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The Relationships Between Frontal Alpha Asymmetry, Mood, and Emotional Memory

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The Relationships Between Frontal Alpha Asymmetry,
Mood, and Emotional Memory

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts
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ABSTRACT

Frontal alpha asymmetry is often used as a metric to compare activation between homologous frontal brain sites. A positive asymmetry refers to greater activation in the left hemisphere than in the right hemisphere, while the opposite is true of negative asymmetries. Two expansive but largely separate bodies of research have examined the relationships between (1) frontal asymmetry scores and mood, and (2) mood and emotional memory performance. Specifically, one body of research has found that positive moods are associated with positive asymmetries while negative moods are associated with negative asymmetries. A second body of literature has examined the effects of mood on affective memory performance found that individuals tend to preferentially recall stimuli whose valence (positivity or negativity) is consistent with their current moods, often at the expense of stimuli whose valence is inconsistent with their current moods. Researchers in this area report that individuals in positive moods tend to recall more positive than negative words while those in negative moods recall more negative than positive words in memory tasks. This effect has been termed mood-congruent memory. As frontal asymmetry appears to underlie mood, and mood differentially affects performance on emotional memory tasks, it is surprising that no research has focused on a possible direct relationship between frontal asymmetry and emotional memory performance.

The present study attempted to replicate previously described relationships between (1) frontal asymmetry and mood, and (2) mood and emotional memory performance. The main goal of the study, however, was to bridge the gap between frontal asymmetry and selective recall of emotional words by attempting to correlate frontal asymmetry indices with emotional memory performance.

Results supported the expected mood-congruent memory effects and a significant relationship between asymmetry and mood in the expected direction. While a correlation between asymmetry and affective memory performance was not found, groups based on asymmetry scores found that the positive asymmetry group showed increased memory performance for positive words and total words, while the negative asymmetry group showed impaired memory for positive words and total words.

Further examination of links between alpha asymmetry and affective memory could corroborate the present asymmetry group differences in memory. Future findings would provide the first neuropsychological underpinning of mood-congruent memory effects. Additionally, support for a relationship between asymmetry and affective memory could lead to the formation of a unifying theory of asymmetry and memory that draws on current models of brain activation, executive function, emotion, and memory.

CHAPTER 1: INTRODUCTION

Frontal Alpha Asymmetry

In order to understand investigations of frontal alpha asymmetry and its relationship to various aspects of emotion and behavior, it is necessary to have an understanding of what is meant by the term alpha asymmetry. Alpha waves in the brain, oscillating at frequencies between 8 and 13 Hertz, are emitted constantly to varying degrees and are widely accepted to be inversely related to cortical activation, as demonstrated by studies measuring simultaneous EEG-fMRI showing this effect (Goldman, Stern, Engel, & Cohen, 2000; Ritter & Villringer, 2006). In other words, as the magnitude of alpha waves in a particular region decreases, that brain area shows a corresponding increase in activity, and vice versa. Much of the research in frontal asymmetry focuses not on the power of the alpha signal in one location but rather on the relative power between two signals in different hemispheres. Most often, this means measuring the relative difference between alpha power in one region in the right hemisphere with the corresponding region in the left hemisphere. When the two signals are equal, the difference score between the two is zero and would be termed symmetrical, indicating equivalent activations in both hemispheres. Most often, however, one side is more active than the other, and the difference score is either positive (indicating higher cortical activity in the left hemisphere) or negative (indicating higher cortical activity in the right hemisphere).

Frontal asymmetry appears to be a biological trait that is moderately stable across time for a variety of populations. In children aged three to nine, significant test-retest correlations of frontal asymmetry of up to three year latencies were around .38, a value that is remarkable given the extraordinary amount of development that occurs in the brain of a child between the ages of three to nine (Vuga et al, 2008). For adults, significant test-retest correlations with latencies of between one and three years was .54 for a combined sample of depressed and normal individuals with no significant group differences (Vuga et al, 2006). Frontal asymmetry is also stable in schizophrenic populations with significant test-retest correlations over a period of three years of .50 even after partialing out changes in positive and negative symptoms over that time period (Jetha, Schmidt, & Goldberg, 2009).

In addition to being a stable trait, frontal asymmetry is also moderately heritable. Field et al (2004) found a significant correlation of .38 between mothers' asymmetries and those of their newborn infants. Twin studies have also provided evidence of the heritability of frontal asymmetry. Gao et al (2009) examined the frontal asymmetries of nine and ten year old monozygotic (MZ) twins and dizygotic (DZ) twins and found higher, more robust correlations between the MZ twins than the DZ twins. Similarly, a study by Anokhin, Heath, and Myers (2006), examining both MZ and DZ twins in young adulthood, concluded that 27% of frontal asymmetry variance was accounted for by genetics while 73% was accounted for by environmental factors. These studies provide evidence of small to moderate heritability of frontal asymmetry in infancy, childhood, and adulthood.

Asymmetry and Individual Differences

Depression

Negative frontal asymmetries (i.e. right asymmetries; greater right activation) have been consistently correlated with depression and negativity in general. A recent meta-analysis of depression and frontal EEG asymmetry found that no less than 39 studies had been dedicated to the question of the relationship between frontal asymmetry and depression and that the studies overwhelmingly observed larger right asymmetries in depressed participants compared to normal participants (Thibodeau, Jorgensen, & Kim, 2006). That review estimated an average effect size of $r = .26$ in studies focused on adults and $r = .29$ in studies focused on children, a difference that was not statistically significant.

Frontal asymmetry has also been found to discriminate between depressed and control groups. Henriques and Davidson (1991) examined the relationship between diagnosed depression and hemispheric asymmetries of all frequency bands. The authors found that, as hypothesized, only alpha-band asymmetry in the mid-frontal region significantly discriminated between depressed and non-depressed participants, with the depressed participants showing negative asymmetries and the non-depressed participants showing positive asymmetries. This finding was corroborated by Baehr, Rosenfeld, Baehr, and Earnest (1998), who found that the mid-frontal asymmetries of a depressed group and a control group, categorized by BDI scores, were significantly different, with the control groups exhibiting positive asymmetries and the depressed group exhibiting negative asymmetries. Similar results have been found in other studies as well (Gotlib, Ranganath, & Rosenfeld, 1998; Mathersul, Williams, Hopkinson, & Kemp, 2008). These

and other results helped establish the widely accepted concept that depression is correlated with negative, or right-sided, alpha asymmetries.

Besides being able to distinguish between depressed and non-depressed groups, frontal asymmetry has been shown to predict who will respond well to antidepressant medications. Bruder and colleagues (2001) found significant hemispheric differences between those who responded well to anti-depressant medication and those who did not respond. They found that the patients who benefited most from medication had more positive asymmetry indices before medication while those who did not benefit had more negative asymmetry indices before medication, leading to the possibility that antidepressants may be less effective in those who show more severe negative asymmetries.

There is also an association between frontal asymmetries and negativity in non-clinical groups. Tomarken, Davidson, Wheeler, and Doss (1992) found that normal participants demonstrating consistent and extreme negative asymmetries scored significantly lower on the positive affect portion of the PANAS than those participants showing consistent and extreme positive asymmetries, who showed the opposite effect. Another study using non-clinical subjects (Schaffer, Davidson, & Saron, 1983) found that frontal asymmetry could discriminate between so-called depressives and non-depressives (categorized by BDI scores), with the depressives exhibiting significantly more negative asymmetries than non-depressives.

In light of the robust connections between frontal asymmetry and depression, as well as the apparent heritability of frontal asymmetries, Smit, Posthuma, Boomsa, and De Geus (2007) examined the explicit possibility that negative asymmetries could be a risk

factor for psychopathology. Results indicated negative asymmetries were a significant risk factor for depression for young females but not for males. Given their large sample ($n = 760$) and the differential effects found in female and male subjects, it is possible that there are sex differences with respect to frontal asymmetry and risk for depression, which the authors suggest should be the focus of future research in the asymmetry and risk for depression literature.

Temperament

Several studies have found associations between resting frontal asymmetry and individual temperament. Schmidt (2002) found that undergraduates who scored high on shyness measures and low on sociability measures exhibited significantly greater right-sided asymmetry than undergraduates who scored low on shyness measures and high on sociability measures. This finding is consistent with the general concept that right-sided asymmetries are correlated with withdrawal behaviors while left-sided asymmetries are correlated with approach behaviors, and may lend insight into the neural correlates of shyness and sociability.

Schmidt (2008) found similar results in 9-month-old infants by assessing second-by-second frontal asymmetries and comparing them with heart rate and temperament. The author found that infants with stable right-sided asymmetries displayed significantly faster resting heart rates and higher levels of maternal-reported fear than the infants in either the left-sided asymmetry group or the variable asymmetry group. Additionally, the infants in the stable left asymmetry group showed significantly higher levels of maternal-reported pleasure than either of the other two groups, and infants in the stable right asymmetry group showed significantly higher levels of maternal-reported fear than either

of the other two groups. These findings support the theory that left-sided asymmetries are related to temperaments generally considered happier and more approach-oriented while right-side asymmetries are related to temperaments generally considered more fearful, shy, or withdrawn. Similarly, Davidson and Fox (1989) found that baseline frontal asymmetries predicted the emotional response of infants who subsequently experienced maternal separation. As predicted, the infants who cried during the maternal separation exhibited greater right-side asymmetries as opposed to the non-crying infants, who exhibited significantly greater left-side asymmetries.

The results of this and previously mentioned studies strongly support the concept that frontal asymmetry is related to individual temperament, with left-side asymmetry correlated with more positive affect and approach behavior and right-side asymmetry correlated with more negative affect and withdrawal behavior. Moreover, these associations have been observed across age ranges from infancy to adulthood, suggesting a stable, long-term relationship between asymmetry and temperament.

Behavior

Temperament and behavior are often related, and a similar line of research has emerged that examines the relationship between frontal asymmetry and behavior. Santesso et al (2008) examined frontal asymmetry in adults as it related to measures of sensation seeking and found that high sensation seeking was correlated with greater left-side asymmetries ($r = .34$). Additionally, the author found a significant correlation between disinhibition and greater left-side asymmetries ($r = .37$) and susceptibility to boredom and greater left-side asymmetries ($r = .45$). This study corroborated earlier results from Sutton and Davidson (1997), who found that higher left-sided asymmetries

were related to increased behavioral activation, whereas higher right-sided asymmetries were related to increased behavioral inhibition.

There also appears to be a relationship between frontal asymmetry and attachment patterns in adults. Comparing asymmetries to groups of various attachment patterns (avoidant, secure, preoccupied, and fearful/avoidant), as determined by various attachment scales, Rognoni, Galati, Costa, and Crini (2008) found a significant correlation between avoidant attachment and greater right-side asymmetry ($r = -.35$). The authors also found a marginally significant correlation between secure attachment and left-side asymmetry ($r = .28$).

Frontal asymmetry also appears to relate to behavior in infancy. Hane, Fox, Henderson, and Marshall (2008) found that infants who displayed significantly more approach-type behaviors (such as reaching for or approaching a puppet) over a nine-month period of observation exhibited left-side asymmetries, while the infants who displayed significantly more withdrawal-type behaviors (such as actively crawling away from a puppet) exhibited right-side asymmetries. This finding is similar to the infant study previously discussed in the temperament section and complements the studies examining this effect in adult populations. Together, these findings support Davidson's model describing the left mid-frontal region as relating to approach behaviors and the right mid-frontal region as relating to withdrawal behaviors, a model that will be examined more closely in the next section.

A Conceptual Model of Frontal Brain Activation

Frontal asymmetry scores, assessed across individuals, have been correlated with various affective states, moods, temperament, and approach and withdrawal behaviors.

The studies just described, and more like them, led to the formulation of a theory of frontal lobe activity and emotion proposed by Davidson (1992). This model, often termed the valence model, proposed that prefrontal cortex activity is central to positive and negative emotions, similar to the studies described in this proposal. More specifically, Davidson's model describes the left prefrontal cortex as central to approach behavior and positive emotions and the right prefrontal cortex as central to withdrawal behavior and negative emotions.

Using measures of alpha asymmetry, Henriques and Davidson (1991) found that depressed participants exhibited significantly lower left-side activation than non-depressed control participants. Investigations of mood induction in normal individuals also found correlations between mood and selective activation in the frontal lobe.

Davidson, Ekman, Saron, Senulis, and Friesen (1990) found significant relative right frontal activity during film clips designed to induce fear and disgust and significant relative left frontal activity during positive emotion film clips, lending additional support to the idea that the left frontal lobe is associated with positive emotion and the right frontal lobe is associated with negative emotion.

Similarly, Sutton and Davidson (1997) examined mid-frontal lobe activation and its relationship with the Behavioral Activation System, thought to be responsible for strong positive affect and approach behavior in goal-oriented situations (quantified by the Behavioral Activation Scale), and the Behavioral Inhibition Scale, thought to be responsible for strong negative affect and withdrawal behavior in threatening situations (quantified by the Behavioral Inhibition Scale). In a landmark finding, the authors reported a significant positive correlation ($r = .53$) between mid-frontal EEG asymmetry

and a BAS minus BIS difference score (a positive difference score indicates more approach behavior while a negative difference score indicates more withdrawal behavior). As asymmetry scores became more positive, the BAS-BIS difference score also became more positive, indicating that higher activation in the left frontal lobe corresponded with more approach behavior while higher activation in the right frontal lobe corresponded with more withdrawal behavior.

Affective Appraisal and Reactivity

This proposal has thus far reviewed evidence that frontal asymmetry is a significant predictor of emotional states and the experience of those states, with left-side asymmetries significantly correlating with approach-related positive emotions and right-side asymmetries significantly correlating with withdrawal-related negative emotions. This finding is robust and has been found for vastly different populations at multiple life stages. However, as this section will review, frontal asymmetry is also correlated with individuals' perception of emotional material. Specifically, asymmetries can predict how people appraise and respond to affective stimuli. Further, there is evidence that the autonomic startle reflex is modulated by affective information. The following evidence supports the widely observed phenomenon that the processing of emotional information often results in biased cognition and sensory perception.

In addition to individual differences involving asymmetry and depression, temperament, and behavior, there are group differences involving the perception of affective stimuli – specifically, left asymmetry groups tend to appraise affective stimuli as more positive and right asymmetry groups tend to appraise affective stimuli as more negative. In addition to the valence of stimuli, left asymmetry groups tend to report more

intensely positive reactions, while their right asymmetry counterparts report more intensely negative reactions.

For instance, Tomarken, Davidson, and Henriques (1990) found that right asymmetries were significantly correlated ($r = .14$) with increased negative reactivity to films. In other words, participants with a right asymmetry reacted more negatively to films than participants with a left asymmetry. The authors' hypothesis that left asymmetry would be correlated with increased positive reactivity to films was not supported, but left asymmetry was found to significantly correlate ($r = .14$) with the affective valence of the response (that is, if participants responded positively or negatively in general).

Similarly, Wheeler, Davidson, and Tomarken (1993) conducted a study in which participants were asked to rate their emotional reactions to affective film clips from commercially available movies. Like Tomarken, Davidson, and Henriques (1990), the authors found a significant correlation between mid-frontal asymmetry and affective reactivity ($r = .57$); unlike Tomarken and colleagues, however, the findings extended beyond negative reactivity to positive reactivity; specifically, the authors found that participants with a greater left asymmetry reported more intense positive reactions to positive films while those with a greater right asymmetry reported more intense negative reactions to negative films.

This effect has also been found with still images of emotional material. Hagemann, Naumann, Becker, Maier, and Bartussek (1998) found that frontal asymmetries predicted how participants reacted to affective photographs. For this study, participants were exposed to thirty affective pictures, half of which were positive and half

of which were negative in valence, with each image presented for six seconds. After the exposure, participants were asked to rate on a zero-to-nine scale their emotional state before continuing to the next slide. The authors found that the tendency to report higher positive reactivity to positive slides significantly correlated with left-side asymmetries ($r = .31$). The analysis of negative reactivity to negative slides yielded a correlation in the expected negative direction, but did not reach significance.

Sutton and Davidson (2000) obtained similar results looking at prefrontal brain areas. The authors found that individuals with greater left prefrontal asymmetries, when asked to choose between two word pairs of equal associative strength, selected a higher number of pleasant word pairs than non-pleasant word pairs ($r = .29$). The hypothesis that right asymmetries would be correlated with the selection of more unpleasant words was not supported, but the results of this study suggest that biases also exist in the cognitive processing of affective stimuli, and that these effects may not be restricted to mid-frontal regions but rather include other areas of the frontal lobe.

In addition to films and photographs, the relationship between frontal asymmetry and biased perception appears to extend to the appraisal of facial expressions. Davidson, Schaffer, and Saron (1985) conducted a study that examined frontal asymmetry and participant ratings of whether faces were positive, neutral, or negative in nature. The authors found a large significant correlation ($r = .74$) between frontal asymmetry and happiness ratings of faces, indicating that individuals with a left-side asymmetry rated faces as more positive than those with a right-side asymmetry.

Jackson and colleagues (2003) have also reported that the magnitude of the startle response to negative stimuli varies as a function of frontal asymmetry. Startle magnitude

to sudden onset auditory tones is measured by the eyeblink response. Typically, startle magnitude is greater when it occurs in the presence of negatively valenced stimuli, such as when subjects are viewing a picture of a dead body or gun pointed directly at a camera, relative to the presence of positive or neutral stimuli (Jackson et al., 2003; Vrana, Spence, & Lang, 1988). In this study, the authors found the expected startle response such that eyeblink magnitude to the auditory tone during the presentation of an unpleasant slide was significantly larger than when it occurred during either a neutral slide or a pleasant slide. However, of greater relevance to the current thesis study, the authors also found that prefrontal asymmetry was significantly and inversely correlated with startle magnitude in the unpleasant condition ($r = -.41$), indicating that relative left-side asymmetry was associated with a smaller startle reflex during an unpleasant stimulus. These findings suggest that frontal asymmetry is also associated with relatively automatic responses that occur when processing emotional stimuli

The findings presented in this section indicate that perceptual biases based on individual differences in alpha asymmetry exist for affective stimuli ranging from films, photographs, and faces as well as relatively automatic reflexes such as the startle reflex. This evidence suggests that frontal asymmetries are associated with biases in perception and responding across a wide variety of emotional stimuli, tasks and behaviors.

Of course, not every study produces results that are consistent with those presented in this section. Hagemann, Hewig, Naumann, Seifert, and Bartussek (2005) found that participants demonstrating right-side asymmetries reported stronger negative reactions to films than neutrals, as the aforementioned studies also found. However, the participants with right-side asymmetries also reported more intense positive reactions to

films, a result which contradicts the findings of the other studies reported in this section. Likewise, Meyers and Smith (1986) conducted a study to examine frontal asymmetries and exposure to positive and negative stimuli and failed to find hemispheric differences during the appraisal of such stimuli. These studies, and others like them, indicate that while a whole host of studies find significant relationships between frontal asymmetry and affective reactivity, the findings in this area are not always consistent.

This section described research demonstrating a strong association between frontal asymmetry and mood as well as appraisal of emotional stimuli. Specifically, individuals with left-side asymmetries, compared to their right asymmetry counterparts and controls, tend to react more intensely to positively-valenced films and photographs, appraise faces as more positive, and select more positively-valenced words, while the opposite is true of right-side asymmetry individuals. Research has also demonstrated that frontal asymmetries are associated with differential magnitude of startle response when viewing positive and negative affective material. Taken as a whole, the presented studies suggest that frontal asymmetry is associated with biases in emotional perception, stimulus appraisal, as well as moods and emotional states. Additionally, there is a considerable literature to suggest that mood also has selective effects on the retrieval of emotional information from memory. This effect has been termed mood-congruent memory (MCM) and is the probability that recall is greater for words whose valence is consistent with the mood of the subjects. Specifically, participants in positive moods will recall a higher number of positive emotional items than negative emotional items, and vice versa for participants in negative moods. As the following section will demonstrate, this

enhanced recall of mood-congruent items occurs often at the expense of items that are mood-incongruent.

Mood Congruent Memory Bias

There is robust support for the concept that the probability of recall is greater for words whose valence is consistent with the mood of the subjects. Moreover, this better recall is often at the expense of items that are mood-incongruent. This concept is referred to as mood-congruent memory and is a well-established finding in mood and memory literature. A review of studies examining mood-congruent memory effects by Blaney (1986) highlights the results of 27 published articles and concludes that, while some questions remain, mood-congruent memory is notable in its scope and consistency. A subsequent meta-analysis by Matt, Vázquez, and Campbell (1992) examined 58 mood-congruent memory studies and reported that non-depressed individuals significantly favor positive over negative stimuli in recall tasks (mean $d = .15$), sub-clinically depressed individuals show roughly equal recall for positive and negative items (mean $d = -.02$), clinically depressed individuals and normals in a depressed mood induction recall significantly more negative than positive items (mean $d = -.19$, $d = -.12$, respectively). A more specific examination of mood-congruent memory in this section will provide an added theoretical rationale for the current thesis study.

A number of experiments have found a strong relationship between depression and affective memory. For instance, Bradley and Mathews (1988) compared a currently depressed group, a depression-recovered group, and a control group on their ability to recall positive and negative adjectives that they had heard on a tape. During the presentation of each word, the participants were asked to decide whether the adjective

accurately described either themselves or a third party. Following a short distracter task, the participants engaged in free recall of the adjectives. The authors found that for adjectives used to describe themselves the depressed group recalled significantly more negative adjectives than both the controls and the recovered depressives. This effect was not seen for adjectives which the groups used to describe a third party, a finding which the authors suggest could be related to the negative self-schema often observed in depression. More recently, Drenfeldt and Roberts (2006) examined this effect for incidental memory (participants were not told that they would have to recall words until after the exposure was complete) rather than explicit memory and found that naturally dysphoric individuals (according to BDI-II scores) recalled significantly more negative self-descriptive adjectives than did controls or experimentally induced dysphoric participants in a surprise free recall task. Additionally, the naturally dysphoric group had a significantly greater negative bias than the experimentally induced dysphoric group and the control group. Similar effects have been found with autobiographical information by Rothkopf and Blaney (1991), who examined whether mood affected the recall of individuals' recent autobiographical memories. The authors measured mood using the Beck Depression Inventory and asked participants to complete a questionnaire in which they were to write down the first memories that come to mind in previous time periods, such as the preceding 24 hours, the preceding week, and so on. They were asked to rate the affect of each memory on a scale of happiness/unhappiness. The authors found that dysphoric participants, as measured by the BDI, rated their memories as less positive than the non-dysphoric participants ($F = 48.00, p < .001$). This early finding was built upon by Rottenberg, Hildner, and Gotlib (2006), who compared the happiest and saddest

memories reported by SCID-diagnosed major depressives and control participants. The authors found significant differences between the groups for the happy memory, with the depressed group exhibiting greater retrieval difficulty, less specific memories, and less memory emotionality than controls, while the two groups did not differ in their reports of the sad memory in terms of specificity, retrieval difficulty, and memory emotionality.

There also exists a robust literature showing that mood-congruent memory effects can be produced in non-clinical, normal participants by conducting positive and negative mood inductions. Gilligan and Bower (1983) showed this effect by asking participants to examine short positive and negative phrases (such as “a grandfather’s death,” or “a comfortable chair”) after either a positive or negative mood induction. The authors found that after the mood inductions (achieved using oral recall of either a happy or sad life memory), participants in the happy condition recalled significantly more happy phrases than sad phrases, and vice versa. The relatively small sample size ($n = 16$) speaks to the robust nature of this finding. An additional example of mood inductions leading to mood-congruent memory effects comes from a study conducted by Brown and Taylor (1986). After mood inductions, participants were exposed to 20 positive and 20 negative adjectives and asked to rate each adjective for whether it described them personally or whether it rhymed with another word. The authors found that during free recall of the items rated as self-descriptive the positive mood induction group recalled significantly more positive than negative adjectives. A similar effect was observed in children by Nasby and Yando (1982). The authors found that after a positive or negative mood induction, fifth-grade children in the positive condition recalled significantly more positive adjectives than controls while children in the negative condition recalled

significantly more negative adjectives than controls. Also, analogous to the previously mentioned findings regarding depressed patients and autobiographical recall, a study by Miranda and Kihlstrom (2005) found that participants in a positive mood induction recalled autobiographical memories that were significantly more positive than participants in both the control group and the negative mood induction group.

There is also evidence that mood-congruent memory occurs during implicit memory tasks as well. A study by Watkins, Vache, Verney, Muller, and Mathews (1996) demonstrated that mood-congruence can occur as a result of priming. The authors found that during a free association task, preceded by a supposedly unrelated imagination exercise involving valenced words from a list, depressed participants produced significantly more negatively valenced words from the target list while non-depressed participants produced significantly more positively valenced words. Both depressed and control groups reported at debriefing that they were not intentionally recalling words from the target list from the beginning of the experiment. Along these same lines, Bradley, Mogg, and Williams (1995) found that, after exposure to depression-related word primes they did not consciously perceive, depressed participants recalled significantly more depression word primes than either control or anxious participants. The authors also found that depressed participants recalled significantly more depression words that they *did* consciously perceive than either controls or anxious participants. In another study with non-clinical participants, Bradley, Mogg, and Williams (1994) reported similar findings – a high negative affect group showed greater priming for negative words than for control or positive words. These studies shows that mood-congruent memory can occur under implicit conditions (i.e. without apparent awareness),

with more positive moods priming more positive words and likewise with negative moods and negative words.

More recently, research has begun to emerge suggesting that mood can elicit “false memories” of emotional stimuli. For instance, Ruci, Tomes, and Zelenski (2009) used mood inductions to create positive, neutral, and negative mood groups and then exposed the participants to positive, negative, and neutral word lists. Each list revolved around a common but unmentioned theme that acted as the lure – for instance, the “anger” list consisted of words semantically and emotionally related to anger, such as “mad, fear, hate, rage, fury,” but not the lure word “anger.” The authors found that in a free recall tasks, participants in the positive mood group recalled significantly more positive lures than those in the neutral and negative mood groups. Likewise, participants in the negative group recalled significantly more negative lures than those in the positive or neutral mood groups. This “false mood-congruent memory” effect was also seen for the positive and negative mood groups in the recognition task. Lastly, the participants in the positive mood group reported actively *remembering* significantly more lures from the positive lists than the negative or neutral lists, and vice versa for participants in the negative mood group. This experiment expanded upon an earlier study that, though not measuring mood directly, compared true and false mood-congruent memory between depressed and control participants and found that the individuals who met DSM-IV diagnosis for Major Depressive Disorder remembered significantly more false lures from the negative word list compared to positive and neutral word lists and controls (Moritz, Gläscher, & Brassens, 2005). Similarly, Moritz, Voigt, Arzola, and Otte (2008) assessed false mood-congruent recognition in depressed and control participants and found that the

depressed group reported falsely recognizing significantly more lures that they rated as having high personal salience. This emerging line of research, while in need of replication and expansion, provides the first evidence that mood can result in affectively selective and vivid “false memories” of stimuli that were not actually presented.

Not all studies find significant mood-congruent memory effects. In a recent review of mood-congruent memory, Barry, Naus, and Rehm (2004) found that roughly eight of 17 studies reported non-significant results. Importantly, these studies finding non-significance featured designs in which the cognitive demands at encoding and test were inconsistent, with some utilizing conceptual tasks (ie, word generation, semantic processing) at encoding and perceptual tasks (ie, word stem completion, priming) at test, and vice versa. The authors argue that to find a strong mood-congruent memory effect the cognitive demands must be similar at both encoding and test. Of those studies that utilize consistent cognitive demands at encoding and test, eight out of 11 find significant results. These studies suggest that affective memory is more susceptible to biased recall if the nature of the cognitive tasks at learning and recall is consistent, and less susceptible to biased recall if the cognitive demands are inconsistent between learning and recall.

Rationale for the Current Study

The Unexamined Relationship between Frontal Asymmetry and Affective Memory

Models of emotion and lateralized frontal lobe activity have postulated that the left frontal lobe is associated with positive emotions and approach-type behaviors while the right frontal lobe is associated with negative emotions and withdrawal-type behaviors. Frontal asymmetry has been demonstrated to be both moderately stable and heritable traits in individuals and has been correlated with depression, with depressed individuals

showing significantly more right-sided asymmetries than controls. Similarly, frontal asymmetry is correlated with temperament and behavior, with happier individuals showing significant left-side asymmetries and approach-type behaviors, such as sensation-seeking in adults and grasping and hugging by infants. Conversely, individuals who show more right-side asymmetries tend to exhibit depressed mood and withdrawal-type behaviors such as avoidance and inhibition in adults and hiding and crying in infants. Frontal asymmetry is also correlated with affective appraisal, with left asymmetry individuals appraising stimuli as more positive than controls, and vice versa for negative asymmetry individuals. Additionally, left asymmetry individuals demonstrate heightened positive reactions to positive stimuli and right asymmetry individuals demonstrate heightened negative reactions to negative stimuli. Lastly, mood has also been shown to be associated with biases in recall of emotional memories. Mood-congruent memory bias refers to the phenomenon where the probability of recall is greater for stimuli that are emotionally-consistent with individuals' moods, often at the expense of words that are emotionally-inconsistent with mood. Individuals in positive moods tend to recall a higher number of positive than negative words while those in negative moods tend to recall a higher number of negative than positive words in memory tasks. This effect has been found in clinically depressed populations, who recall more negative than positive words in recall tasks. Mood congruent memory bias is also observed in non-depressed normal participants who experience mood inductions, with those in the positive induction group recalling more positive than negative words and those in the negative induction group recalling more negative than positive words. Additionally, research has shown that mood congruent recall occurs after implicit

exposure to stimuli, such as through priming, and in incidental memory tasks, where participants are not told they will have to remember words until after the exposure. Lastly, mood has been shown to elicit “false memories” in participants, who report with confidence that they had previously seen words that were not on the target list (lures). Interestingly, participants selectively remember lures that are congruent to their mood, with positive mood individuals reporting they had seen more positive than negative lures, and vice versa for the negative mood individuals.

Somewhat surprisingly, there are currently no published studies examining the relationship between frontal asymmetry and mood-congruent memory. Given the findings that memory biases highly correlate with mood and that mood is strongly associated with frontal asymmetry, it is reasonable to suspect that frontal asymmetry indices may predict performance on affective memory tasks. If such a relationship does exist, it is possible that frontal asymmetry could completely or partially mediate the relationship between mood and affective memory bias, providing a potential neuropsychological underpinning of mood congruent memory bias.

Purpose of the Current Study

The purpose of the current study was to replicate and corroborate the strong evidence of (1) frontal asymmetry as a correlate of mood, and (2) mood as a correlate of affective memory performance. Additionally, given the connections between (A) frontal asymmetry and mood and (B) mood and affective memory performance, the experimenter attempted to correlate frontal asymmetry and affective memory performance, forming a bridge between these two separate but seemingly related literatures. Based on the evidence presented thus far, it is reasonable to predict such a

correlation may exist. Finally, the current study investigated whether frontal asymmetry is a complete or partial mediator of mood-congruent memory bias, a possibility that has not been previously investigated.

Hypotheses and Predictions

The current experiment will test four hypotheses:

1. The first hypothesis is that *mood-congruent memory bias will be observed*; specifically, the mood measures will significantly correlate with the number of valenced words recalled such that participants in more negative moods will recall more negative words while participants in more positive moods will recall more positive words.
2. The second hypothesis is that the *frontal asymmetries will significantly correlate with the mood measures* such that negative asymmetries will be correlated with negative moods and positive asymmetries will be correlated with positive moods.

These first two hypotheses basically reflect replications of the MCM effect and the association of frontal alpha asymmetry with mood. The next two hypotheses are unique to this study:

3. The third hypothesis is that *frontal asymmetry will significantly correlate with the number of valenced words recalled*; specifically, positive asymmetry indices will correlate with more positive words being recalled and negative asymmetry indices will correlate with more negative words being recalled.
4. Lastly, the fourth hypothesis is that *frontal asymmetry will mediate the correlation between mood and valenced words recalled*.

CHAPTER 2: METHODS

Participants

Studies involving EEG and depression typically find medium effect sizes. A bivariate correlation power analysis calculated with a medium effect size ($r = .3$), .8 power, and alpha of .05 produced a desired sample size of 85. Accordingly, 98 participants from the University of South Florida undergraduate research pool (SONA) took part in the study. Though some studies involving EEG and depression recruit only females because of an increased tendency to find effects in depressed populations, this study recruited both males and females because this experiment involves non-clinical participants. The sample consisted of 27 males (27.55 percent) and 71 females (72.45 percent) with a median grade level of 14 (sophomore) and mean age of 20 years. The sample was 52 percent Caucasian, 24 percent Hispanic, 13 percent African-American, six percent Asian and five percent other ethnicities.

Exclusion criteria for this study dictated that potential participants meeting one or more of the following descriptions were not recruited: those with a history of brain trauma, neurological disorder, loss of consciousness for more than ten minutes, left-hand dominant, and those taking psychoactive medication. Individuals reporting prior brain trauma were excluded due to the possibility of confounds resulting from potentially diminished global or local functionality. Left-handed individuals were also excluded, given potential organizational or functional inconsistencies in the brain compared to right-handed individuals. Individuals currently taking psychoactive medication were

excluded since such medications can affect asymmetries and brain chemistry. Lastly, anyone currently in treatment for depression was excluded on the basis that the study target is a normal population and the results could be skewed by a small number of severely depressed individuals.

A total of 4 participants were eliminated from the sample. One participant was excluded from analyses due to a neurological disorder. Three additional participants were excluded from analyses due to hardware and/or software failures during EEG acquisition that rendered their data unusable. The final sample for analysis consisted of 94 participants, suggesting adequate power for analyses.

Experimenters

Three experimenters collected data for this study. Ross Ávila collected the data for 68 participants, Robert Salazar collected the data for 16 participants, and Kira Yorzinski collected the data for 14 participants. Ms. Yorzinski and Mr. Salazar are research assistants in the Cimino lab and underwent training in EEG lab protocol, net handling, net application, and software use. Additionally, both RAs completed three supervised net applications, observed Mr. Ávila collect data for three participants, and were observed collecting data for three participants before they were cleared to collect data unsupervised.

Measures

The Positive and Negative Affect Scale (PANAS) was administered to measure participant mood. To maximize validity, it is desirable to measure mood as close in time to the EEG measurement as possible, so the measure instructed participants to indicate to what extent they felt a certain way “right now, that is, at the present moment.” The

PANAS is an appropriate mood measure for this study because it describes both positive and negative affect, the positive and negative scales are highly uncorrelated, the measure has high internal consistency, appears to be stable over a two month period, and correlates highly with other prominent affect scales (Watson, Clark, & Tellegen, 1988). Moreover, it has previously been used in several studies examining mood and frontal asymmetry (Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997; Tomarken, Davidson, Wheeler, & Doss, 1992). For analysis, a difference score was calculated wherein the total scores on the 10 negative items were subtracted from the total scores on the 10 positive items. The result of this calculation is that positive difference scores indicate higher positive mood and negative difference scores indicate higher negative mood.

The Beck Depression Inventory (BDI-II) was also administered to provide an additional measure of affect and to allow comparisons with previous frontal asymmetry work, which often use the BDI in studies involving mood or depression. The BDI-II features high internal consistency ($\alpha = .91$), high test-retest reliability at one week ($r = .93$), and high validity as measured by a correlation of .71 with the Hamilton Psychiatric Rating Scale for Depression (Beck, Steer, Ball, & Ranieri, 1996; Beck, Steer, & Brown, 1996). The inclusion of this robust and sensitive affect measure increased the validity of the current study's measurement of mood, and the measure's ease of administration allowed for the collection of data at a minimal burden to the participant.

The Affective Norms for English Words (ANEW) database was utilized for the memory tasks (Bradley & Lang, 1999). Each word in the ANEW database is accompanied by normative data that includes ratings of valence, arousal, dominance, and

frequency, allowing experimenters to balance words for these qualities. The ANEW has often been used in studies involving affective memory performance, making it a logical choice for this study (Clark-Foos & Marsh, 2008; Davidson, McFarland & Glisky, 2006; Gibbs, Naudts, Spencer, & David, 2007; Kapucu, Rotello, Ready, & Seidl, 2008). Eighteen words, composed of 9 positive and 9 negative words, were used to prevent a potential ceiling effect without cognitively over-burdening participants during the recall phase, and the words were balanced on valence, arousal, frequency, and word length. The study as originally proposed suggested using a list of 24 words. See Appendix A for a description of the methods and results of a pilot study that led to the modification of the study word list.

EEG Recording and Quantification

In frontal asymmetry research, the International 10/20 System of electrode placement is almost universally used. However, the Geodesic Sensor Nets used at the University of South Florida easily translate to the 10/20 System with GSN electrodes 24 (left mid-frontal) and 124 (right mid-frontal) corresponding to 10/20 electrodes F3 and F4, respectively. The data for the study was collected in an electromagnetically shielded room. The electrodes of interest, located in the mid-frontal area, were used to measure average alpha power (8-13 Hz), which is accepted to be inversely related to cortical activity.

Eight minutes is the suggested length of resting asymmetry measurement to obtain acceptable internal consistency reliability, though some measurements as short as two minutes have also demonstrated reliability (Allen, Coan, & Nazarian, 2004). As such, eight 60-second blocks were recorded, four with eyes open and four with eyes

closed, for each participant at rest. The order of the eyes-open and eyes-closed was randomized between participants. According to Allen, Coan, and Nazarian (2004), in their review of the methodology of over 70 frontal asymmetry studies, the most commonly utilized reference site is the vertex, an area located near the top of the head. However, the vertex has been described by Coan and colleagues as the most troubling reference, as the vertex electrode is highly electrically active and is believed to over- or underestimate effects. According to a methodological review by Hagemann (2004), the correlation between asymmetry scores obtained by vertex and average reference was $r = -.004$, indicating the common variance of the scores obtained by the two references was essentially zero. The author reports there is very little convergent validity between reference schemes. In other words, different reference montages appear to measure psychometrically distinct properties of brain activation. As such, treating reference montages as interchangeable is not advised. For these reasons, it is common practice for asymmetry researchers to report results obtained using several reference montages. For purposes of this study, results obtained using common vertex (Cz), average reference (AR) and linked mastoids (LM) montages are all reported.

Resting frontal asymmetry data requires a number of steps to transform the raw signals into useful, analyzable metrics. First, all 60-second recordings were marked for bad channels, which were subsequently replaced with the average of activity at adjacent electrodes. Following bad channel replacement, the data was segmented into 117 epochs roughly 2.048 seconds in length which overlap one another by 1.5 seconds. Epochs of this configuration are necessary to conduct a Fourier transform (which assumes a periodic signal), which is used to isolate the alpha power band from the raw data. Once epoched,

a MATLAB-based blink rejection algorithm automatically rejected epochs with activity exceeding 75 μV in amplitude, a threshold consistent with eyeblink magnitude and other movement artifacts. A Fast Fourier Transform (FFT) was conducted on all artifact-free epochs after the data had been weighted with a Hamming window. The power spectra for the epochs were then averaged for each minute. Weighted averages across the eight minutes for each participant were computed based on the number of artifact-free epochs in each 60-second segment. Alpha power was taken as the average power in the 8 to 13 Hertz band. An alpha asymmetry index was calculated for each participant by taking the difference of natural log transformed scores for electrodes 124 (right mid-frontal) and 24 (left mid-frontal). The asymmetry index was calculated by subtracting the left hemisphere electrode from the homologous right hemisphere electrode ($\ln[124] - \ln[24]$) such that higher values indicate greater left hemisphere activation relative to right hemisphere activation. Log transforming the average power values increases normality of the distribution, as un-transformed data tend to display problematic levels of skewness and kurtosis. Once the difference score between the natural log transformed data is calculated, the metric is ready for regression or correlation with other measures. For an in-depth methodological review, see Allen, Coan, and Nazarian (2004), which served as a guide for this study's EEG data processing.

Procedure

Upon obtaining informed consent, participants completed the BDI-II and PANAS in a quiet room. Following completion of the mood measures, the participants were placed in an electromagnetically shielded room and the EEG net was attached. Participants were told to relax and concentrate on simple breathing during the

measurements and that they would not be performing a task. The experimenter remained silent during the EEG acquisition other than to instruct the participant to open or close their eyes as the randomized order dictated. After the eight 60-second recordings, the EEG net was removed.

Next, participants were presented with a list of 18 words from the ANEW database on a computer monitor at a rate of one word every two seconds. This method of stimuli exposure increased standardization across subjects as compared to verbal enunciation by the experimenter, whose timing, voice inflection, or level of attention could vary between participants. The order of the words was randomized between participants. Participants were told they would need to recall as many words as possible at a future point. Following the learning period, a 5-minute multiplication math task was administered as a distracter task to prevent subjects from rehearsing word list items. A math distracter was appropriate because it is non-verbal and unlikely to provide verbal interference with items to be remembered from the list. The task consisted of eight pages of multiplication problems and the participants were told to complete the problems by hand and show their work. After five minutes, the experimenter stopped the participants, who were permitted to complete their current problem. After the distracter period ended, free recall began with the participants verbally recalling as many words from the list of 18 as possible. Participants were given as much time as they needed for this task, though no participant took more than two minutes for recall. Following the free recall segment, the recognition task was administered. The task consisted of the 18 target words from the original word list and 18 new words (i.e. foils) not previously presented. Word foils were also selected from the ANEW norms and were balanced with the target words for

valence, arousal, frequency, and word length. The words appeared serially, in randomized order between participants, on a computer screen. A forced choice design was used such that each word remained on the screen until the participants indicated using a keypad whether each word was on the original list. After the recognition task, participants were presented with a list of all words used in the study (target and foil words) and asked to rate each word on valence and arousal. After completion of these ratings, participants were debriefed and given the opportunity to ask questions before their involvement in the study ended.

CHAPTER 3: RESULTS

Diagnostics

IBM SPSS Statistics 19.0 for Windows was used to manage and analyze all data. Prior to conducting correlation analyses to examine the hypothesized relationships, the data distributions were examined and participants' data points were examined for potential outliers. Examination of boxplots and standardized residuals confirmed most of the data points of interest fell within the accepted limit of plus or minus 3 standard deviations from the mean with the exception of nine participants. In order to be marked as an outlier, a data point exceeded the accepted limit of plus or minus 3 standard deviations from the mean for standardized residuals and exceeded the Cook's distance cutoff value of .043 ($4/n$). For standardized residual values and Cook's distance values, see Table 1. As can be seen in the table, two participants' mood measures (the BDI-II and the Negative Affect subscale) featured outlying data points. Examination of the data points found participant 22 reporting a score of 20 on the BDI-II and participant 73 reporting a 24 on the Negative Affect subscale. According to Beck et al. (1996), a score of 20 on the BDI-II corresponds to a level of depression on the border between mild and moderate, indicating that while the statistical software marked the value as an outlier, the data point does not represent an extreme value when evaluated in terms of the measure's diagnostic categories. Also, this value is lower than the mean BDI-II score obtained in a sample of depressed individuals (Beck, Steer, Ball, & Ranieri, 1996). For these reasons, the data point was retained in analyses. However, a score of 24 on the Negative Affect

scale appears to be a departure from the normative data. According to Watson, Clark, and Tellegen (1988), the mean Negative Affect score in a large sample ($n = 660$) of undergraduate participants was 14.8 with a standard deviation of 5.4. Based on the normative data, a score of 24 appears to be a genuine outlier and was excluded from analyses.

The bulk of outliers, however, occurred in the alpha asymmetry indices for seven participants. There are several reasons to retain these data points in the analyses. First, examination of the alpha asymmetry data found no errors in coding or calculation. Additionally, the participants in question all reported scores on the BDI-II and PANAS that are theoretically consistent with the asymmetries exhibited by all seven participants, meaning participants with positive asymmetries had lower BDI-II scores and more positive PANAS scores, and vice versa for negative asymmetries. Lastly, when the participants are excluded, all of the significant relationships reported in this section remain significant, meaning the significance of the relationships is not dependent upon the relatively outlying values of these participants. For these reasons, the dataset was analyzed with all asymmetry values included.

The dataset was also examined to ensure that the assumptions of correlation analyses were met. Scatterplots of regression standardized residuals and predicted values verified the assumptions of homoscedasticity and linearity. Durbin-Watson statistic values (mean: 2.03, range: 1.83 – 2.17) fell within accepted limits, supporting the assumption of independence of errors. Histograms and descriptive statistics were examined for skewness and kurtosis, the values of which can be found among descriptive statistics in Tables 2, 3, 4, and 5 for mood, free recall, recognition, and alpha asymmetry

measures, respectively. Following the guidelines of Tabachnick and Fidell (1996) for significance testing of skewness and kurtosis, values were compared to zero (perfectly normal) by dividing the skewness and kurtosis values by their respective standard errors to obtain z-scores. Using the convention .001 for significance tests, any z-score that exceeded 3.90 was flagged as being significantly different from zero. Based on this criteria, the data indicated acceptable levels of skewness and kurtosis for most of the free recall and recognition variables. However, there were several elevated skewness and kurtosis values for the alpha asymmetry indices, suggesting some non-normal distributions. Common methods of normalizing data include log-transformation. However, the asymmetry measures are already natural log transformed as part of the calculation of the index, $\ln(124) - \ln(24)$. According to Allen, Coan, and Nazarian (2004), raw asymmetry data tends to be extremely skewed. For instance, in their review, the authors found that the raw EEG data was skewed for 94 percent of electrode sites and featured non-normal kurtosis for 83 percent of sites. After the natural log transform, there were significant deviations from normality in 33 percent and 39 percent of sites for skewness and kurtosis, respectively. In this dataset, as is ideal, the transformation made the EEG distributions more normal. Having already been log transformed, some of the asymmetry indices remained somewhat non-normal but vastly improved from their raw distributions. As asymmetry researchers do not further transform the data, the asymmetry indices were analyzed as-is.

While skewness and kurtosis values for nearly all non-EEG variables fell within acceptable limits, five variables featured significant Kolmogorov-Smirnov z-values, indicating departures from normality. The variables are as follows: (1) Free recall for

positive words, (2) free recall for negative words, (3) Negative Affect subscale, (4) Positive Recognition Accuracy Index, and (5) Negative Recognition Accuracy Index. As is commonly done in attempts to normalize data, these five variables were subjected to a non-linear transform, in this case natural log-transformed for consistency with the transforms applied to the EEG variables. However, the transformations did not improve the Kolmogorov-Smirnov statistics for any variable and had mostly adverse effects on skewness and kurtosis statistics. The same pattern of non-improvement was also present when the variables were transformed using the square root. Normality statistics of original and transformed variables can be seen in Table 6. As transforming the data did not unambiguously improve any distributions, and transformed variables can be more difficult to interpret, the original, un-transformed variables were used in analyses despite not being perfectly distributed. It is important to note, however, that for the five variables featuring significant Kolmogorov-Smirnov statistics there was only one incidence of significant skewness (Negative Affect subscale) and no incidences of kurtosis according to z-scores. It is possible, though by no means assured, that the medium sample size could be influencing the Kolmogorov-Smirnov statistics of these variables. As sample sizes become larger, increasingly small differences between the data distribution and the hypothetical normal distribution to which Kolmogorov-Smirnov statistics are compared can become significant.

As the Kolmogorov-Smirnov statistics and skewness/kurtosis values paint conflicting images of the distributions, it is likely that any deviations from normality in the dataset are relatively minor. Even so, violations of the normality assumption can have profound impacts on correlation analyses. For instance, the most likely issue arising

from calculating correlations using non-normal data is that the coefficients can be difficult to accurately estimate, resulting in potential under- and over-estimation of effects. As the variables appear to only slightly deviate from normality, if at all, the use of Pearson's r remains appropriate. In this case, any under- or over-estimation of coefficients should be minimal. As a result, any significant correlations likely indicate valid relationships between variables even if the correlation coefficients themselves are not as precise as those that would be obtained from perfectly normal distributions.

Lastly, it should be noted that while the final sample consisted of 94 participants, the linked mastoid referenced EEG data of seven additional participants were entirely rejected by the automated MATLAB ocular artifact removal algorithm. As such, only 87 participants are featured for any correlations with alpha asymmetry of the linked mastoids reference as one of the variables.

Hypothesis 1: Mood-congruent Memory

The first hypothesis is that mood-congruent memory effects will be detected in the form of significant correlations between mood measures and memory measures such that memory of positive words increases as mood becomes more positive and memory of negative words increases as mood becomes more negative. Specifically, significant negative correlations are predicted between positive words recalled and both BDI-II scores and the Negative Affect subscale, and positive correlations are predicted between positive words recalled and both the Positive Affect subscale and the PANAS net score. The inverse relationships are expected for negative words recalled. Mood-congruent effects are hypothesized to occur for both free recall and recognition memory.

Free Recall

A Pearson product-moment correlation coefficient was computed to assess the relationship between mood and the valence of words recalled in the free recall task. There was a significant negative correlation between the number of positive words recalled and BDI-II scores ($r = -.257, n = 94, p < .012$). Figure 1 summarizes this relationship. Overall, there was a strong, negative correlation between the variables with recall of positive words increasing as BDI-II scores decrease (lower BDI-II scores are indicative of more positive mood). Additionally, a significant positive correlation was found between PANAS net score (positive affect minus negative affect) and number of positive words recalled ($r = .229, n = 94, p < .026$), indicating again the number of positive words recalled increased as participant mood became more positive. This relationship was also present using the Positive Affect subscale of the PANAS as the mood variable ($r = .216, n = 94, p < .036$). This set of correlations indicated that some mood-congruent memory effects were detected in the free recall task as expected. However, neither net free recall score (positive words minus negative words) nor recall of negative words were significantly correlated with any mood measure. A correlation matrix between all free recall and mood measures can be found in Table 7.

An additional finding related to mood and memory involves overall recall. A negative Pearson correlation between total number of words recalled and BDI-II scores ($r = -.290, n = 94, p < .005$) indicated that total number of words recalled increased as BDI-II scores decreased. Figure 2 shows this relationship. Similar results were obtained by correlations between total number of words recalled and (a) PANAS net scores ($r = .231,$

$n = 94, p < .025$) and (b) Positive Affect scores ($r = .223, n = 94, p < .031$), demonstrating increased total recall as levels of positive affect increased.

Recognition

Some mood-congruent memory effects were also detected in the recognition task. A negative Pearson correlation coefficient between scores on the Positive Recognition Accuracy Index (positive hits minus positive false alarms) and BDI-II scores showed a significant negative relationship ($r = -.344, n = 94, p < .001$). This recognition index reflects accuracy of positive words, or how accurate the participant is in identifying if a positive word was presented or not. This correlation shows that accuracy for positive words decreases as mood becomes more negative. Figure 3 shows this relationship. The fact that mood-congruent effects occurred during the recognition task in addition to free recall of positive words suggests the broad nature of the effect.

Though there were no significant correlations between Negative Recognition Accuracy Index and mood measures in the expected directions. There was a significant negative correlation between Negative Recognition Accuracy Index and the Negative Affect subscale ($r = -.253, n = 94, p < .05$), indicating that participants were more accurate in judging whether or not negative words were shown or not as levels of negative affect decreased. This last finding is the opposite of what was expected. A correlation matrix between recognition and mood measures can be found in Table 8.

Mood was also found to be significantly correlated with total recognition accuracy. This finding is similar to the finding that negative mood was associated with decreased overall free recall which was reported in the previous section. This relationship is demonstrated by negative correlations between the Total Recognition Accuracy Index,

or how accurate the participant is in discerning whether a word (positive or negative) was shown or not, and (a) BDI-II score ($r = -.313, n = 94, p < .002$) and (b) Negative Affect score ($r = -.253, n = 94, p < .014$). This finding suggests that as subjects' mood became more negative performance on total recognition accuracy decreased. The relationship between BDI-II score and Total Recognition Accuracy is shown in Figure 4.

Hypothesis 2: Alpha Asymmetry and Mood

The second hypothesis is that alpha asymmetry scores will significantly correlate with mood such that mood become more positive as asymmetry indices become more positive or left-sided, and mood will become more negative as asymmetry indices become more negative or right-sided. Specifically, asymmetry indices will be found to negatively correlate with BDI-II scores and the Negative Affect subscale, and positively correlate with the Positive Affect subscale and PANAS net scores.

Three EEG reference montages were used: average reference, linked mastoids, and vertex. Table 9 shows the numbers of artifact-free epochs included in analysis by reference montage. Though not widely reported in the literature, the ratio of rejected epochs to total epochs in the current study is slightly less than that reported in a prior study (Allen, Urry, Hitt, & Coan, 2004). The prior study reported roughly 50 percent of all epochs were rejected due to artifacts, compared to roughly 35 percent rejected in this study.

As expected, frontal asymmetry was found to predict participant mood. Specifically, significant negative correlations between BDI-II scores and alpha asymmetry (eyes open, eyes closed, and total) were found using the average reference montage ($r = -.258, n = 94, p < .012$). Figure 5 shows this relationship. The analysis

yielded no significant correlations between alpha asymmetry and any mood variable when vertex or linked mastoids reference montages were used. The correlations between mood variables and asymmetry indices can be found in Table 10.

Hypothesis 3: Alpha Asymmetry and Memory

The third hypothesis is that alpha asymmetry will significantly correlate with the valence of words recalled. Specifically, recall of positive words will be positively correlated with more positive, left-sided asymmetries. Inversely, recall of negative words will be positively correlated with more negative, right-sided asymmetries. The same relationships are hypothesized to occur for the recognition indices.

Hypothesis 3 Analysis- Free Recall

Contrary to pre-test predictions, no significant correlations in the expected directions were found between any free recall variables and alpha asymmetry of any montage. However, there was a significant correlation between the number of negative words recalled and alpha asymmetry during eyes closed segments only using vertex as the reference ($r = .223, n = 94 p < .05$). This finding indicates that as asymmetries became more positive (left-sided), recall of negative words increases. This correlation is in the opposite direction of the hypothesized relationship and will be discussed in greater detail in the discussion section.

Ancillary Analyses Relevant to Hypothesis 3- Free Recall

Though the hypothesized correlations between free recall and alpha asymmetry did not materialize, there is some evidence of differential free recall based on asymmetry indices. Splitting each asymmetry index at its median score yielded two equal-sized asymmetry groups (“high,” or more positive asymmetries, and “low,” or more negative

asymmetries). For average reference, t-tests found a trend for group differences for total words recalled, with the high asymmetry group recalling almost one word more than the low asymmetry group at $t(92) = -1.61, p < .11$. This result, and additional asymmetry group differences discussed below, can be found in Table 12.

Examination of more extreme groups was possible by also creating equal-sized tertiles and comparing the highest third and lowest third for the asymmetry data. Subsequent t-tests comparing the highest and lowest thirds found a trend for group differences (average reference) for net free recall scores (positive words minus negative words), with the high asymmetry tertile featuring significantly more positive net recall scores than the low asymmetry tertile at $t(60) = -1.71, p < .09$. Similarly, there was a trend for the high asymmetry tertile recalling more positive words than the low asymmetry tertile at $t(60) = -1.56, p < .12$.

Hypothesis 3 Analysis: Recognition Memory

While no significant correlations were found between recognition performance and alpha asymmetry, several relationships reached the level of trends. Specifically, Positive Recognition Accuracy Index scores were correlated with eyes open, eyes closed, and total alpha asymmetry values for average reference at the level of trends ($p = .111$, $p = .118$ and $p = .108$, respectively). Table 11 shows the trends by reference montage.

Ancillary Analyses Relevant to Hypothesis 3- Recognition Memory

Groups were again divided into high versus low asymmetry groups via median split to further explore possible differences in recognition memory performance between these groups. Significant differences between the high and low asymmetry groups (vertex reference) were found for performance on the Positive Recognition Accuracy

Index at $t(92) = -2.15, p < .03$, with the high asymmetry group recognizing significantly more positive words than the low asymmetry group. The high asymmetry group recognized roughly seven words while the low asymmetry group recognized roughly six words. Similarly, for asymmetry groups using average reference, the high asymmetry group also recognized roughly seven positive words while the low asymmetry group recognized roughly six positive words at $t(92) = -2.88, p < .01$. Lastly, there were group differences (average reference) on the Total Recognition Accuracy Index at $t(92) = -2.03, p < .05$, with the high asymmetry group recognizing roughly 13 total words while the low asymmetry group recognized roughly 12 words.

In order to create groups that differed to a greater degree on frontal alpha asymmetry, equal-sized tertiles were again calculated and comparison on memory measures were made between the highest third and lowest third asymmetry groups. As in the ancillary free recall results, there were group differences using asymmetry tertiles for aspects of recognition memory performance. For average reference, the high asymmetry tertile featured significantly higher scores than the low tertile on the Positive Recognition Accuracy Index at $t(60) = -2.42, p < .02$. For asymmetry tertiles using the vertex reference, there was a trend for the high asymmetry tertile having higher scores than the low tertile group on the Positive Recognition Accuracy Index at $t(60) = -1.73, p < .09$.

Results also suggest group differences for recognition biases based on word valence. The Negative Recognition Bias Index is a measure of the tendency to report having seen a negative word on the recognition task regardless of whether or not it was a target or lure and is calculated as negative hits plus negative false alarms. Using vertex reference, there was a significant group difference for Negative Recognition Bias with

the low asymmetry tertile featuring higher levels of negative recognition bias than the high tertile group at $t(60) = 2.03, p < .05$. There was also a trend for group differences using average reference with the low asymmetry tertile reporting higher levels of Negative Recognition Bias $t(60) = 1.61, p < .11$. See Table 12 for all asymmetry group differences on memory items.

Hypothesis 4: Mediation Analysis

The final hypothesis is that alpha asymmetry will mediate the relationship between mood and the valence of words recalled. Specifically, alpha asymmetry will mediate mood-congruent memory effects such that mood will no longer be a significant predictor of memory performance when alpha asymmetry is accounted for.

In order to determine if asymmetry does mediate the relationship between mood and memory, four statistical steps must be taken. As reported earlier in this section, the first step of establishing a significant relationship between mood, as the predictor, and emotional memory, as the criterion, was met. The second mediation step was also met, as there was a significant relationship between mood, as the predictor, and alpha asymmetry, as a potential mediator. However, the third step of establishing a relationship between alpha asymmetry, as the potential mediator, and emotional memory, the criterion, was not successful. While there was one significant correlation between free recall of negative words and alpha asymmetry, it was in the opposite direction than expected and the EEG segments in question did not correlate with mood and thus failed the second step. Additionally, the relationships between alpha asymmetry and recognition memory only reached the level of trends. Overall, the mediation analysis was

unsuccessful because the necessary conditions were not met by the data. Figures 6 and 7 show the mediation steps for free recall and recognition, respectively.

TABLE 1: Outlier Characteristics by Variable

Variable	Participant	Value	Residuals*	Cook's d
BDI-II	22	20	3.12	.054
NA	73	24	3.38	.072
Eyes Open (LM)	70	1.05	3.42	.088
	98	-1.04	-3.82	.094
Eyes Closed (LM)	70	.880	3.12	.072
	98	-.787	-3.03	.059
Total Asymmetry (LM)	70	.912	3.24	.079
	98	-.860	-3.33	.071
Eyes Open (Cz)	79	1.59	4.63	.911
	80	1.50	4.22	.228
Eyes Closed (Cz)	4	5.34	3.12	.072
	13	4.07	3.01	.052
	16	4.56	3.31	.167
Total Asymmetry (Cz)	79	1.35	4.46	.843
	80	1.39	4.27	.233
Eyes Open (AR)	80	1.50	4.73	.286
Eyes Closed (AR)	80	1.28	4.33	.240
Total Asymmetry (AR)	80	1.39	4.76	.289

Note. *Standardized, BDI-II = Beck Depression Inventory II, NA = Negative Affect subscale, LM = Linked Mastoids, Cz = Vertex, AR = Average Reference

TABLE 2: Descriptive Statistics of Mood Measures

Mood measure	Mean	SD	Skewness	Kurtosis
BDI-II	6.11	4.52	.675	.224
PANAS Net	17.71	8.61	.157	-.238
PA	30.93	8.33	-.150	-.377
NA	13.10	3.21	1.35*	1.65

Note. *Significantly different from normal using the z distribution and $p < .001$, BDI-II = Beck Depression Inventory II, PANAS Net = Positive and Negative Affect Scale net score, PA = Positive Affect subscale, NA = Negative Affect subscale, SD = Standard Deviation

TABLE 3: Descriptive Statistics of Free Recall Measures

Free recall measure	Mean	SD	Skewness	Kurtosis
Positive words	3.27	1.59	.078	-.818
Negative words	2.71	1.41	.105	-.221
Total words	6.03	2.27	-.375	.181
Net	.56	1.97	-.123	.109
Errors	.63	.842	1.46*	2.30*

Note. *Significantly different from normal using the z distribution and $p < .001$, Net = positive words minus negative words, Errors = extra-list intrusions, SD = Standard Deviation

TABLE 4: Descriptive Statistics of Recognition Measures

Recognition measure	Mean	SD	Skewness	Kurtosis
Positive Hits	7.32	1.39	-.620	-.054
Negative Hits	7.56	1.29	-1.25*	2.19*
Total Hits	14.88	2.17	-.629	-.053
Positive Misses	1.68	1.39	.620	-.054
Negative Misses	1.44	1.29	1.25*	2.19*
Total Misses	3.12	2.17	.629	-.053
Positive Correct Rejections	8.04	1.20	-1.95*	6.10*
Negative Correct Rejections	7.88	1.13	-.876	.396
Total Correct Rejections	15.93	2.02	-1.11*	1.21
Positive False Alarms	.96	1.20	1.95*	6.10*
Negative False Alarms	1.11	1.12	.908	.473
Total False Alarms	2.06	2.03	1.12*	1.21
Positive RAI	6.36	1.86	-.812	.443
Negative RAI	6.46	1.71	-.534	-.440
Total RAI	12.82	2.95	-.373	-.584

Note. * Significantly different from normal using the z distribution and $p < .001$, RAI = Recognition Accuracy Index (hits minus false alarms), SD = Standard Deviation

TABLE 5: Descriptive Statistics of Alpha Asymmetry Indices by Reference Montage

Alpha asymmetry	Mean	SD	Skewness	Kurtosis
Eyes open (AR)	-.129	.332	1.03*	6.30*
Eyes closed (AR)	-.149	.318	.393	4.35*
Total (AR)	-.149	.314	.881	5.87*
Eyes open (LM)	.060	.256	-.043	3.30*
Eyes closed (LM)	.039	.270	.675	1.74
Total (LM)	.039	.268	.598	2.31*
Eyes open (Cz)	-.109	.374	1.64*	7.50*
Eyes closed (Cz)	.378	1.23	2.19*	4.51*
Total (Cz)	-.129	.348	1.37*	6.43*

Note. * Significantly different from normal using the z distribution and $p < .001$, SD = Standard Deviation, AR = Average Reference, LM = Linked Mastoids, Cz = Vertex

TABLE 6: Distribution Characteristics of Original and Natural Log-Transformed Variables

Variable	K-S Statistic	Skewness	Kurtosis
Positive Free Recall	1.55*	.078	-.818
Negative Free Recall	1.40*	.105	-.221
NA	1.87*	1.40†	1.73
Positive RAI	1.71*	-.812	.443
Negative RAI	1.93*	-.534	-.440
Ln(Positive Free Recall)	1.63*	-.654	-.463
Ln(Negative Free Recall)	2.24*	-1.47†	2.30†
Ln(NA)	1.80*	.897	.146
Ln(Positive RI)	2.18*	-3.33†	18.15†
Ln(Negative RI)	2.20*	-1.14†	1.00

Note. * $p < .05$, † Significantly different from normal using the z distribution and $p < .001$, K-S = Kolmogorov-Smirnov Z-scores, RAI = Recognition Accuracy Index (hits minus false alarms), NA = Negative Affect subscale, Ln = Natural log

TABLE 7: Correlations Between Free Recall and Mood Measures

Free Recall variable	BDI-II	PA	NA	PANAS Net
Positive words	-.257*	.216*	-.025	.229*
Negative words	-.159	.082	-.090	.129
Net Recall	-.096	.120	.045	.090
Total Recall	-.290**	.223*	-.073	.231*

Note. * $p < .05$, ** $p < .01$, BDI-II = Beck Depression Inventory II, PA = Positive Affect subscale, NA = Negative Affect subscale, PANAS Net = Positive and Negative Affect Scale net score

TABLE 8: Correlations Between Recognition and Mood Measures

Recognition index	BDI-II	PA	NA	PANAS Net
Positive RAI	-.389**	.222*	-.169†	.282**
Negative RAI	-.118	-.141	-.253*	-.037
Total RAI	-.313**	.058	-.253*	.156

Note. * $p < .05$, ** $p < .01$, † $p < .1$, BDI-II = Beck Depression Inventory II, PA = Positive Affect subscale, NA = Negative Affect subscale, PANAS Net = Positive and Negative Affect Scale net score, RAI = Recognition Accuracy Index (hits minus false alarms)

TABLE 9: Total and Percentage Artifact-free Epochs Included in Analysis by Reference Montage

Reference montage	Artifact-free epochs*	Percentage of total epochs
Average reference ($n = 94$)	657.02 (169.06)	70.19 %
Linked mastoids ($n = 87$)	652.68 (179.30)	69.73 %
Vertex ($n = 94$)	608.48 (234.37)	65.01 %

Note. * Mean (Standard Deviation)

TABLE 10: Correlations Between Mood Measures and Asymmetry Indices by Reference Montage

Alpha asymmetry	BDI-II	PA	NA	PANAS net
Eyes open (AR)	-.219*	.010	-.058	.033
Eyes closed (AR)	-.275**	.083	-.018	.087
Total (AR)	-.258*	.063	-.021	.069
Eyes open (LM)	-.009	.096	.007	.091
Eyes closed (LM)	.030	.008	.025	-.002
Total (LM)	.016	.031	.018	.023
Eyes open (Cz)	-.042	-.007	-.053	.014
Eyes closed (Cz)	.063	.145	.052	.120
Total (Cz)	-.090	.020	-.029	.030

Note. * $p < .05$, ** $p < .01$, BDI-II = Beck Depression Inventory II, PA = Positive Affect subscale, NA = Negative Affect subscale, PANAS net = Positive and Negative Affect Scale net score, AR = Average Reference, LM = Linked Mastoids, Cz = Vertex

TABLE 11: Correlations Between Recognition Index Scores and Alpha Asymmetry by Reference Montage

Alpha asymmetry	Positive RAI	<i>p</i>	Negative RAI	<i>p</i>
Eyes open (AR)	.166	.111	.019	.858
Eyes closed (AR)	.162	.118	-.041	.694
Total (AR)	.167	.108	-.027	.800
Eyes open (LM)	.113	.301	.146	.181
Eyes closed (LM)	.086	.427	.165	.128
Total (LM)	.091	.403	.165	.127
Eyes open (Cz)	.052	.620	-.118	.257
Eyes closed (Cz)	.091	.381	-.005	.980
Total (Cz)	.074	.477	-.119	.254

Note. RAI = Recognition Accuracy Index (hits minus false alarms), AR = Average Reference, LM = Linked Mastoids, Cz = Vertex

TABLE 12: Asymmetry Group Differences for Memory Measures

Measure	High	Low	<i>t</i>	<i>p</i> -value	Groups
Positive Recall	3.35	2.77	-1.56	.12	AR tertiles
Net Recall	.65	-.10	-1.71	.09	AR tertiles
Total Recall	6.40	5.66	-1.61	.11	AR median
Positive RAI	6.89	5.83	-2.88	.01	AR median
Positive RAI	6.77	5.96	-2.15	.03	Cz median
Positive RAI	6.77	5.74	-2.42	.02	AR tertiles
Positive RAI	6.61	5.87	-1.73	.09	Cz tertiles
Total RAI	13.43	12.21	-2.03	.05	AR median
Negative RB	8.32	8.94	1.61	.11	AR tertiles
Negative RB	8.16	8.97	2.03	.05	Cz tertiles

Note. RAI = Recognition Accuracy Index (hits minus false alarms), RB = Recognition Bias, AR = Average Reference, Cz = Vertex. “Median” refers to groups split at the median value for each measure. “Tertiles” refers to groups composed of the top third and bottom third of each measure.

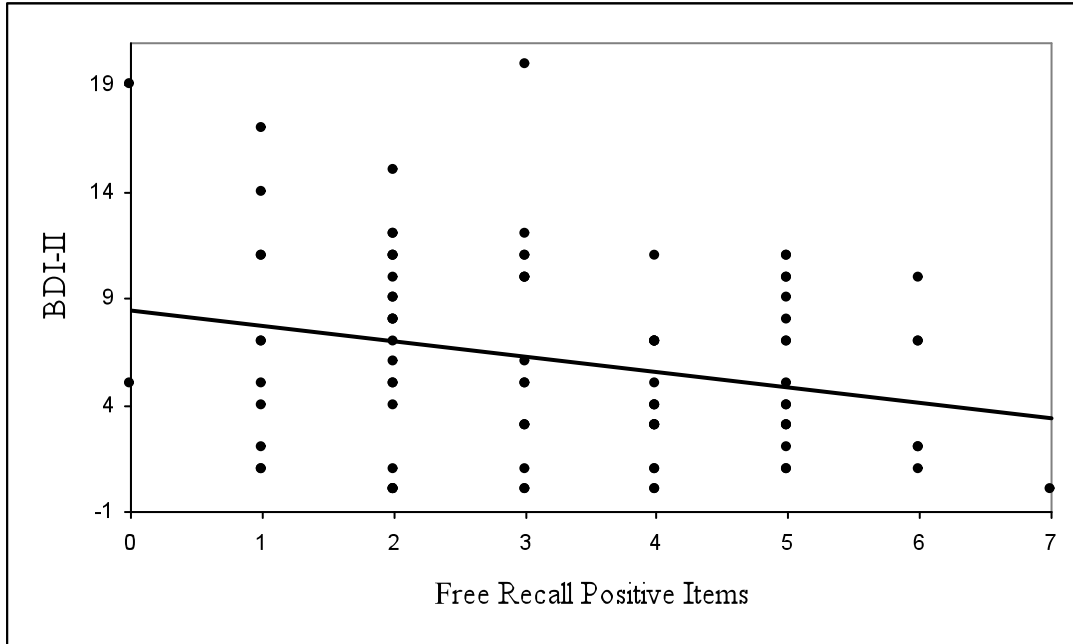


FIGURE 1: The relationship between BDI-II score and number of positive words recalled during the free recall task.

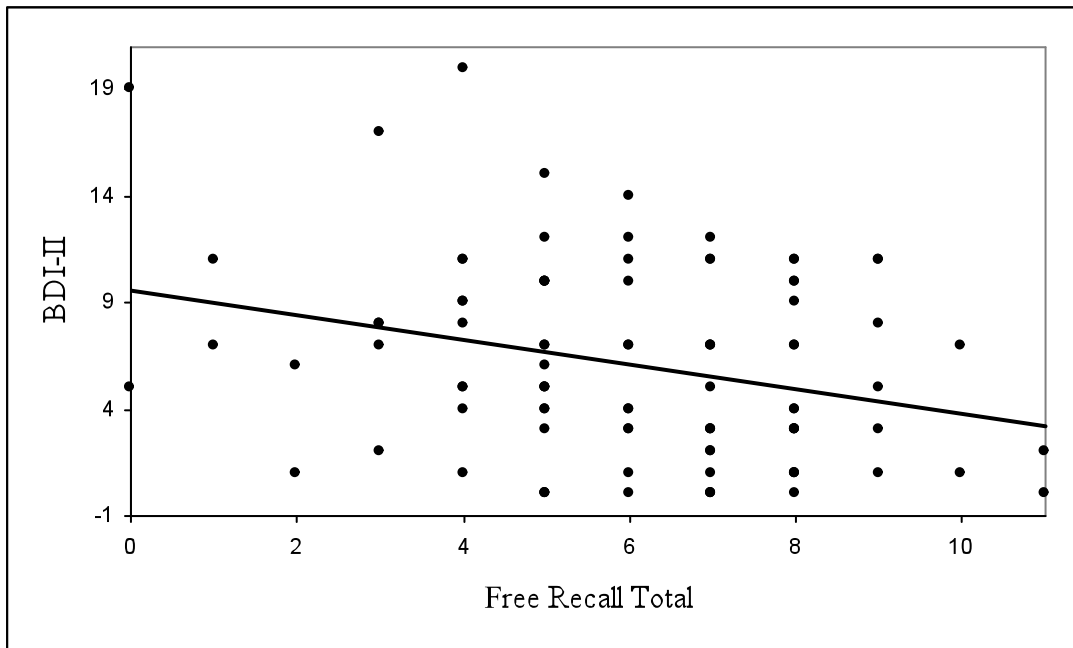


FIGURE 2: The relationship between BDI-II score and total number of words free recalled during the free recall task.

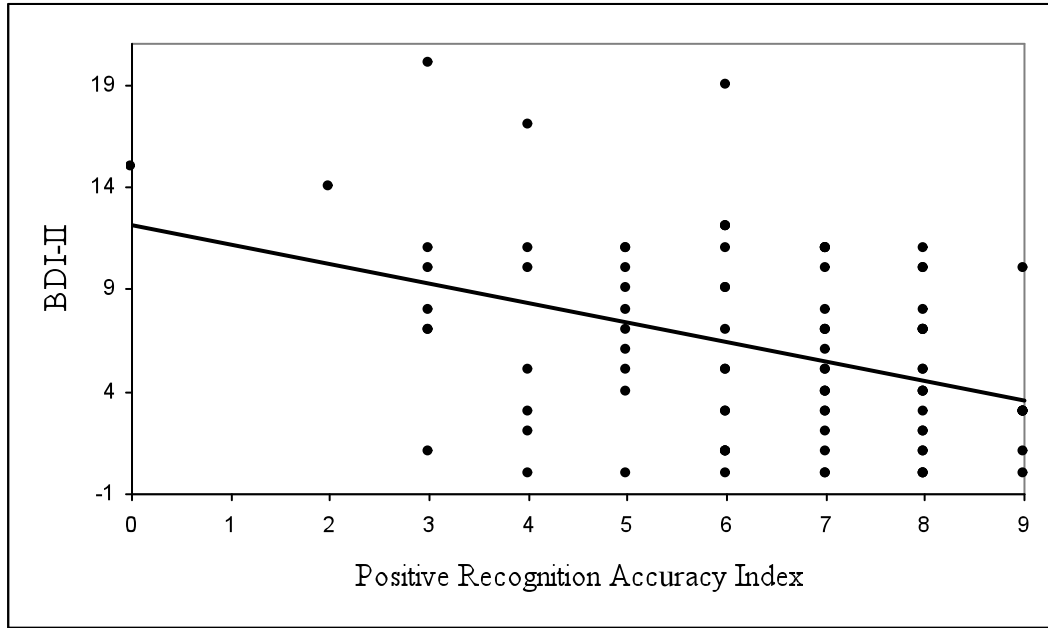


FIGURE 3: The relationship between BDI-II score and the Positive Recognition Accuracy Index.

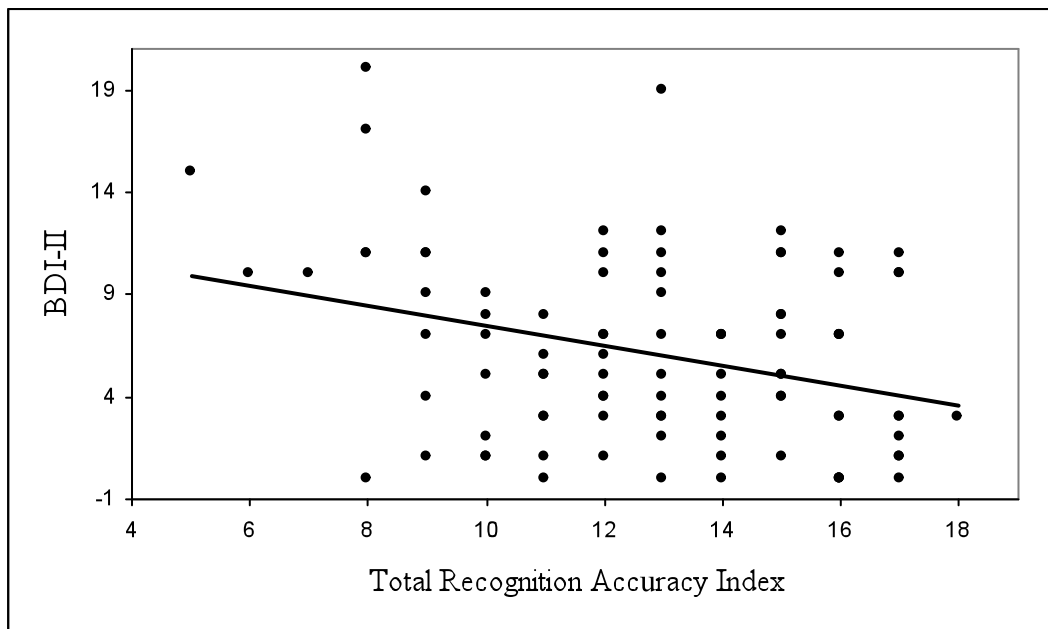


FIGURE 4: The relationship between BDI-II score and the Total Recognition Accuracy Index.

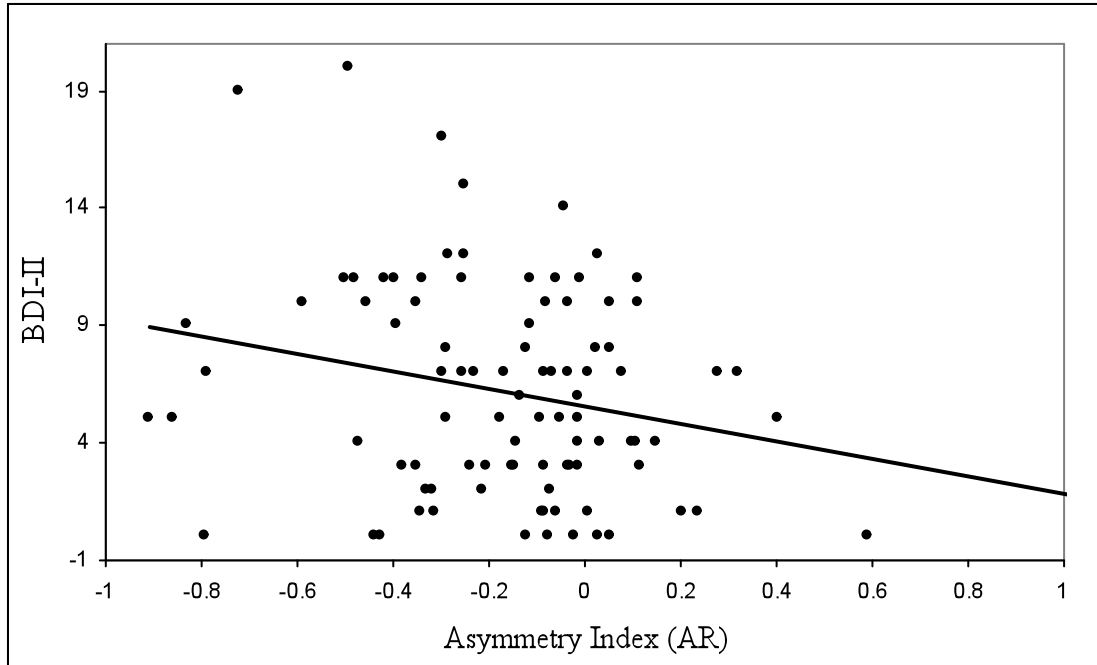


FIGURE 5: The relationship between BDI-II score and total alpha asymmetry of the average reference.

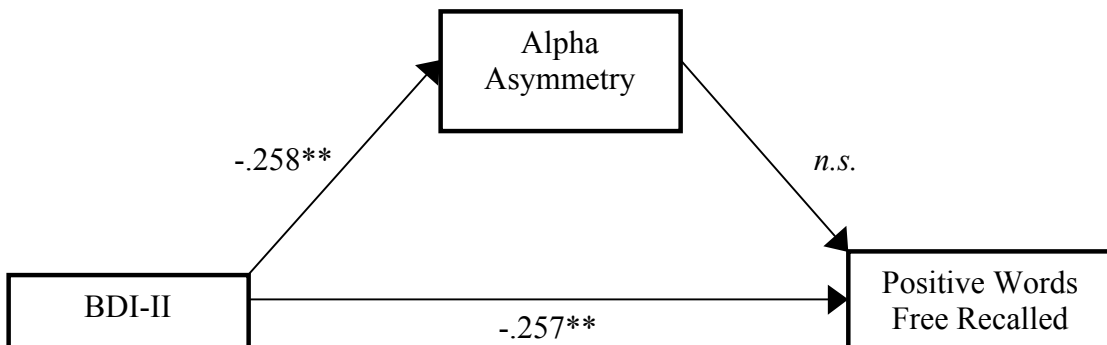


FIGURE 6: Standardized regression coefficients for the relationship between mood (BDI-II) and positive words recalled as mediated by alpha asymmetry.

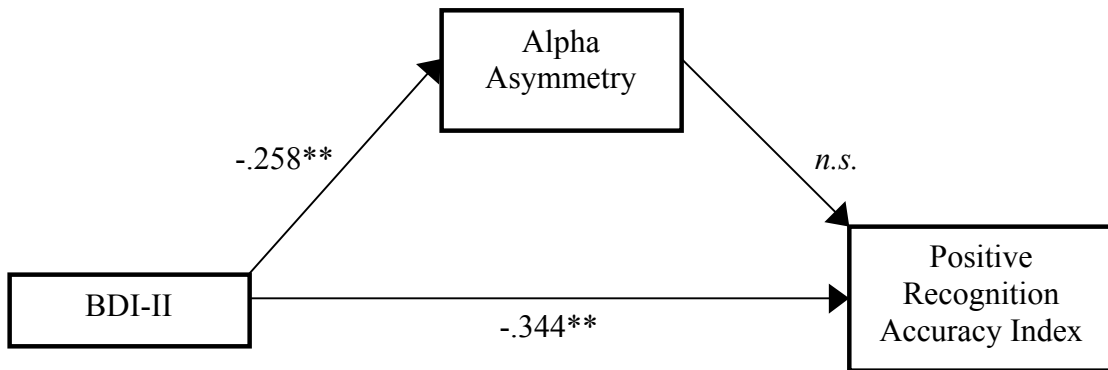


FIGURE 7: Standardized regression coefficients for the relationship between mood (BDI-II) and Positive Recognition Accuracy Index as mediated by alpha asymmetry

CHAPTER 4: DISCUSSION

The purpose of the present study was to test for a possible relationship between alpha asymmetry and affective memory and determine if asymmetry mediates mood-congruent memory effects. Alpha asymmetry indices were calculated by subtracting left mid-frontal activity from right mid-frontal activity, yielding a single metric which when positive indicates greater relative left hemisphere activation and when negative indicates greater right hemisphere activation. Mood was measured by administration of the Beck Depression Inventory II and the Positive and Negative Affect Scale. Leading up to the mediation analysis, mood-congruent memory effects were produced for both free recall and recognition tasks, and alpha asymmetry predicted participant mood. While these findings represent replications of previously published results, the ultimate goal of establishing a correlation between asymmetry and affective memory was not strictly successful. However, asymmetry groups did significantly differ in recognition memory performance and there are additional reasons for optimism for future studies examining this potential relationship.

The Effect of Mood on Affective Memory Performance

The first hypothesis tested in this study was that mood would predict recall and recognition performance for positive and negative words. Specifically, recall and recognition of positive words would increase as mood became more positive, while recall and recognition of negative words would increase as mood became more negative. As expected, recall and recognition of positive words increased as mood became more

positive. For free recall, this relationship was evident through a negative correlation with the BDI-II and positive correlations with PANAS net scores and the Positive Affect subscale. For recognition, the relationship was evident through a negative correlation with the BDI-II. These effects are consistent with the studies presented in the introduction examining mood-congruent memory effects. However, contrary to predictions, there were no significant relationships between free recall of negative words and any mood measure. For recognition memory, the only significant relationship was a negative correlation between recognition performance for negative words and the Negative Affect subscale. This relationship was not expected, and will be discussed in greater detail later in this section. Lastly, it was found that overall free recall and recognition memory performance increased with mood. For free recall, this relationship was seen in positive correlations with PANAS net scores and the Positive Affect subscale, and a negative correlation with the BDI-II. For recognition, there were negative correlations between total recognition scores and the BDI-II and Negative Affect subscale, indicating greater recognition performance as negative affect decreased, or impaired performance in the presence of higher negative affect. These findings are consistent with studies finding impaired memory performance in the presence of increased negative affect. For example, Bearden and colleagues (2006) found that both unipolar and bipolar depression groups performed significantly worse on verbal free recall and recognition tasks utilizing the 16-word California Verbal Learning Test (CVLT). Similarly, Fossati and colleagues (2004) found significantly impaired free recall performance in depressed patients compared to matched controls. As such, this study's finding of increasing memory performance with increasing mood is not

surprising. In summary, mood-congruent memory effects were found for aspects of both free recall and recognition memory performance. Participant performances were consistent with the hypothesis that recall and recognition of positive words would increase as mood became more positive and decrease as mood became more negative.

The Relationship between Mood and Alpha Asymmetry

The second hypothesis tested in this study was that alpha asymmetry would predict mood. Specifically, mood would become more positive as asymmetries became more positive, or left-sided, and mood would become more negative as asymmetries became more negative, or right-sided. As expected, alpha asymmetry (average reference) predicted mood as measured by the BDI-II, with BDI-II scores decreasing as asymmetries became more positive. This finding represents a successful replication of the numerous studies described in the introduction that reported correlations between asymmetry indices and mood measures. However, it is important to note that asymmetry indices using vertex and linked mastoids as reference montages did not significantly correlate with any mood measure. The issue of reference montages has been discussed in this paper, but average reference is generally considered to be the most ideal, if underused, montage according to Allen, Coan, and Nazarian (2004), as it is the reference that is most electrically neutral. Vertex and mastoids can be more active, leading to potential over- or under-estimation of effects. The correlation found in this study is likely valid despite non-significant results for other montages, as it utilized the preferred average reference and represents a relationship that has been previously replicated numerous times in the literature. In summary, alpha asymmetry successfully predicted participant mood as per hypothesis two. Specifically, mood became more positive as

asymmetries became more positive (left-sided) and more negative as asymmetries became more negative. This relationship was detected using the average reference, arguably the most ideal montage for alpha asymmetry research.

The Relationship between Alpha Asymmetry and Affective Memory Performance

The third and fourth hypotheses tested in this study were that alpha asymmetry would predict performance on free recall and recognition memory tasks and that alpha asymmetry would mediate the relationship between mood and affective memory. Specifically, it was hypothesized that as asymmetries became more positive, participants would show increased memory for positive words on free recall and recognition tasks. Similarly, it was expected that as asymmetries became more negative, participants would show increased memory for negative words on free recall and recognition tasks. Unfortunately, the planned correlations between these variables did not yield significant results. As such, the mediation analysis was not successful as there were no significant correlations between asymmetry and memory measures in the expected directions. It is possible that such relationships, while hypothesized, simply do not exist. However, trends between asymmetry and recognition of positive words as well as differential recognition of positive and total words between high and low asymmetry groups suggest that there may in fact be relationships between asymmetry and memory not detected by the correlations in this study. Additionally, if effect sizes between asymmetry indices and memory measures are small, larger sample sizes may be necessary. There is certainly evidence and incentive for future studies to take up the question of whether affective memory performance can be predicted by alpha asymmetry.

Theoretical Implications

While the predicted Pearson correlations between asymmetry and memory performance were not significant, the differences in recognition memory performance found between high and low asymmetry groups is promising. If future studies find additional evidence of a relationship between asymmetry and affective memory, it would represent a significant synthesis between multiple bodies of literature and could bolster and bring closer together existing models of emotion, mood, motivation, and memory.

The Davidson model described in the introduction could potentially explain the finding that overall recognition memory performance increased with asymmetry scores as well as the increased recognition of positive words in the high (left-sided) asymmetry group. Based upon his and other research, Davidson theorized that the left prefrontal cortex was associated with positive emotion and behavioral activation (BAS), while the right prefrontal cortex was associated with negative emotion and behavioral inhibition (BIS). The increased memory performance as asymmetries became more left-sided could be due to increased levels of behavioral activation in the participants, perhaps leading to greater engagement in and/or attention to the memory tasks resulting in enhanced performance. Consistent with this possibility, Gable and Harmon-Jones (2008) measured attention in participants assigned to one of two affect and motivation inductions: high-motivation-positive and low-motivation-positive. After the inductions, participants completed a visual-processing task designed to assess local versus global breadth of attention. The authors found that only participants in the high-motivation-positive induction showed increased levels of local, focused attention and decreased attention to extraneous, distracting peripheral information. If participants in the current study with

more positive, left-sided asymmetries experienced higher levels of approach motivation, it is possible they were more focused on the memory tasks. Such an increase in attention and focus could account for the higher rates of recall and recognition demonstrated by the high asymmetry groups. Additionally, since the potential increase in attention results from increased left-hemisphere activation, the increased local attention could be focused not just on the task in general but more selectively on the positive stimuli. If this was the case, it could explain the increased rates of recognition of positive words seen in the high asymmetry group compared to the low asymmetry group. To test this possibility, a future study aimed at examining the relationship between asymmetry and memory could include measures of behavioral activation and inhibition to potentially correlate with memory performance.

More positive, left-sided asymmetry scores could also be indicative of better executive functioning which could result in increased memory performance. As executive abilities are recruited to aid in recall of words in a memory task, it might be expected that a participant with more intact executive functioning would perform better on a memory task. Along these lines, Tremont and colleagues (2000) compared free recall performance on the California Verbal Learning Test between low and high executive functioning groups and found significantly impaired performance in the group with lower executive functioning. There is also evidence that increased executive functioning is correlated with more positive, left-sided asymmetries. A very recent study by Choi and colleagues (2011) examined the effect of alpha asymmetry biofeedback on the symptoms and cognition of depressed participants. The authors showed participants their real-time asymmetry indices and provided reinforcement when activation increased

in the left hemisphere or decreased in the right hemisphere. After five training sessions, the authors found that the biofeedback group (compared to a placebo group) featured significantly decreased depressive symptoms and significantly improved levels of executive function as measured by performance on the Semantic Fluency Task. Interestingly, the improvements in executive function and depressive symptoms persisted at a one-month follow-up and even increased, though not to a significantly different degree than post-treatment levels. These two studies provide additional evidence that the enhanced recognition of words by the high asymmetry group in the current study could be due to better executive functioning, which has been related to increased performance on verbal memory tasks.

Unanticipated Results

There were two significant unanticipated findings among the results. First, there was a significant negative correlation between the Negative Recognition Accuracy Index and the Negative Affect subscale. This correlation indicates that the ability to accurately discern whether negative words were shown or not increased as negative affect decreased, contrary to predictions. It was hypothesized that the ability to discern whether negative words were shown or not would increase as negative affect increased. While not expected, it is possible that the increase in performance for the recognition of negative words as negative affect decreased is due to a general increase in recognition memory performance in more positive moods. Consistent with this interpretation, results showed that total recognition performance increased as mood became less negative. This relationship was found using BDI-II scores and Negative Affect subscale scores.

An additional unanticipated finding was the positive correlation between the number of negative words recalled and eyes-closed alpha asymmetry (vertex reference). It was hypothesized that asymmetry indices would positively correlate with the number of positive words recalled and negatively correlate with the number of negative words recalled. In other words, it was believed individuals would recall more positive words as left-side brain activation increased, and would recall more negative words as right-side brain activation increased. However, the positive correlation between the number of negative words recalled and eyes-closed alpha asymmetry (vertex reference) indicates that as asymmetries became more left-sided, the number of negative words recalled increased, contrary to pre-test predictions.

There are a number of potential explanations for this correlation. The first and simplest is that the relationship represents statistical noise. As there are nine asymmetry indices (eyes open, eyes closed, and total for three reference montages) and four free recall measures (positive words, negative words, net words, and total words), there were 36 possible correlations, 35 of which did not reach significance. Additionally, it could be possible that individuals with more positive asymmetries have higher overall memory performance, not just memory for negative words. As presented in the results section, high and low asymmetry groups created by splitting the asymmetry indices at their median scores found significantly higher total recognition memory for the high asymmetry group, indicating the group with more positive asymmetries performed better on the recognition memory task. There was also a trend for increased total free recall for the high asymmetry group versus the low asymmetry group. Additionally, an independent samples t-test comparing asymmetry scores of individuals recalling six or

more total words ($n = 55$) and individuals recalling 5 or fewer total words ($n = 39$) found a significant difference between asymmetries using the index in question (eyes closed, vertex reference). Specifically, the higher-recall group had a mean asymmetry score of .615 while the lower-recall group had a mean asymmetry score of .043, a difference that reached statistical significance at $t(92) = 2.27, p < .026$. This test shows that the group with higher total recall had more positive asymmetries, and the group with lower total recall had more negative asymmetries. It is possible that the increased recall of negative words as asymmetries became more positive is a function of the more positive asymmetries seen in participants with increased total memory performance.

Limitations and Future Research

The main purpose of this study was to attempt to fill a gap in the asymmetry literature. Specifically, there are currently no published studies testing the relationship between frontal alpha asymmetry and affective memory. This study aimed to demonstrate that asymmetry would predict the valence of words recalled and recognized by individuals. No such correlations were found. However, the presence of a trend correlation between frontal alpha asymmetry (average reference) and the Positive Recognition Accuracy Index and significant differences between high and low asymmetry groups for recognition memory suggest the possibility of a relationship between asymmetry and memory. As the initial power analysis for a medium effect size called for 85 participants, the current study may have lacked the power to detect smaller effects using correlations. If the magnitude of a relationship between asymmetry and affective memory is small, a larger sample size would be needed to detect it. Future research should utilize an effect size large enough to detect small effects.

As mood-congruent memory is a well-established finding in the mood and memory literature, additional examinations of this effect are less important than more examinations of asymmetry and memory. Similarly, the relationships between mood and asymmetry have been reproduced in large numbers of studies. As mood-congruent memory and mood and asymmetry correlations are necessary elements of any mediation analysis like the one attempted in this study, future research should primarily focus on the possibility of predicting recall based on alpha asymmetry and report these other findings in the process.

There are modifications to the procedure used in this study that could potentially make the detection of such relationships more probable. First, while many studies examining mood-congruent memory and asymmetry-mood relationships utilize positive and negative mood inductions to exaggerate participants' emotional states, this study took a more naturalistic approach by examining non-manipulated resting alpha asymmetry. This approach could have potentially limited the study's ability to detect effects. The fact that this study found significant relationships between mood and recall as well as between asymmetry and mood without using mood inductions is a testament to the strength of these naturally occurring relationships. However, mood inductions in future studies could make differences in asymmetry and recall more pronounced. Analysis of variance or t-tests could show that groups based on asymmetry scores after mood inductions might show differential free recall of positive and negative words, similar to the findings presented in the current study for recognition memory. An additional limitation of this study is that we only utilized EEG recordings from before the participants were introduced to the word lists and did not record EEG activity during the

memory tasks. A future study could benefit from recording EEG data throughout the memory tasks in addition to taking a pre-test resting measurement. For instance, researchers could attempt to predict whether participants recall or recognize more positive or negative words based on the positivity or negativity of their asymmetries during the learning phase of the word list. An additional examination could look at whether the magnitude of change between baseline asymmetries and asymmetries during the learning phase predict recall or recognition, as larger changes in alpha (either positive or negative) during encoding could potentially be predictive of differential word recall or recognition. While total alpha power at each mid-frontal site during the resting baseline reading in this study was not significantly associated with recall or recognition performance, future researchers could examine absolute power at each mid-frontal site to see if changes in alpha on the left or right side during encoding predict recall or recognition. Lastly, researchers could record alpha during the testing phase to see if alpha asymmetry during recall or recognition predict differential performance. The potential analyses suggested here could determine whether alpha asymmetry at either the encoding or testing phases of memory tasks is strongly predictive of word recall or recognition. Perhaps that relationship, and not a relationship between resting baseline asymmetry and memory, would mediate the relationship between mood and affective memory. For a procedure similar to the one used in this study, recording EEG during the learning and testing phases of the memory tasks in addition to a baseline measurement would only increase recording time by roughly ten minutes and could lead to potentially predictive asymmetry data from the real-time encoding and testing phases of the memory tasks.

The discovery of additional significant relationships between resting alpha asymmetry and affective memory would provide a neuropsychological underpinning of mood-congruent memory. Specifically, such a relationship could potentially suggest that higher relative activation in one hemisphere may predispose individuals to attend to and more successfully encode information that is congruent with that hemisphere, such as positive, left-sided activation or negative, right-sided activation. The relationship, if expanded upon in future research, would represent a novel link between the mood-congruent memory and asymmetry-mood research, which are as yet related but separate bodies of literature.

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APPENDIX A: PILOT STUDY

Pilot Study

A brief pilot study consisting of two small group sessions were conducted to test aspects of the proposed procedure for the main study. Specifically, the pilot studies were run to (1) examine the distribution of mood and memory results to ensure adequate distribution for correlations, (2) confirm that the valence and arousal of words selected were perceived by participants in a manner consistent with the ANEW valence and arousal values, and (3) to conduct preliminary correlations between mood and memory items.

METHODS

Participants

All participants were University of South Florida undergraduates recruited through SONA for class credit. A total of 20 USF undergraduates earned two credits by participating in one of two pilot study sessions each lasting roughly 45 minutes. The first session consisted of 11 participants and the second session consisted of nine participants. The overall sample consisted of three males (15 percent) and 17 females (85 percent) and was 45 percent African-American and 55 percent Caucasian.

Measures

The Positive and Negative Affect Scale (PANAS) and the Beck Depression Inventory II (BDI-II) were administered to measure mood. Target and lure words used for the memory tasks were taken from the Affective Norms for English Words (ANEW) word list. For psychometric properties, references, and rationale for use of these measures, see Methods in the main paper.

Appendix A (Continued)

Procedure

Session 1

The first session was conducted in a group setting. Once all students were present, the experimenter began by introducing the study and obtaining informed consent from all participants. Following consent, each participant completed the BDI-II and PANAS. Once the mood measures were completed, participants were exposed to 24 words from the ANEW database, 12 of which were positive and 12 of which were negative, on a projected screen at a rate of one word every three seconds. After a math distracter task consisting of multiplication problems and lasting five minutes, participants were asked to silently write down all the words they could remember from the ANEW list. Upon completion of the free recall task, participants completed a word recognition task in which all 24 target words and 24 additional ANEW words matched for valence, arousal, frequency, and word length were displayed via projector one at a time in a random order while participants indicated on paper whether each word was or was not a target word. Next, the participants rated each word for valence and arousal in order to confirm that the words selected from the ANEW were perceived by the participants in a manner consistent with the ANEW normative data. Lastly, participants were debriefed and given the opportunity to ask questions about the study.

Session 2

The procedure for session two (n=9) was identical to that of session one with the exception of a reduced target word list of 18 instead of 24 words for the free recall task. Similarly, the recognition test portion contained 36 words, consisting of the 18 target

Appendix A (Continued)

words and 18 additional ANEW words matched for valence, arousal, frequency, and word length.

RESULTS

Mood Measures

Independent t-tests indicated the two pilot groups did not report significantly different scores on either mood measure. For this reason, the mood statistics reported will be collapsed across groups. For the BDI-II, the group reported a mean score of 9.3, a standard deviation of 6.56, and a range from 1 to 27. For the Positive Affect subtest of the PANAS, the group reported a mean of 17.95, a standard deviation of 12.12, and a range from 1 to 39. For the Negative Affect subtest, the group reported a mean of 22.5, a standard deviation of 12.36, and a range from 10 to 46. For the PANAS net score, the group reported an average of 11.75, standard deviation of 8.38, and a range from -8 to 27.

Memory Tasks

Free Recall Task

The first pilot study group (n=11) recalled a mean total of 6.64 words out of 24 (27.65 percent of target words recalled) with a standard deviation of 2.16 words. The group recalled an average of 3.73 positive words and 2.91 negative words recalled, though this difference did not reach significance. The group was largely accurate in their recall with an average extra-list intrusion of .55 words.

The second pilot study group (n=9) were exposed to a reduced list of 18 target words. The participants recalled an average of 6.00 words out of 18 (33.33 percent target words recalled) with a standard deviation of 2.83 words. The group recalled an average

Appendix A (Continued)

of 3.56 positive words and 2.44 negative words, though the difference was not significant. The group was also fairly accurate, with an average extra-list intrusion of .89 words.

Recognition Task

Recognition Indices was calculated by subtracting false alarms from hits for positive words, negative words, and total words. These indices are a more valid assessment of a participant's ability to discern whether a word was presented or not than hits alone as it accounts for guessing and errors. The first pilot group completed the recognition task with the original list of 24 target words and 24 matched foils. The range of Total Recognition Accuracy Index scores was three to 22 with a mean of 13.91 and standard deviation of 6.09. This performance represents an accuracy of 57.92 percent. For comparison, the less stringent average number of hits alone was 19.82 words or 82.58 percent accuracy.

The second group completed the recognition task with a reduced list of 18 targets and 18 foils. The range of Total Recognition Accuracy Index scores was four to 18 with a mean of 12.2 and a standard deviation of 3.90. This performance represents an accuracy of 67.89 percent. For comparison, the average number of hits alone was 14.44 words or 80.22 percent accuracy.

Word List Appraisals

Independent t-tests comparing participants' valence ratings of target and foil words to the ANEW normative data showed no significant difference. However, participants' arousal ratings were significantly different from the ANEW ratings ($p < .05$).

Appendix A (Continued)

After the list was reduced for the second pilot session, however, participants' valence and arousal ratings did not significantly differ from the ANEW ratings.

Mood-congruent Memory

There were no significant correlations between mood measures and recall or recognition of positive or negative words. However, there was a significant negative correlation between total number of words recalled and negative affect as measured by the PANAS ($r = -.45, p < .05$), indicating participants in more negative moods did not recall as many words as those in more positive moods.

DISCUSSION

The descriptive statistics of the mood measures and memory tasks imply adequate spread and variance for statistical analyses. The participants' appraisals of the target words were consistent with the ANEW database and indicated the words selected were perceived by participants as intended by the experimenter.

However, the analysis of free recall data from session one reported a recall mean of 6.64 words out of 24 (or 27.65%), which was lower than recall rates obtained in previous empirical studies. For instance, MacDowell (1984) found free recall scores of about 10 words out of 24 (about 40%) in a depressed population. Similarly, Denny (1992) found that non-depressed participants had mean free recall scores of slightly more than eight words out of 24 (about 33%). The free recall accuracy percentage for the first pilot session was notably lower. In an attempt to increase the percentage recalled, I reduced the list from 24 to 18, with nine positive and nine negative words making up the new list, in an attempt to decrease the cognitive burden. The results from the second pilot

Appendix A (Continued)

session using this reduced list showed a mean recall of 6 words of the 18, or 33.33%. While the percentage increased, the raw number of words recalled decreased slightly. There are several potential explanations for these results compared to those of previous studies. First, the memory tasks were administered in a group format where diffusion of responsibility may have occurred, whereas the main study utilized individual administration. Second, the sample sizes were small, giving the proportion of students not exerting much effort on the task a large influence on the results. For instance, there were two participants who recalled only three words, which is low for a free recall task. These two subjects also scored poorly on the recognition task, one of whom scoring scarcely greater than chance, suggesting low effort on the tasks. Removal of these two participants from the data results in a mean free recall score of almost seven words (around 38%), a level more consistent with prior findings. Third, the participants wrote their answers on paper in a group setting, whereas an individual and oral administration (such as in the main study) would almost certainly increase participants' effort on the tasks. Lastly, a free recall performance of between six and seven words may simply be the average performance of USF undergraduates. Due to the reduced cognitive workload of a smaller list, the increased recall after low-effort participants were excluded, and a 10 percent increase in recognition accuracy, the 18-word list was chosen over the 24-word list for use in the main study.

While the pilot study did not find any significant mood congruent memory effects, the sample size was small ($n = 20$) compared to the sample size called for by the

Appendix A (Continued)

power analysis ($n = 85$). With a proper sample size, and thus adequate power to detect relationships, such effects should become evident.

APPENDIX B: STIMULI, MEASURES, AND DISTRACTERS

Affective Norms for English Words (ANEW) words used in this study:

Positive target	Negative target	Positive lures	Negative lures
candy	frigid	rabbit	dummy
crown	fault	smooth	mold
mail	evil	breeze	dump
kitten	crude	movie	severe
kids	pest	humane	manure
bliss	fungus	wink	flood
tune	blind	greet	deceit
melody	tomb	pride	broken
heal	stink	ocean	crime

Appendix B (Continued)

The Positive and Negative Affect Scale

The PANAS

This scale consists of a number of words that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that word. Indicate to what extent you feel this way right now, that is, at the present moment. Use the following scale to record your answers.

1	2	3	4	5
very slightly or not at all	a little	moderately	quite a bit	extremely

_____	interested	_____	irritable
_____	distressed	_____	alert
_____	excited	_____	ashamed
_____	upset	_____	inspired
_____	strong	_____	nervous
_____	guilty	_____	determined
_____	scared	_____	attentive
_____	hostile	_____	jittery
_____	enthusiastic	_____	active
_____	proud	_____	afraid

Appendix B (Continued)

The Beck Depression Inventory II

Name: _____ Marital Status: _____ Age: _____ Sex: _____

Occupation: _____ Education: _____

Instructions: This questionnaire consists of 21 groups of statements. Please read each group of statements carefully, and then pick out the **one statement** in each group that best describes the way you have been feeling during the **past two weeks, including today**. Circle the number beside the statement you have picked. If several statements in the group seem to apply equally well, circle the highest number for that group. Be sure that you do not choose more than one statement for any group, including Item 16 (Changes in Sleeping Pattern) or Item 18 (Changes in Appetite).

1. Sadness

- 0 I do not feel sad.
- 1 I feel sad much of the time.
- 2 I am sad all the time.
- 3 I am so sad or unhappy that I can't stand it.

2. Pessimism

- 0 I am not discouraged about my future.
- 1 I feel more discouraged about my future than I used to be.
- 2 I do not expect things to work out for me.
- 3 I feel my future is hopeless and will only get worse.

3. Past Failure

- 0 I do not feel like a failure.
- 1 I have failed more than I should have.
- 2 As I look back, I see a lot of failures.
- 3 I feel I am a total failure as a person.

4. Loss of Pleasure

- 0 I get as much pleasure as I ever did from the things I enjoy.
- 1 I don't enjoy things as much as I used to.
- 2 I get very little pleasure from the things I used to enjoy.
- 3 I can't get any pleasure from the things I used to enjoy.

5. Guilty Feelings

- 0 I don't feel particularly guilty.
- 1 I feel guilty over many things I have done or should have done.
- 2 I feel quite guilty most of the time.
- 3 I feel guilty all of the time.

6. Punishment Feelings

- 0 I don't feel I am being punished.
- 1 I feel I may be punished.
- 2 I expect to be punished.
- 3 I feel I am being punished.

7. Self-Dislike

- 0 I feel the same about myself as ever.
- 1 I have lost confidence in myself.
- 2 I am disappointed in myself.
- 3 I dislike myself.

8. Self-Criticalness

- 0 I don't criticize or blame myself more than usual.
- 1 I am more critical of myself than I used to be.
- 2 I criticize myself for all of my faults.
- 3 I blame myself for everything bad that happens.

9. Suicidal Thoughts or Wishes

- 0 I don't have any thoughts of killing myself.
- 1 I have thoughts of killing myself, but I would not carry them out.
- 2 I would like to kill myself.
- 3 I would kill myself if I had the chance.

10. Crying

- 0 I don't cry anymore than I used to.
- 1 I cry more than I used to.
- 2 I cry over every little thing.
- 3 I feel like crying, but I can't.

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Appendix B (Continued)

11. Agitation

- 0 I am no more restless or wound up than usual.
- 1 I feel more restless or wound up than usual.
- 2 I am so restless or agitated that it's hard to stay still.
- 3 I am so restless or agitated that I have to keep moving or doing something.

12. Loss of Interest

- 0 I have not lost interest in other people or activities.
- 1 I am less interested in other people or things than before.
- 2 I have lost most of my interest in other people or things.
- 3 It's hard to get interested in anything.

13. Indecisiveness

- 0 I make decisions about as well as ever.
- 1 I find it more difficult to make decisions than usual.
- 2 I have much greater difficulty in making decisions than I used to.
- 3 I have trouble making any decisions.

14. Worthlessness

- 0 I do not feel I am worthless.
- 1 I don't consider myself as worthwhile and useful as I used to.
- 2 I feel more worthless as compared to other people.
- 3 I feel utterly worthless.

15. Loss of Energy

- 0 I have as much energy as ever.
- 1 I have less energy than I used to have.
- 2 I don't have enough energy to do very much.
- 3 I don't have enough energy to do anything.

16. Changes in Sleeping Pattern

- 0 I have not experienced any change in my sleeping pattern.

- 1a I sleep somewhat more than usual.
- 1b I sleep somewhat less than usual.

- 2a I sleep a lot more than usual.
- 2b I sleep a lot less than usual.

- 3a I sleep most of the day.
- 3b I wake up 1-2 hours early and can't get back to sleep.

17. Irritability

- 0 I am no more irritable than usual.
- 1 I am more irritable than usual.
- 2 I am much more irritable than usual.
- 3 I am irritable all the time.

18. Changes in Appetite

- 0 I have not experienced any change in my appetite.

- 1a My appetite is somewhat less than usual.
- 1b My appetite is somewhat greater than usual.

- 2a My appetite is much less than before.
- 2b My appetite is much greater than usual.

- 3a I have no appetite at all.
- 3b I crave food all the time.

19. Concentration Difficulty

- 0 I can concentrate as well as ever.
- 1 I can't concentrate as well as usual.
- 2 It's hard to keep my mind on anything for very long.
- 3 I find I can't concentrate on anything.

20. Tiredness or Fatigue

- 0 I am no more tired or fatigued than usual.
- 1 I get more tired or fatigued more easily than usual.
- 2 I am too tired or fatigued to do a lot of the things I used to do.
- 3 I am too tired or fatigued to do most of the things I used to do.

21. Loss of Interest in Sex

- 0 I have not noticed any recent change in my interest in sex.
- 1 I am less interested in sex than I used to be.
- 2 I am much less interested in sex now.
- 3 I have lost interest in sex completely.

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9 10 11 12 ABCDE

Appendix B (Continued)

The math distracter

$$\triangleright 58 \times 97 =$$

$$\triangleright 93 \times 23 =$$

$$\triangleright 84 \times 62 =$$

$$\triangleright 64 \times 33 =$$

$$\triangleright 83 \times 27 =$$

$$\triangleright 95 \times 88 =$$

$$\triangleright 41 \times 97 =$$

$$\triangleright 16 \times 93 =$$

$$\triangleright 98 \times 62 =$$

$$\triangleright 80 \times 34 =$$

$$\triangleright 82 \times 53 =$$

$$\triangleright 42 \times 17 =$$

$$\triangleright 79 \times 82 =$$

$$\triangleright 14 \times 80 =$$

$$\triangleright 86 \times 51 =$$

$$\triangleright 32 \times 82 =$$