Theta power during the 2000 ms delay condition on behavioral performance (see Table 13). There were no significant effects for P1, N170 and Total Theta power during the 2000 ms delay condition in response to Happy Open, Happy Closed, Neutral, and Sad. Overall, in response to Fear, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^{2\text{adj}} = 0.197$, $F(3,23) = 3.120$, $p = 0.046$). P1 amplitude significantly predicted behavioral performance such that as P1 amplitude increased, behavioral performance improved ($\beta = 0.508$, $p = 0.028$). Overall, in response to Anger, the regression model accounted for a significant proportion of the variance in behavioral performance ($R^{2\text{adj}} = .381$, $F(3,24) = 6.550$, $p = 0.002$). P1 amplitude significantly predicted behavioral performance such that as P1 amplitude increased behavioral performance improved ($\beta = 0.390$, $p = 0.034$).

CHAPTER FIVE

DISCUSSION

The goal of the current study was to explore the mechanisms of facial emotion memory and clarify whether type of emotion, length of delay interval, or robustness of encoding the initial stimulus were associated with accurate facial emotion recognition and memory. Results confirmed that negative emotions and robust encoding of stimuli are strong influencers of effective emotion processing. Both P1 (at occipital sites) and N170 amplitudes (at parietal sites), differed by emotional expression. Larger P1 amplitudes at occipital electrode sites were the best predictors of correct matching of negative emotions such as Fear and Anger while correct matching of positive emotions (Happy Open and Happy Closed) were more consistently associated with P1 amplitudes at parietal sites. Correct matching of faces expressing Fear was predicted by ERPs and Theta Power more than any other emotion. Furthermore, P1 and N170 amplitudes and Total theta power all predicted behavioral performance to Fear stimuli in different ways during the three delay conditions. Theta Power analyses indicated that increased synchronization of activity in the theta frequency band following presentation of visual stimuli of facial emotions is associated with encoding the stimuli, but not necessarily maintaining them in working memory. Theta Power was greater during the shorter delay condition (500 ms) than in longer conditions (1000 and 2000 ms) and in the Early portion of the delay conditions, but smallest in the Middle portion of the delay conditions. Theta Power did not differ by emotional expression and results of Theta Power as a predictor of behavioral performance are inconclusive. Overall, results indicate the importance of the

robust encoding of a visual stimulus and early maintenance of emotional expressions for emotion memory.

This finding is consistent with previous literature in that larger P1 amplitudes are common to occipital sites and larger N170 amplitudes are common to parietal sites near the fusiform gyrus (Allison et al., 1994; Bentin, Allison, Puce, Perez, & McCarthy, 1996; Clark, Fan, & Hillyard, 1994; Di Russo, Martínez, Sereno, Pitzalis, & Hillyard, 2002; Eimer & McCarthy, 1999; Herrmann, Ehlis, Ellgring, & Fallgatter, 2005). In addition, increased P1 and N170 amplitudes have been found to be associated with improved behavioral performance on visual recognition and attention tasks (Caharel, Courty, Bernard, Lalonde, & Rebaï, 2005; Heinze et al., 1994; Mangun, 1995; Rossion et al., 1999). The finding that P1 amplitudes are greater for positive emotions at the occipital sites suggests that the low-level features of happy facial expressions are particularly salient and prompt basic visual stimuli processing. In comparison, negative emotions were associated with larger N170 amplitudes at parietal sites which suggests that the static features of the face are prominent in these emotional expressions and direct visual attention to process the visual presentation of the face. Visual information is processed through a “stream” of neural activity that begins in the visual or occipital cortex with more basic sensory processing and continues toward the front of the brain with increasing complexity of processing (Halgren, Baudena, Heit, Clarke, & Marinkovic, 1994; Haxby et al., 1994; Linkenkaer-Hansen et al., 1998; Mangun, 1995). Following this stream, the P1 component is earlier and represents sensory processing in occipital regions and the N170 component is later and represents more complex processing in the more anterior fusiform gyrus. Our findings suggest that negative emotions, processed later in the

“stream”, may require more complex processing or increased processing resources than positive emotions.

In partial support of Hypothesis 1 (Aim 1), our results indicated that both N170 and P1 amplitudes differ by emotion at the P7, P8, and O1 electrode sites. As expected, N170 amplitudes were greater in response to visual stimuli of negative emotions (Fear and Anger) compared to stimuli of positive and neutral emotions (Happy Open, Happy Closed, and Neutral). At the P8 electrode site, where most studies report emotion-modulated N170 effects (Brenner et al., 2014; Streit et al., 1999, 2001; Herrmann 2005), N170 amplitude in response to Anger was also significantly greater than N170 amplitude in response to Sad. These results are consistent with the theory that some expressions of negative emotion (Fear, Anger) inspire faster and more protective behavioral responses than positive emotions (Happy and Very Happy) for evolutionary advantages (Fox et al., 2000; Hansen & Hansen, 1988).

Inconsistent with our hypotheses, P1 amplitudes in occipital regions (O1 electrode site) were significantly greater in response to positive emotions than to neutral and negative emotions. Increased P1 amplitudes have been associated with selective and transient attention (Clark & Hillyard, 1996; Eimer, Holmes, & McGlone, 2003), encoding of low-level features of the visual stimulus and are especially large in response to faces compared to other visual stimuli. This could suggest that the low-level features of faces prompt increased attention to visual presentations of faces (Halgren, 2000; Herrmann, Ehlis, Ellgring, & Fallgatter, 2005; Rossion & Caharel, 2011). The finding of greater P1 amplitudes in occipital regions in response to positive emotions than negative emotions may represent more resources attending to positive emotions in early visual processing,

that the low-level features of positive emotions are more salient than those of negative emotions, or it could be that both of these phenomena explain increased P1 in occipital sites. Future research that provides systematic study of the psychophysical properties of facial stimuli from negative and positive emotion categories would help to further clarify the interpretation of the current results.

Contrary to Hypothesis 2 (Aim 2), there were no differences in the magnitude of theta power for emotional expressions. This finding is inconsistent with findings from Brenner et. al. (2014) which found that larger theta power was associated with negative emotion expressions compared to positive and neutral emotions. There are two likely explanations for these disparate findings. First, it is possible that, contrary to Brenner et al. (2014), negative emotions do not pull more neural resources than positive ones in order to complete this memory task. Second, it is likely that previous results averaged both the impact of the emotion with that of arousal. Brenner et al. (2014) combined theta power from fearful, angry, and sad faces to create the response to negative facial emotions, and combined the two types of happy expressions to create the response to positive facial emotions. This had the result of combining varying levels of arousal associated with each emotion into one broad valence variable. The current study examined responses to each emotional expression separately. Since anger and fear are associated with higher levels of arousal than sadness (Balconi & Pozzoli, 2009) it is possible that the combination of valence and arousal across multiple emotions is needed to affect theta power during the delay. Therefore, the differences in findings from the two related studies suggests a complex combination of arousal and valence. This explanation of the apparently conflicting results is consistent with Almeida et al. (2016). Almeida and

colleagues found that regardless of emotional category, N170 amplitudes were found to be significantly influenced by perceived arousal. In fact, they propose that differences in ERP amplitudes by emotions are a result of increases in power (alpha, β , and theta) that follow from the perceived emotional arousal of the stimuli. Additionally, emotional valence has been found to affect memory performance such that emotional stimuli that are more arousing are associated with improved memory as compared to less arousing emotional stimuli (Cahill, 1995; Lang 2009). Future studies might consider comparing neutral expressions to the group of positive emotions and the group of negative emotions to provide further clarification of the relationship between theta power and emotion memory.

Theta Power did not distinguish emotions nor did it consistently predict correct matching of emotional expressions between stimulus 1 and 2, as expected. Rather, ERPs and Theta Power predicted behavioral performance most consistently for faces expressing Fear such that larger P1 amplitudes at occipital sites, and not N170 amplitudes at parietal sites as hypothesized, predicted correct matching of facial expressions. This finding is consistent with many studies that identify earlier ERPs to fearful expressions than other emotions and before the encoding of faces as indicated by the N170 peak (Adolphs et al., 2001; Batty & Taylor, 2003; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005; van Heijnsbergen, Meeren, Grèzes, & de Gelder, 2007). Vuilleumier (2005) considers a two-stage hypothesis of emotion processing where emotional significance is initially appraised within the amygdala before further processing. He proposes that some emotional stimuli, such as fearful expressions, “require less sensory evidence and proceed quicker than the more elaborate and prolonged cortical processing associated

with conscious awareness”. In further support of this hypothesis, Fear has been shown to be associated with early spatial attention (Armony, 2002; Vuilleumier & Schwartz, 2001) and increased arousal (Brosch, Sander, Pourtois, & Scherer, 2008; Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005), both of which are also associated with better performance on emotion memory tasks (Cahill & McGaugh, 1995; Compton, 2003; Deiber et al., 2007; Lang, Dhillon, & Dong, 1995; Machinskaya, Rozovskaya, Kurgansky, & Pechenkova, 2016; Missonnier et al., 2006).

As hypothesized for our second aim, there were significant differences in the magnitude of theta power for the varying time delays. Generally, at P8, O1, and O2 theta power was greatest in the 500 ms delay condition and also significantly greater during the 1000 ms delay compared to the 2000 ms delay. This pattern was consistent with Hypothesis 1 (Aim 2). Overall at the P7 electrode site, findings were similar, but there were also differences in theta power magnitude by emotion. This finding suggests that theta power declines linearly throughout the length of time required to maintain emotions in memory, as opposed to a persistent theta power magnitude throughout the delay. It is consistent with Brenner et al. (2014) which found that theta power was greater during earlier epochs (500-1000 ms) post-stimulus onset than later epochs (1000-2000 ms). This is also consistent with the theory of theta power synchronization as discussed in Klimesch et al. (1999), which proposes that event-related increases in theta synchronization are associated with the encoding of new information and is linked with long-term potentiation. Specifically in terms of theta desynchronization, the same review proposes that theta activity, following the encoding of new information desynchronizes over time. The results of a later study by Klimesch et al. in 2006 found that

desynchronization of theta activity during delay intervals was associated with episodic trace decay or difficulty maintaining memory during delay periods. The longer the delay, the more theta activity becomes desynchronized.

Similarly, Theta Power was greatest in the Early portion of the delay conditions. This phenomenon was also captured in a study by Raghavarchi et. al. 2001 that they described as the “cognitive ‘gating’ of a brain oscillation” during a working memory task. In their study, the amplitude of theta oscillations increased at the start of the trial, continued throughout the trial and delay period, and decreased sharply at the end. This gating phenomenon of theta power during working memory suggests that theta oscillations are important in organizing multi-item working memory (Raghavarchi et al., 2001; Sauseng, Griesmayr, Freunberger, & Klimesch, 2010; Tesche & Karhu, 2000). In the present study memory load was not measured and the tasks did not have explicit memory load differences. Theta Power as measured by the current study declines over time as hypothesized and as demonstrated in previous studies, yet there was no significant relationship between this decline and emotion memory performance as predicted. Thus, if Theta Power is a measurement of how well an emotional stimulus is maintained in memory, emotion memory does not depend on emotion memory maintenance. If theta power instead represents organization of multiple items in memory, this organizational property is not necessary for correct emotion memory performance. The increase in early theta activity following presentation of a visual emotional stimulus overlaps with the P1 and N170 event-related potentials and is associated with the initial encoding of the stimulus. These measurements of the robustness of encoding of the

stimulus appear to be more significantly related to memory performance in this task than maintenance of theta power throughout the delay.

At the P8, O1, and O2 electrode sites, theta power was greater during the Late latency than during the Middle latency of the 1000 ms and 2000 ms delay intervals. This indicates that at these sites theta magnitude was greatest immediately following the presentation of the first visual stimulus, declined during the middle of the delay interval, and increased again prior to the presentation of the second stimulus. This finding might be comparable to evidence of an anticipatory response that has been widely studied in alpha band oscillations (Haegens, Luther, & Jensen, 2012; Rohenkohl & Nobre, 2011; Worden, Foxe, Wang, & Simpson, n.d.). To our knowledge, there are no studies that replicate the findings of anticipatory theta activity. Further research is needed to test this hypothesis and further explain the increased theta oscillations during the Late latencies of the delay conditions.

As previously noted, there are several suggested changes to study design that would further clarify the current results. In order to explain the lack of a relationship between the various emotions and behavioral performance, it would serve to combine emotions into the categories of negative, positive, and neutral with the current dataset to replicate Brenner et. al. 2014. Additionally, future studies might benefit from measuring perceived or self-reported arousal of the varying emotions which may have a confounding effect on the current data. Analyzing arousal as a predictor of behavioral performance and further exploration of the relationship between arousal and emotion memory will benefit future research. The small size of the sample in this study made it

difficult to analyze the highly complex relationships between variables, future studies would benefit from larger sample sizes.

The current study confirms that robust encoding of a visual presentation of an emotional expression is required for correct identification of emotion. It is especially important that low-level features of faces, such as those represented by large P1 amplitudes in occipital regions, are effectively processed for in emotion memory tasks. Since Theta Power did not significantly predict behavioral performance for emotion memory in this study and may not represent maintenance of emotions in memory, further research is needed to determine the neurological processes associated with memory maintenance. Fearful faces are perceived and encoded better than other emotions and strong encoding of faces improves emotion memory performance. Poor encoding of facial emotion expressions is associated with poor emotion memory performance suggesting that improved emotion memory may require more intentional sustained attention during the initial encoding of the stimulus. The current study sought to provide further explanation of the mechanisms of facial emotion memory and to determine whether type of emotion, length of delay interval, or robustness of encoding the initial stimulus were associated with performance. Early and robust encoding of emotional expressions represented by P1 and N170 amplitudes predicts accurate facial emotion recognition and memory more so than theta power during the delay (or the maintenance of the emotion in memory). Emotion expressions influenced encoding of the stimulus in different ways with fearful expressions eliciting robust encoding. For this task, the length of the delay interval did not seem to influence emotion memory. The influence of encoding of emotional stimuli on correct identification of emotions in this task indicates

that robust initial perception of emotional expressions is necessary for accurate emotion memory.

The goal of the current study was to explore the mechanisms of facial emotion memory and clarify whether type of emotion, length of delay interval, or robustness of encoding the initial stimulus were associated with accurate facial emotion recognition and memory. Results confirmed that negative emotions and robust encoding of stimuli are strong influencers of effective emotion processing. Both P1 (at occipital sites) and N170 amplitudes (at parietal sites), differed by emotional expression. Larger P1 amplitudes at occipital electrode sites were the best predictors of correct matching of negative emotions such as Fear and Anger while correct matching of positive emotions (Happy Open and Happy Closed) were more consistently associated with P1 amplitudes at parietal sites. Correct matching of faces expressing Fear was predicted by ERPs and Theta Power more than any other emotion. Furthermore, P1 and N170 amplitudes and Total theta power all predicted behavioral performance to Fear stimuli in different ways during the three delay conditions. Theta Power analyses indicated that increased synchronization of activity in the theta frequency band following presentation of visual stimuli of facial emotions is associated with encoding the stimuli, but not necessarily maintaining them in working memory. Theta Power was greater during the shorter delay condition (500 ms) than in longer conditions (1000 and 2000 ms) and in the Early portion of the delay conditions, but smallest in the Middle portion of the delay conditions. Theta Power did not differ by emotional expression and results of Theta Power as a predictor of behavioral performance are inconclusive. Overall, results indicate the importance of the

robust encoding of a visual stimulus and early maintenance of emotional expressions for emotion memory.

This finding is consistent with previous literature in that larger P1 amplitudes are common to occipital sites and larger N170 amplitudes are common to parietal sites near the fusiform gyrus and increased P1 and N170 amplitudes have been found to be associated with improved behavioral performance (refs). The finding that P1 amplitudes are greater for positive emotions at the occipital sites suggests that the low-level features of happy facial expressions are particularly salient and prompt basic visual stimuli processing. In comparison, negative emotions were associated with larger N170 amplitudes at parietal sites which suggests that the static features of the face are prominent in these emotional expressions and direct visual attention to process the visual presentation of the face.

In partial support of Hypothesis 1 (Aim 1), our results indicated that both N170 and P1 amplitudes differ by emotion at the P7, P8, and O1 electrode sites. As expected, N170 amplitudes were greater in response to visual stimuli of negative emotions (Fear and Anger) compared to stimuli of positive and neutral emotions (Happy Open, Happy Closed, and Neutral). At the P8 electrode site, where most studies report emotion-modulated N170 effects (Brenner et al., 2014; Streit et al., 1999, 2001; Hermmann 2005), N170 amplitude in response to Anger was also significantly greater than N170 amplitude in response to Sad. These results are consistent with the theory that some expressions of negative emotion (Fear, Anger) inspire faster and more protective behavioral responses than positive emotions (Happy and Very Happy) for evolutionary advantages (Fox et al., 2000; Hansen & Hansen, 1988).

Inconsistent with our hypotheses, P1 amplitudes in occipital regions (O1 electrode site) were significantly greater in response to positive emotions than to neutral and negative emotions. Increased P1 amplitudes have been associated with selective and transient attention (Clark & Hillyard, 1996; Eimer, Holmes, & McGlone, 2003), encoding of low-level features of the visual stimulus and are especially large in response to faces compared to other visual stimuli. This could suggest that the low-level features of faces prompt increased attention to visual presentations of faces (Halgren, 2000; Herrmann, Ehlis, Ellgring, & Fallgatter, 2005; Rossion & Caharel, 2011). The finding of greater P1 amplitudes in occipital regions in response to positive emotions than negative emotions may represent more resources attending to positive emotions in early visual processing, that the low-level features of positive emotions are more salient than those of negative emotions, or it could be that both of these phenomena explain increased P1 in occipital sites. Future research that provides systematic study of the psychophysical properties of facial stimuli from negative and positive emotion categories would help to further clarify the interpretation of the current results.

Contrary to Hypothesis 2 (Aim 2), there were no differences in the magnitude of theta power for emotional expressions. This finding is inconsistent with findings from Brenner et al. (2014) which found that larger theta power was associated with negative emotion expressions compared to positive and neutral emotions. There are two likely explanations for these disparate findings. First, it is possible that, contrary to Brenner et al. (2014), negative emotions do not pull more neural resources than positive ones in order to complete this memory task. Second, it is likely that previous results averaged both the impact of the emotion with that of arousal. Brenner et al. (2014) combined theta

power from fearful, angry, and sad faces to create the response to negative facial emotions, and combined the two types of happy expressions to create the response to positive facial emotions. This had the result of combining varying levels of arousal associated with each emotion into one broad valence variable. The current study examined responses to each emotional expression separately. Since anger and fear are associated with higher levels of arousal than sadness (Balconi & Pozzoli, 2009) it is possible that the combination of valence and arousal across multiple emotions is needed to affect theta power during the delay. Therefore, the differences in findings from the two related studies suggests a complex combination of arousal and valence. This explanation of the apparently conflicting results is consistent with Almeida et al. (2016). Almeida and colleagues found that regardless of emotional category, N170 amplitudes were found to be significantly influenced by perceived arousal. In fact, they propose that differences in ERP amplitudes by emotions are a result of increases in power (alpha, β , and theta) that follow from the perceived emotional arousal of the stimuli. Additionally, emotional valence has been found to affect memory performance such that emotional stimuli that are more arousing are associated with improved memory as compared to less arousing emotional stimuli (Cahill, 1995; Lang 2009). Future studies might consider comparing neutral expressions to the group of positive emotions and the group of negative emotions to provide further clarification of the relationship between theta power and emotion memory.

Theta Power did not distinguish emotions nor did it consistently predict correct matching of emotional expressions between stimulus 1 and 2, as expected. Rather, ERPs and Theta Power predicted behavioral performance most consistently for faces expressing

Fear such that larger P1 amplitudes at occipital sites, and not N170 amplitudes at parietal sites as hypothesized, predicted correct matching of facial expressions. This finding is consistent with many studies that identify earlier ERPs to fearful expressions than other emotions and before the encoding of faces as indicated by the N170 peak (Adolphs et al., 2001; Batty & Taylor, 2003; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005; van Heijnsbergen, Meeren, Grèzes, & de Gelder, 2007). Vuilleumier (2005) considers a two-stage hypothesis of emotion processing where emotional significance is initially appraised within the amygdala before further processing. He proposes that some emotional stimuli, such as fearful expressions, “require less sensory evidence and proceed quicker than the more elaborate and prolonged cortical processing associated with conscious awareness”. In further support of this hypothesis, Fear has been shown to be associated with early spatial attention (Armony, 2002; Vuilleumier & Schwartz, 2001) and increased arousal (Brosch, Sander, Pourtois, & Scherer, 2008; Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005), both of which are also associated with better performance on emotion memory tasks (Cahill & McGaugh, 1995; Compton, 2003; Deiber et al., 2007; Lang, Dhillon, & Dong, 1995; Machinskaya, Rozovskaya, Kurgansky, & Pechenkova, 2016; Missonnier et al., 2006).

As hypothesized for our second aim, there were significant differences in the magnitude of theta power for the varying time delays. Generally, at P8, O1, and O2 theta power was greatest in the 500 ms delay condition and also significantly greater during the 1000 ms delay compared to the 2000 ms delay. This pattern was consistent with Hypothesis 1 (Aim 2). Overall at the P7 electrode site, findings were similar, but there were also differences in theta power magnitude by emotion. This finding suggests that

theta power declines linearly throughout the length of time required to maintain emotions in memory, as opposed to a persistent theta power magnitude throughout the delay. It is consistent with Brenner et al. (2014) which found that theta power was greater during earlier epochs (500-1000 ms) post-stimulus onset than later epochs (1000-2000 ms). This is also consistent with the theory of theta power synchronization as discussed in Klimesch et al. (1999), which proposes that event-related increases in theta synchronization are associated with the encoding of new information and is linked with long-term potentiation. Specifically in terms of theta desynchronization, the same review proposes that theta activity, following the encoding of new information desynchronizes over time. The results of a later study by Klimesch et al. in 2006 found that desynchronization of theta activity during delay intervals was associated with episodic trace decay or difficulty maintaining memory during delay periods. The longer the delay, the more theta activity becomes desynchronized.

Similarly, Theta Power was greatest in the Early portion of the delay conditions. This phenomenon was also captured in a study by Raghavarchi et. al. 2001 that they described as the “cognitive ‘gating’ of a brain oscillation” during a working memory task. In their study, the amplitude of theta oscillations increased at the start of the trial, continued throughout the trial and delay period, and decreased sharply at the end. This gating phenomenon of theta power during working memory suggests that theta oscillations are important in organizing multi-item working memory (Raghavarchi et al., 2001; Sauseng, Griesmayr, Freunberger, & Klimesch, 2010; Tesche & Karhu, 2000). In the present study memory load was not measured and the tasks did not have explicit memory load differences. Theta Power as measured by the current study declines over

time as hypothesized and as demonstrated in previous studies, yet there was no significant relationship between this decline and emotion memory performance as predicted. Thus, if Theta Power is a measurement of how well an emotional stimulus is maintained in memory, emotion memory does not depend on emotion memory maintenance. If theta power instead represents organization of multiple items in memory, this organizational property is not necessary for correct emotion memory performance. The increase in early theta activity following presentation of a visual emotional stimulus overlaps with the P1 and N170 event-related potentials and is associated with the initial encoding of the stimulus. These measurements of the robustness of encoding of the stimulus appear to be more significantly related to memory performance in this task than maintenance of theta power throughout the delay.

At the P8, O1, and O2 electrode sites, theta power was greater during the Late latency than during the Middle latency of the 1000 ms and 2000 ms delay intervals indicating that theta magnitude was greatest immediately following the presentation of the first visual stimulus and then declined, but eventually increased again prior to the presentation of the second stimulus. This finding might be evidence of an anticipatory response that has been widely studied in alpha band oscillations, but has not been observed in the theta band until now. Interestingly, this phenomenon was not observed during the 500 ms delay interval possibly because....

As previously noted, there are several suggested changes to study design that would further clarify the current results. In order to explain the lack of a relationship between the various emotions and behavioral performance, it would serve to combine emotions into the categories of negative, positive, and neutral with the current dataset to

replicate Brenner et. al. 2014. Additionally, future studies might benefit from measuring perceived or self-reported arousal of the varying emotions which may have a confounding effect on the current data. Analyzing arousal as a predictor of behavioral performance and further exploration of the relationship between arousal and emotion memory will benefit future research. The small size of the sample in this study made it difficult to analyze the highly complex relationships between variables, future studies would benefit from larger sample sizes.

The current study confirms that robust encoding of a visual presentation of an emotional expression is required for correct identification of emotion. It is especially important that low-level features of faces, such as those represented by large P1 amplitudes in occipital regions, are effectively processed for in emotion memory tasks. Since Theta Power did not significantly predict behavioral performance for emotion memory in this study and may not represent maintenance of emotions in memory, further research is needed to determine the neurological processes associated with memory maintenance. Fearful faces are perceived and encoded better than other emotions and strong encoding of faces improves emotion memory performance. Poor encoding of facial emotion expressions is associated with poor emotion memory performance suggesting that improved emotion memory may require more intentional sustained attention during the initial encoding of the stimulus. The current study sought to provide further explanation of the mechanisms of facial emotion memory and to determine whether type of emotion, length of delay interval, or robustness of encoding the initial stimulus were associated with performance. Early and robust encoding of emotional expressions represented by P1 and N170 amplitudes predicts accurate facial emotion

recognition and memory more so than theta power during the delay (or the maintenance of the emotion in memory). Emotion expressions influenced encoding of the stimulus in different ways with fearful expressions eliciting robust encoding. For this task, the length of the delay interval did not seem to influence emotion memory. The influence of encoding of emotional stimuli on correct identification of emotions in this task indicates that robust initial perception of emotional expressions is necessary for accurate emotion memory.

REFERENCES

- Adolphs, R. (2003). Cognitive neuroscience: Cognitive neuroscience of human social behaviour. *Nature Reviews Neuroscience*, 4(3), 165–178.
<https://doi.org/10.1038/nrn1056>
- Adolphs, R., Kawasaki, H., Kaufman, O., Damasio, H., Damasio, A. R., Granner, M., ... Howard, M. A. (2001). Single-neuron responses to emotional visual stimuli recorded in human ventral prefrontal cortex. *Nature Neuroscience*, 4(1), 15–16.
<https://doi.org/10.1038/82850>
- Aftanas, L. I., Varlamov, A. A., Pavlov, S. V., Makhnev, V. P., & Reva, N. V. (2002). Time-dependent cortical asymmetries induced by emotional arousal: EEG analysis of event-related synchronization and desynchronization in individually defined frequency bands. *International Journal of Psychophysiology*, 44(1), 67–82. [https://doi.org/10.1016/S0167-8760\(01\)00194-5](https://doi.org/10.1016/S0167-8760(01)00194-5)
- Aftanas, L. I., Varlamov, A. A., Pavlov, S. V., Makhnev, V. P., & Reva, N. V. (2001). Affective picture processing: event-related synchronization within individually defined human theta band is modulated by valence dimension. *Neuroscience Letters* (Vol. 303). [https://doi.org/10.1016/S0304-3940\(01\)01703-7](https://doi.org/10.1016/S0304-3940(01)01703-7)
- Aftanas, L. I., Varlamov, A. A., Reva, N. V., & Pavlov, S. V. (2003). Disruption of early event-related theta synchronization of human EEG in alexithymics viewing affective pictures. *Neuroscience Letters* (Vol. 340). [https://doi.org/10.1016/S0304-3940\(03\)00070-3](https://doi.org/10.1016/S0304-3940(03)00070-3)
- Aiken, L., & West, S. (1991). *Multiple Regression: testing and interpreting interactions*. Newbury Park, CA: SAGE Publications.
- Allison, T., Ginter, H., McCarthy, G., Nobre, A. C., Puce, A., Luby, M., & Spencer, D. D. (1994). Face recognition in human extrastriate cortex. *Journal of Neurophysiology*, 71(2), 821–5. Retrieved from <http://0-jn.physiology.org.catalog.llu.edu/content/71/2/821.abstract>
- Armony, J. (2002). Modulation of spatial attention by fear-conditioned stimuli: an event-related fMRI study. *Neuropsychologia*, 40(7), 817–826.
[https://doi.org/10.1016/S0028-3932\(01\)00178-6](https://doi.org/10.1016/S0028-3932(01)00178-6)
- Balconi, M., & Lucchiari, C. (2006). *EEG correlates (event-related desynchronization) of emotional face elaboration: A temporal analysis*. *Neuroscience Letters* (Vol. 392). <https://doi.org/10.1016/j.neulet.2005.09.004>
- Balconi, M., & Pozzoli, U. (2003). Face-selective processing and the effect of pleasant and unpleasant emotional expressions on ERP correlates. *International Journal of Psychophysiology*, 49(1), 67–74. [https://doi.org/10.1016/S0167-8760\(03\)00081-3](https://doi.org/10.1016/S0167-8760(03)00081-3)
- Balconi, M., & Pozzoli, U. (2009). Arousal effect on emotional face comprehension:

- Frequency band changes in different time intervals. *Physiology & Behavior*, 97(3), 455–462. <https://doi.org/10.1016/j.physbeh.2009.03.023>
- Başar, E. ro., Schürmann, M. arti., & Sakowitz, O. live. (2001). The selectively distributed theta system: functions. *International Journal of Psychophysiology*, 39(2), 197–212. [https://doi.org/10.1016/S0167-8760\(00\)00141-0](https://doi.org/10.1016/S0167-8760(00)00141-0)
- Batty, M., & Taylor, M. J. (2003). Early processing of the six basic facial emotional expressions. *Cognitive Brain Research*, 17(3), 613–620. [https://doi.org/10.1016/S0926-6410\(03\)00174-5](https://doi.org/10.1016/S0926-6410(03)00174-5)
- Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological Studies of Face Perception in Humans. *Journal of Cognitive Neuroscience*, 8(6), 551–565. <https://doi.org/10.1162/jocn.1996.8.6.551>
- Benton, A. L. (1980). The neuropsychology of facial recognition. *The American Psychologist*, 35(2), 176–186. <https://doi.org/10.1037/0003-066X.35.2.176>
- Bernstein, M., Oron, J., Sadeh, B., & Yovel, G. (2014). An Integrated Face–Body Representation in the Fusiform Gyrus but Not the Lateral Occipital Cortex. *Journal of Cognitive Neuroscience*, 26(11), 2469–2478. https://doi.org/10.1162/jocn_a_00639
- Blau, V. C., Maurer, U., Tottenham, N., McCandliss, B. D., Batty, M., Taylor, M., ... Amaral, D. (2007). The face-specific N170 component is modulated by emotional facial expression. *Behavioral and Brain Functions*, 3(1), 7. <https://doi.org/10.1186/1744-9081-3-7>
- Brenner, C. A., Rumak, S. P., & Burns, A. M. N. (2016). Facial emotion memory in schizophrenia: From encoding to maintenance-related EEG. *Clinical Neurophysiology*, 127(2), 1366–1373. <https://doi.org/10.1016/j.clinph.2015.10.061>
- Brenner, C. A., Rumak, S. P., Burns, A. M. N., & Kieffaber, P. D. (2014). The role of encoding and attention in facial emotion memory: An EEG investigation. <https://doi.org/10.1016/j.ijpsycho.2014.06.006>
- Brenner, C. A., Sporns, O., Lysaker, P., & O'Donnell, B. (2003). EEG synchronization to modulated auditory tones in schizophrenia, schizoaffective disorder, and schizotypal personality disorder. *American Journal of Psychiatry*, 160(12), 2238–2240.
- Brosch, T., Sander, D., Pourtois, G., & Scherer, K. R. (2008). Beyond Fear: Rapid Spatial Orienting Toward Positive Emotional Stimuli. *Psychological Science*, 19(4), 362–370. <https://doi.org/10.1111/j.1467-9280.2008.02094.x>
- Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology*, 77, 305–327.

- Caharel, S., Courtaf, N., Bernard, C., Lalonde, R., & Rebaï, M. (2005). *Familiarity and emotional expression influence an early stage of face processing: An electrophysiological study. Brain and Cognition* (Vol. 59).
<https://doi.org/10.1016/j.bandc.2005.05.005>
- Cahill, L., & McGaugh, J. L. (1995). A Novel Demonstration of Enhanced Memory Associated with Emotional Arousal. *Consciousness and Cognition*, 4(4), 410–421. <https://doi.org/10.1006/ccog.1995.1048>
- Chang, Y.-C., & Huang, S.-L. (2012). The influence of attention levels on psychophysiological responses. *International Journal of Psychophysiology*, 86(1), 39–47. <https://doi.org/10.1016/j.ijpsycho.2012.09.001>
- Clark, V. P., & Hillyard, S. A. (1996). Spatial Selective Attention Affects Early Extrastriate But Not Striate Components of the Visual Evoked Potential. *Journal of Cognitive Neuroscience*, 8(5), 387–402.
<https://doi.org/10.1162/jocn.1996.8.5.387>
- Compton, R. J. (2003). The Interface Between Emotion and Attention: A Review of Evidence from Psychology and Neuroscience. *Behavioral and Cognitive Neuroscience Reviews*, 2(2), 115–129.
<https://doi.org/10.1177/1534582303002002003>
- Csukly, G., Stefanics, G., Komlósi, S., Czigler, I., & Czobor, P. (2014). Event-related theta synchronization predicts deficit in facial affect recognition in schizophrenia. *Journal of Abnormal Psychology*, 123(1), 178–189.
<https://doi.org/10.1037/a0035793>
- Deiber, M.-P., Missonnier, P., Bertrand, O., Gold, G., Fazio-Costa, L., Ibañez, V., & Giannakopoulos, P. (2007). Distinction between Perceptual and Attentional Processing in Working Memory Tasks: A Study of Phase-locked and Induced Oscillatory Brain Dynamics. *Journal of Cognitive Neuroscience*, 19(1), 158–172.
<https://doi.org/10.1162/jocn.2007.19.1.158>
- Eimer, M. C., & McCarthy, R. A. (1999). Prosopagnosia and structural encoding of faces: Evidence from event-related potentials. *NeuroReport*, 10, 255–259.
- Eimer, M., Holmes, A., & McGlone, F. P. (2003). The role of spatial attention in the processing of facial expression: An ERP study of rapid brain responses to six basic emotions. *Cognitive, Affective, & Behavioral Neuroscience*, 3(2), 97–110.
<https://doi.org/10.3758/CABN.3.2.97>
- Engell, A. D., & Haxby, J. V. (2007). Facial expression and gaze-direction in human superior temporal sulcus. *Neuropsychologia*, 45(14), 3234–3241.
<https://doi.org/10.1016/j.neuropsychologia.2007.06.022>
- Field, T., Woodson, R., Greenberg, R., & Cohen, D. (1982). Discrimination and imitation of facial expression by neonates. *Science*, 218(4568).

- Fox, E., Lester, V., Russo, R., Bowles, R. J., Pichler, A., & Dutton, K. (2000). Facial Expressions of Emotion: Are Angry Faces Detected More Efficiently? *Cognition & Emotion*, *14*(1), 61–92. <https://doi.org/10.1080/026999300378996>
- George, N., Dolan, R. J., Fink, G. R., Baylis, G. C., Russell, C., & Driver, J. (1999). Contrast polarity and face recognition in the human fusiform gyrus. *Nature Neuroscience*, *2*(6), 574–580.
- George, N., Driver, J., & Dolan, R. J. (2001). Seen gaze-direction modulates fusiform activity and its coupling with other brain areas during face processing. *NeuroImage*, *13*(6 Pt 1), 1102–1112. <https://doi.org/10.1006/nimg.2001.0769>
- George, N., Evans, J., Fiori, N., Davidoff, J., & Renault, B. (1996). Brain events related to normal and moderately scrambled faces. *Cognitive Brain Research*, *4*(2), 65–76. [https://doi.org/10.1016/0926-6410\(95\)00045-3](https://doi.org/10.1016/0926-6410(95)00045-3)
- González-Roldan, A. M., Martínez-Jauand, M., Muñoz-García, M. A., Sitges, C., Cifre, I., & Montoya, P. (2011). Temporal dissociation in the brain processing of pain and anger faces with different intensities of emotional expression. *Pain*, *152*(4), 853–859. <https://doi.org/10.1016/j.pain.2010.12.037>
- Graham, R., & LaBar, K. S. (2012). Neurocognitive mechanisms of gaze-expression interactions in face processing and social attention. *Neuropsychologia*, *50*(5), 553–566. <https://doi.org/10.1016/j.neuropsychologia.2012.01.019>
- Gratton, G., Coles, M. G. ., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, *55*(4), 468–484. [https://doi.org/10.1016/0013-4694\(83\)90135-9](https://doi.org/10.1016/0013-4694(83)90135-9)
- Güntekin, B., & Başar, E. (2009). Facial affect manifested by multiple oscillations. *International Journal of Psychophysiology*, *71*(1), 31–36. <https://doi.org/10.1016/j.ijpsycho.2008.07.019>
- Halgren, E. (2000). Cognitive Response Profile of the Human Fusiform Face Area as Determined by MEG. *Cerebral Cortex*, *10*(1), 69–81. <https://doi.org/10.1093/cercor/10.1.69>
- Halgren, E., Baudena, P., Heit, G., Clarke, M., & Marinkovic, K. (1994). Spatio-temporal stages in face and word processing. 1. Depth recorded potentials in the human occipital and parietal lobes. *Journal of Physiology-Paris*, *88*(1), 1–50. [https://doi.org/10.1016/0928-4257\(94\)90092-2](https://doi.org/10.1016/0928-4257(94)90092-2)
- Halgren, E., Dale, A. M., Sereno, M. I., Tootell, R. B. H., Marinkovic, K., & Rosen, B. R. (1999). Location of human face-selective cortex with respect to retinotopic areas. *Human Brain Mapping*, *7*(1), 29–37. [https://doi.org/10.1002/\(SICI\)1097-0193\(1999\)7:1<29::AID-HBM3>3.0.CO;2-R](https://doi.org/10.1002/(SICI)1097-0193(1999)7:1<29::AID-HBM3>3.0.CO;2-R)
- Hansen, C. H., & Hansen, R. D. (1988). Finding the face in the crowd: An anger

- superiority effect. *Journal of Personality and Social Psychology*, 54(6), 917–924.
<https://doi.org/10.1037/0022-3514.54.6.917>
- Haxby, J. V., Gobbini, M. I., Furey, M. L., Ishai, A., Schouten, J. L., Pietrini, P., ... Gauthier, I. (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science (New York, N.Y.)*, 293(5539), 2425–30.
<https://doi.org/10.1126/science.1063736>
- Haxby, J. V., Ungerleider, L. G., Horwitz, B., Maisog, J. M., Rapoport, S. I., & Grady, C. L. (1996). Face encoding and recognition in the human brain (positron emission tomography/cerebral blood flow). *Neurobiology*, 93, 922–927.
- Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, 4(6), 223–233.
[https://doi.org/10.1016/S1364-6613\(00\)01482-0](https://doi.org/10.1016/S1364-6613(00)01482-0)
- Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2002). Human neural systems for face recognition and social communication. *Biological Psychiatry*, 51(1), 59–67.
[https://doi.org/10.1016/S0006-3223\(01\)01330-0](https://doi.org/10.1016/S0006-3223(01)01330-0)
- Hayes, A. F. (2013). *Introduction to Mediation, Moderation and Conditional Process Analysis*. New York: Guilford Press.
- Hecaen, H., Angelergues, R., Charcot, J. M., Wilbrand, H., Millian, G., Hoff, H., and Pötzl, O., ... Cibis, P., and Bay, E. (1962). Agnosia for Faces (Prosopagnosia). *Archives of Neurology*, 7(2), 92–100.
<https://doi.org/10.1001/archneur.1962.04210020014002>
- Heinze, H.-J., Luck, S. J., Munte, T. F., Gös, A., Mangun, G. R., & Hillyard, S. A. (1994). Attention to adjacent and separate positions in space: An electrophysiological analysis. *Perception & Psychophysics*, 56(1), 42–52.
<https://doi.org/10.3758/BF03211689>
- Herrmann, M. J., Ehlis, A.-C., Ellgring, H., & Fallgatter, A. J. (2005). Early stages (P100) of face perception in humans as measured with event-related potentials (ERPs). *Journal of Neural Transmission (Vienna, Austria : 1996)*, 112(8), 1073–81.
<https://doi.org/10.1007/s00702-004-0250-8>
- Hoffman, K. L., Gothard, K. M., Schmid, M. C., & Logothetis, N. K. (2007). *Facial-Expression and Gaze-Selective Responses in the Monkey Amygdala*. *Current Biology* (Vol. 17). <https://doi.org/10.1016/j.cub.2007.03.040>
- Jemel, B., Schuller, A.-M., Cheref-Khan, Y., Goffaux, V., Crommelinck, M., & Bruyer, R. (2003). Stepwise emergence of the face-sensitive N170 event-related potential component. *Neuroreport*, 14(16), 2035–2039. <https://doi.org/10.1097/00001756-200311140-00006>
- Jensen, O., & Tesche, C. D. (2002). Frontal theta activity in humans increases with

- memory load in a working memory task. *European Journal of Neuroscience*, 15(8), 1395–1399. <https://doi.org/10.1046/j.1460-9568.2002.01975.x>
- Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: a module in human extrastriate cortex specialized for face perception. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, 17(11), 4302–11. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/9151747>
- Kim, D.-W., Shim, M., Song, M. J., Im, C.-H., & Lee, S.-H. (2015). Early visual processing deficits in patients with schizophrenia during spatial frequency-dependent facial affect processing. *Schizophrenia Research*, 161(2), 314–321. <https://doi.org/10.1016/j.schres.2014.12.020>
- Kim, J. J., Andreasen, N. C., O'leary, D. S., Wiser, A. K., Boles Ponto, L. L., Watkins, G. L., & Hichwa, R. D. (1999). Direct comparison of the neural substrates of recognition memory for words and faces. *Brain*, 122, 1069–1083.
- Klimesch, W., Hanslmayr, S., Sauseng, P., Gruber, W., Brozinsky, C. J., Kroll, N. E. A., ... Doppelmayr, M. (2006). Oscillatory EEG correlates of episodic trace decay. *Cerebral Cortex (New York, N.Y. : 1991)*, 16(2), 280–90. <https://doi.org/10.1093/cercor/bhi107>
- Knyazev, G. G., Slobodskoj-Plusnin, J. Y., & Bocharov, A. V. (2009). Event-related delta and theta synchronization during explicit and implicit emotion processing. *Neuroscience*, 164(4), 1588–1600. <https://doi.org/10.1016/j.neuroscience.2009.09.057>
- Krolak-Salmon, P., Fischer, C., Vighetto, A., & Mauguiere, F. (2001). Processing of facial emotion expression: Spatio-temporal data as assessed by scalp event-related potentials. *European Journal of Neuroscience*.
- Krombholz, A., Schaefer, F., & Boucsein, W. (2007). Modification of N170 by different emotional expression of schematic faces. *Biological Psychology*, 76(3), 156–162. <https://doi.org/10.1016/j.biopsycho.2007.07.004>
- Labouvie-Vief, G., DeVoe, M., & Bulka, D. (1989). Speaking about feelings: Conceptions of emotion across the life span. *Psychology and Aging*, 4(4), 425–437. <https://doi.org/10.1037/0882-7974.4.4.425>
- Lang, A., Dhillon, K., & Dong, Q. (1995). The effects of emotional arousal and valence on television viewers' cognitive capacity and memory. *Journal of Broadcasting & Electronic Media*, 39(3), 313–327. <https://doi.org/10.1080/08838159509364309>
- Linkenkaer-Hansen, K., Palva, J. M., Sams, M., Hietanen, J. K., Aronen, H. J., & Ilmoniemi, R. J. (1998). Face-selective processing in human extrastriate cortex around 120 ms after stimulus onset revealed by magneto- and electroencephalography. *Neuroscience Letters*, 253(3), 147–150. [https://doi.org/10.1016/S0304-3940\(98\)00586-2](https://doi.org/10.1016/S0304-3940(98)00586-2)

- Machinskaya, R. I., Rozovskaya, R. I., Kurgansky, A. V., & Pechenkova, E. V. (2016). Cortical functional connectivity during the retention of affective pictures in working memory: EEG-source theta coherence analysis. *Human Physiology*, *42*(3), 279–293. <https://doi.org/10.1134/S0362119716020122>
- Mangun, G. R. (1995). Neural mechanisms of visual selective attention. *Psychophysiology*, *32*(1), 4–18. <https://doi.org/10.1111/j.1469-8986.1995.tb03400.x>
- McCarthy, G., & Nobre, A. C. (1993). Modulation of semantic processing by spatial selective attention. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *88*(3), 210–219. [https://doi.org/10.1016/0168-5597\(93\)90005-A](https://doi.org/10.1016/0168-5597(93)90005-A)
- McCarthy, G., Puce, A., Gore, J. C., & Allison, T. (1997). Face-Specific Processing in the Human Fusiform Gyrus. *Journal of Cognitive Neuroscience*, *9*(5), 605–610. <https://doi.org/10.1162/jocn.1997.9.5.605>
- Meadows, J. C. (1974). The anatomical basis of prosopagnosia. *Journal of Neurology, Neurosurgery, and Psychiatry*, *37*(5), 489–501. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/4209556>
- Missonnier, P., Deiber, M.-P., Gold, G., Millet, P., Gex-Fabry Pun, M., Fazio-Costa, L., ... Ibáñez, V. (2006). Frontal theta event-related synchronization: comparison of directed attention and working memory load effects. *Journal of Neural Transmission*, *113*(10), 1477–1486. <https://doi.org/10.1007/s00702-005-0443-9>
- Morrison, R. L., Bellack, A. S., & Mueser, K. T. (1988). Deficits in Facial-affect Recognition and Schizophrenia. *Schizophrenia Bulletin*, *14*(1), 67–83. <https://doi.org/10.1093/schbul/14.1.67>
- Morton, K. R., Worthley, J. S., Nitch, S. R., Lamberton, H. H., Loo, L. K., & Testerman, J. K. (2000). Integration of Cognition and Emotion: A Postformal Operations Model of Physician-Patient Interaction. *Journal of Adult Development*, *7*(3), 151–160. <https://doi.org/10.1023/A:1009542229631>
- Münte, T. F., Brack, M., Grootheer, O., Wieringa, B. M., Matzke, M., & Johannes, S. (1998). Brain potentials reveal the timing of face identity and expression judgments. *Neuroscience Research*, *30*(1), 25–34. [https://doi.org/10.1016/S0168-0102\(97\)00118-1](https://doi.org/10.1016/S0168-0102(97)00118-1)
- Nakao, T., Bai, Y., Nashiwa, H., & Northoff, G. (2013). Resting-state EEG power predicts conflict-related brain activity in internally guided but not in externally guided decision-making. *NeuroImage*, *66*, 9–21. <https://doi.org/10.1016/j.neuroimage.2012.10.034>
- Pascalis, O., & Bachevalier, J. (1998). Face recognition in primates : a cross - species study. *Behavioural Processes*, *43*, 87–96. <https://doi.org/10.1016/S0376->

- Perrett, D., Rolls, E., & Caan, W. (1982). Visual neurones responsive to faces in the monkey temporal cortex. *Experimental Brain Research*. Retrieved from <http://link.springer.com/article/10.1007/BF00239352>
- Perrett, D., Smith, P., & Potter, D. (1985). Visual cells in the temporal cortex sensitive to face view and gaze direction. *Of the Royal ...*. Retrieved from <http://rspb.royalsocietypublishing.org/content/royprsb/223/1232/293.full.pdf>
- Pourtois, G., Dan, E. S., Grandjean, D., Sander, D., & Vuilleumier, P. (2005). Enhanced extrastriate visual response to bandpass spatial frequency filtered fearful faces: Time course and topographic evoked-potentials mapping. *Human Brain Mapping*, 26(1), 65–79. <https://doi.org/10.1002/hbm.20130>
- Pourtois, G., Sander, D., Andres, M., Grandjean, D., Reveret, L., Olivier, E., & Vuilleumier, P. (2004). Dissociable roles of the human somatosensory and superior temporal cortices for processing social face signals. *European Journal of Neuroscience*, 20(12), 3507–3515. <https://doi.org/10.1111/j.1460-9568.2004.03794.x>
- Puce, A., Allison, T., Asgari, M., Gore, J. C., & McCarthy, G. (1996). Differential Sensitivity of Human Visual Cortex to Faces, Letterstrings, and Textures: A Functional Magnetic Resonance Imaging Study. *Journal of Neuroscience*, 16(16).
- Puce, A., Allison, T., Bentin, S., Gore, J. C., & McCarthy, G. (1998). Temporal cortex activation in humans viewing eye and mouth movements. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, 18(6), 2188–99. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/9482803>
- Raghavarchi, S., Kahana, M. J., Rizzuto, D. S., Caplan, J. B., Kirschen, M. P., Bourgeois, B., ... Lisman, J. E. (2001). Gating of human theta oscillations by a working memory task. *Journal of Neuroscience*, 21(9), 3175–3183. <https://doi.org/10.1002/hipo.450050110>
- Rolls, E. (1984). Neurons in the cortex of the temporal lobe and in the amygdala of the monkey with responses selective for faces. *Human Neurobiology*. Retrieved from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.352.4216&rep=rep1&type=pdf>
- Rossion, B., & Caharel, S. (2011). ERP evidence for the speed of face categorization in the human brain: Disentangling the contribution of low-level visual cues from face perception. *Vision Research*, 51(12), 1297–1311. <https://doi.org/10.1016/j.visres.2011.04.003>
- Rossion, B., Campanella, S., Gomez, C. ., Delinte, A., Debatisse, D., Liard, L., ... Guerit, J.-M. (1999). Task modulation of brain activity related to familiar and unfamiliar face processing: an ERP study. *Clinical Neurophysiology*, 110(3), 449–462.

[https://doi.org/10.1016/S1388-2457\(98\)00037-6](https://doi.org/10.1016/S1388-2457(98)00037-6)

- Rousselet, G. A., Husk, J. S., Bennett, P. J., Sekuler, A. B., M., E., M., E., ... S., W. (2005). Spatial scaling factors explain eccentricity effects on face ERPs. *Journal of Vision*, 5(10), 1. <https://doi.org/10.1167/5.10.1>
- Sabatinelli, D., Bradley, M. M., Fitzsimmons, J. R., & Lang, P. J. (2005). Parallel amygdala and inferotemporal activation reflect emotional intensity and fear relevance. *NeuroImage*, 24(4), 1265–1270. <https://doi.org/10.1016/j.neuroimage.2004.12.015>
- Salillas, E., El Yagoubi, R., & Semenza, C. (2008). Sensory and cognitive processes of shifts of spatial attention induced by numbers: An ERP study. *Cortex*, 44(4), 406–413. <https://doi.org/10.1016/j.cortex.2007.08.006>
- Sams, M., Hietanen, J. ., Hari, R., Ilmoniemi, R. ., & Lounasmaa, O. . (1997). Face-specific responses from the human inferior occipito-temporal cortex. *Neuroscience*, 77(1), 49–55. [https://doi.org/10.1016/S0306-4522\(96\)00419-8](https://doi.org/10.1016/S0306-4522(96)00419-8)
- Sarnthein, J., Petsche, H., Rappelsberger, P., Shaw, G. L., & von Stein, A. (1998). Synchronization between prefrontal and posterior association cortex during human working memory. *Proceedings of the National Academy of Sciences of the United States of America*, 95(12), 7092–6. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/9618544>
- Sato, W., Kochiyama, T., Yoshikawa, S., & Matsumura, M. (2001). Emotional expression boosts early visual processing of the face: ERP recording and its decomposition by independent component analysis. *COGNITIVE NEUROSCIENCE AND NEUROPSYCHOLOGY NEUROREPORT*, 12(4), 959–4965.
- Sauseng, P., Griesmayr, B., Freunberger, R., & Klimesch, W. (2010). Control mechanisms in working memory: A possible function of EEG theta oscillations. *Neuroscience and Biobehavioral Reviews*. <https://doi.org/10.1016/j.neubiorev.2009.12.006>
- Seeck, M., Mainwaring, N., Ives, J., Blume, H., Dubuisson, D., Cosgrove, R., ... Schomer, D. L. (1993). Differential neural activity in the human temporal lobe evoked by faces of family members and friends. *Annals of Neurology*, 34(3), 369–72. <https://doi.org/10.1002/ana.410340311>
- Sergent, J., Ohta, S., & MacDonald, B. (1992). Functional neuroanatomy of face and object processing: A positron emission tomography study. *Brain*, 115(1), 15–36.
- Straube, T., Langohr, B., Schmidt, S., Mentzel, H.-J., & Miltner, W. H. R. (2010). Increased amygdala activation to averted versus direct gaze in humans is independent of valence of facial expression. *NeuroImage*, 49(3), 2680–2686. <https://doi.org/10.1016/j.neuroimage.2009.10.074>

- Streit, M., Ioannides, A. A., Liu, L., Wölwer, W., Dammers, J., Gross, J., ... Müller-Gärtner, H.-W. (1999). Neurophysiological correlates of the recognition of facial expressions of emotion as revealed by magnetoencephalography. *Cognitive Brain Research*, 7(4), 481–491. [https://doi.org/10.1016/S0926-6410\(98\)00048-2](https://doi.org/10.1016/S0926-6410(98)00048-2)
- Streit, M., Wölwer, W., Brinkmeyer, J., Ihl, R., & Gaebel, W. (2001). EEG-correlates of facial affect recognition and categorisation of blurred faces in schizophrenic patients and healthy volunteers. *Schizophrenia Research*, 49(1–2), 145–155. [https://doi.org/10.1016/S0920-9964\(00\)00041-4](https://doi.org/10.1016/S0920-9964(00)00041-4)
- Sur, S., & Sinha, V. K. (2009). Event-related potential: An overview. *Industrial Psychiatry Journal*, 18(1), 70–3. <https://doi.org/10.4103/0972-6748.57865>
- Tanskanen, T., Näsänen, R., Montez, T., Päälyssaho, J., & Hari, R. (2005). Face recognition and cortical responses show similar sensitivity to noise spatial frequency. *Cerebral Cortex (New York, N.Y. : 1991)*, 15(5), 526–34. <https://doi.org/10.1093/cercor/bhh152>
- Tesche, C. D., & Karhu, J. (2000). Theta oscillations index human hippocampal activation during a working memory task. *Proceedings of the National Academy of Sciences of the United States of America*, 97(2), 919–24. <https://doi.org/10.1073/pnas.97.2.919>
- Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., ... Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, 168(3), 242–249. <https://doi.org/10.1016/j.psychres.2008.05.006>
- Tsoneva, T., Baldo, D., Lema, V., & Garcia-Molina, G. (2011). EEG-rhythm dynamics during a 2-back working memory task and performance. In *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*. <https://doi.org/10.1109/IEMBS.2011.6090952>
- van Heijnsbergen, C. C. R. J., Meeren, H. K. M., Grèzes, J., & de Gelder, B. (2007). Rapid detection of fear in body expressions, an ERP study. *Brain Research*, 1186, 233–241. <https://doi.org/10.1016/j.brainres.2007.09.093>
- Vuilleumier, P., & Schwartz, S. (2001). Beware and be aware: Capture of spatial attention by fear-related stimuli in neglect. *Neuroreport*, 12(6), 1119–1122. Retrieved from <http://0-ovidsp.uk.ovid.com.catalog.llu.edu/sp-3.24.1b/ovidweb.cgi?QS2=434f4e1a73d37e8cd39f90c3d533e15ae9854acde4e40d19acbe5bfd04c02f9498af073bacee5037c20dd3da698ba7e19c3308241d452d2f5ec06c9c2355d897c61447cb7781ed3e641d1d7cb6fd3327ff59517b4fb0dba482d35ec>
- Vuilleumier, P., Richardson, M. P., Armony, J. L., Driver, J., & Dolan, R. J. (2004). Distant influences of amygdala lesion on visual cortical activation during emotional face processing. *Nature Neuroscience*, 7(11), 1271–1278.

<https://doi.org/10.1038/nn1341>

Zhang, D., Wang, L., Luo, Y., Luo, Y., Tamietto, M., Gelder, B. de, ... Lamme, V. (2012). Individual Differences in Detecting Rapidly Presented Fearful Faces. *PLoS ONE*, 7(11), e49517. <https://doi.org/10.1371/journal.pone.0049517>