DISSERTATION

THE INTERACTION OF EXECUTIVE FUNCTIONING AND EMOTIONAL PROCESSING, AS MEASURED ELECTROPHYSIOLOGICALLY

Submitted by

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ABSTRACT

THE INTERACTION OF EXECUTIVE FUNCTIONING AND EMOTIONAL PROCESSING, AS MEASURED ELECTROPHYSIOLOGICALLY

The current study investigated the interaction between emotion and executive functions. To better understand this relationship, responses to emotional images were measured electrophysiologically while participants performed a delayed match to sample task using emotional images from the International Affective Picture System as the stimuli. Participants rated the emotionality of the second, target image after being exposed to a first, probe image. The electrophysiological responses were measured as a late positive potential (LPP) elicited from the second images. The LPPs varied based on the emotionality of both the first and second image. Negative images were susceptible to manipulation from the first images. Additionally, participants completed an n-back test to assess their overall executive functioning. No relationship was found between the n-back task and electrophysiological responses. These results fit with a valence hypothesis and provide support to the theory that executive functions for emotional information are served by different, or at least additional, factors than those for cognitive working memory.

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Overview

Emotions play a central role in the history of psychology as an impetus for research, discovery, and treatment (Dalgleish, 2004). The study of emotional processing remains important because of the role emotions have in psychological well-being and in many psychological disorders. A wide array of psychological disorders is associated with emotional processing difficulties, particularly mood and affective disorders (Davidson, 2000) and post traumatic stress disorder (Whalley et. al. 2009). Beyond diagnosable disorders, emotions influence how people interact with the world; we pay more attention to emotionally salient stimuli (Ohman, Flykt & Esteves, 2001) and tend to remember emotionally salient information (Labar &Cabeza, 2006).

Because of the far reaching influence of emotions, understanding how emotions interact with cognitive processes could facilitate the treatment of emotional disorders and help boost cognition with emotional cues or strategies. Historically, emotions and cognition have been researched as separate branches that only recently are being intertwined. The current study investigates whether emotional processing, as measured electrophysiologically, may be influenced by executive functions, one type of higher level cognitive processing.

Emotions and Electrophysiology

Electrophysiological responses to emotional information have been well studied. Brain responses to emotional information assessed electrophysiologically are typically measured by the late positive potential (LPP). The LPP is a positive voltage trending component that appears around 300 ms post-stimulus onset (Hajcak, Dunning & Foti, 2009). This component is thought to reflect changes in electric potential within the dendrites of neurons, with excellent temporal resolution (Rugg, 1996). The amount of change in neuronal activity, as reflected by the amplitude of the LPP waveform, can be compared across types of stimuli. The amplitude of

LPPs elicited in response to emotional information, either positive or negative, are consistently heightened compared to those for neutral information for a variety of stimuli (Cacioppo, Crites, Gardner, & Berntson, 1994; Foti & Hajcak, 2008; Hajcak, 2009; Wood & Kisley, 2006), particularly for negative information (Ito, Larsen, Smith, & Cacioppo, 1998). The disproportionate and robust response to negative information compared to positive or neutral information is referred to as the negativity bias and is theorized to reflect remnants of an evolutionary need to bolster information processing of threatening stimuli (Rozin & Royzman, 2001). The negativity bias has behavioral consequences such as loss aversion, the predilection of an individual to avoid a loss than to acquire something of equal or greater value (Tversky & Kahneman, 1984; Rozin & Royzman, 2001) which is one of the first examples of how emotion interacts with cognition.

Interactions between Emotions and Cognitive Processes

Emotions have clear influences on cognition. For example, memory benefits have long been observed for emotionally salient information (LaBar & Phelps, 1998; review by Hamann, 2001). Cahill and colleagues (1996) had participants view either emotional or neutral film clips during a positron emission tomography (PET) scan. The participants recalled more pieces of information from the emotional films than from the neutral films, suggesting a memory benefit for emotional information. Additionally, this was among the first studies to highlight the importance of the amygdala in emotion and cognitive interactions. The amygdala, located alongside the hippocampus—a hub for memory formation along with other medial temporal lobe structures, has been shown to be central to emotional processing (Phelps, 2006).

A commonly reported psychological phenomenon is that of a ‘flashbulb’ memory, an emotionally charged personal life event. In a recent study that investigated memories around the attacks of September 11th at three different time points, researchers found that memories for such events are remembered for longer periods (i.e. they have a diminished forgetting curve), however, memory for the emotion experienced during such an event is not reliable (Hirst et. al. 2010). This pattern of results illuminates a problem with the interaction of cognition and emotions, that is, emotions, particularly heightened emotions, can impair cognition. Specifically, high levels of prolonged stress, or ongoing emotionally distressing circumstances, have been shown to impair memory formation (McEwen, 2000).

While the previously mentioned cases highlight the role of emotions on memory, increasingly, studies have investigated potential cognitive factors that influence emotional responses. One approach has been to alter the cognitive framing of emotional information, that is, slightly change the context of how emotional information is received. Kisley et al. (2011) investigated the effect of cognitive framing on emotional processing by randomly assigning participants into two groups. One group was told to evaluate if each image viewed was negative or not (the negative condition) while the other was to evaluate if each image was positive or not (the positive condition). Both groups responded to the same set of images, and the mere act of framing the instructions influenced the size of the electrophysiological responses. Brain responses to negative images were attenuated in the positively framed condition, a surprising result considering the robustness of the negativity bias. Other research suggests that the cognitive task of evaluation influences affective processing in terms of electrophysiological measures. Ito and Cacioppo (2000) reported that stimuli that were different from the evaluative category elicited heightened responses.

Hajcak and Niewenhuis (2006) investigated the ability to regulate emotional responses through reappraisal strategies in which participants generated an alternative, less-negative assessment of the emotional stimuli. They found that this type of reappraisal diminished LPP responses to the stimuli as compared to the condition in which the participants attended to the negative connotation. Conversely, as in the aforementioned cases of cognitive control over emotions, researchers have also found that cognitive strategies can decrease fear (Delgado, Laboiliere & Phelps, 2006), dampen reward expectations (Delgado, Gillis, & Phelps, 2008) or heighten neurological responses around reward (Knutson, Fong, Adams, Varner, & Hommer, 2001) and other emotional responses (Ochsner & Gross, 2005).

Taken together, the abovementioned studies suggest that affective processing, measured by LPP, is influenced by several different forms of cognition. Neuroimaging work has added to the understanding of interactions between emotion and cognition. For example, both the prefrontal cortex and the anterior cingulated have been shown to be crucial in emotional processing (Simpson et. al., 2000) as they are in many forms of cognition (Badre & D'Esposito, 2007; Bush, Luu & Posner, 2000; Sawaguchi & Golman-Rakic, 1991; Smith & Jonides, 1999). One cognitive domain that has been of particular interest in terms of the interaction between emotions and cognition is executive functioning. Executive functioning refers to the ability to maintain or manipulate information in service to a task goal such as problem solving, planning or reasoning (Baddeley, 1996). Maintenance refers to the ability to keep information active while manipulation refers to the performance of operations on active information. Both of these processes require the DLPFC, but manipulation to a greater extent (D'Esposito, Postle, Ballard, & Lease, 1999). An interaction between cognition and emotional processing could potentially rely on such maintenance of either an emotional state or a cognitive goal and a manipulation of either the goal or the cognitive state. In the brain, the dorsolateral prefrontal cortex (DLPFC) and the ventromedial prefrontal cortex (VMPFC) are crucial for regulation and control of emotions and these are the very regions that are repeatedly identified as crucial players in working memory and executive functioning (Sawaguchi & Golman-Rakic, 1991; Smith & Jonides, 1999). This anatomical overlap further suggests that executive functioning may be crucial in emotional processing and vice versa.

Understanding the potential interaction between executive functions and emotional processing could provide clues as to how both executive functions and emotional processes occur as well as how to potentially improve both of these processes. However, few studies directly test this type of interaction. Studies of early cognition, such as attention, and emotional processing consistently show that emotional stimuli demand more resources than non-emotional stimuli (Ohman et al, 2001; e.g. Pessoa, Padmala, & Moland, 2005). Gray (2001) tangentially investigated the interaction between emotion and working memory. Gray induced emotional states on participants prior to their participation on both a spatial and verbal version of a working memory n-back test. His results were mixed; a pleasant induction enhanced verbal tasks while impairing spatial ones. The opposite was found for unpleasant induction states. This discrepancy is consistent with research suggesting that separate networks serve to regulate positive and negative information (Kim & Hamann, 2007). Davidson (1995) proposed the valence hypothesis, stating that different neuroanatomical pathways served to process affective information. His hypothesis is supported by the aforementioned studies. Furthermore, Dolcos, LaBar, and Cabeza (2004) had participants rate the valence of an image (positive, neutral or negative) while undergoing fMRI. They compared the ratings and brain activation to subsequent memory for the images. They found that images rated as positive when viewed were accompanied by greater activation in the left DLPFC and positive images showed greater activation in the VMPFC. The authors interpret the activation patterns as highlighting the importance of working memory and executive functioning in emotion and cognition.

Aims and Task Development

While some evidence suggests that executive abilities could interact with emotional processing as observed in responses to emotional information, this issue has not been sufficiently addressed in the literature. Using the strong history of LPP in emotional processing provides an opportunity to do this. The goal of the current study is to investigate the relationship between executive functions and emotional processing, as measured electrophysiologically. I expected the amplitudes of the brainwaves (the LPP) to change with executive abilities. To address this question I created a task that simultaneously tasked executive functioning and fit within the confines of ERP paradigms to elicit the LPP waveform. Borrowing from animal literature, a typical delayed match to sample task was developed (as in Miller, Erikson & Desimone, 1996). In Miller et al., the subject, in their case a macaque monkey, was presented with an initial "probe" image for a brief period of time followed by a short delay and then another, non-matching image. Finally, an image that does match the target image, either partially or entirely was presented and confirmed by the participant. This task relied on executive functions because of the requirement to maintain the probe image across a delay and to make an evaluative comparison (a manipulation) of the non-matching image after the delay. To edit this task to use with emotional images, the task has been adapted in two crucial ways. First, presentation of each emotional image must be sufficient. In electrophysiological research with emotional images, presentation is usually around 1000 ms, enough time to elicit the late positive potential. Second, the comparisons of interest here are the potential changes in brain activity that arise from the influence of the emotionality of the probe image on the second. Therefore, the response of interest is that to the second image. For this reason, the confirmation phase of the task was a forced 4-choice. Additionally, we cross-compared emotionality to investigate the influence of the first image emotion type on the second image response. All images were selected from the International Affective Picture System (IAPS) which tracks normative data for valence and arousal of hundreds of images. Images used were matched for arousal. Neutral images were items such as 5920, 7640, with a mean valence rating of 4.89 and mean arousal of 6.12. Positive images were items such as 7502, 8034, 8170, and 8499 (*Mv* ~= 7.51, *Ma* ~= 6.10). Negative images will be items such as 3550, 6821, 9300, and 9902 (*Mv* ~= 2.37, *Ma*~= 6.05).

To directly assess cognitive executive functioning an updated n-back task (Gevins & Cutillo, 1993) was created with the task stimuli adapted to be fitting with the current study. This task displays a series of stimuli to the participant who must respond when the stimulus presented matches that presented ‘n’ number of items ago. This task tests working memory due to the required maintenance of the previous item and manipulation of the previous series of items in contrast to the current item. These differences have also been reflected in different cortical activation patterns based on the value of n (Jonides et al., 1997). Typically n ranges from zero to three and has been explored across a variety of stimulus types (see meta-analysis Owen, McMillan, Laird & Billmore, 2005). The n-back used neutral images from IAPS as the stimuli to keep stimuli constant across both tasks, with n’s of one and three. Participants were scored on target accuracy.

Hypotheses

1. 2nd image analysis: The LPP amplitude in response to the 2nd image will be influenced by the emotional valence of the initial probe image. One possible relationship is that the mere presence of an emotional probe image

will boost a later emotional response. An alternate possibility is that the LPP in response to the 2nd image could selectively be accentuated only in a case of either congruent or incongruent emotional valence. For example, an initial positive image could accentuate a response to a later presented positive image only or it may accentuate the response to a later presented negative image only while an initial neutral image would have no effect.

2. The LPP amplitude in response to the second image will be influenced by executive functioning ability. Performance on executive functioning task will contribute to later emotional response. It is predicted that executive performance will provide a mechanism for greater modulation of later electrophysiological responses to the emotional images.

Method

Participants

A total of 136 participants took part in the study. Ninety-nine met minimum criteria data for inclusion, outlined in the results section (48 female, mean age 19.14 years). Participants were undergraduate students at Colorado State University and received course credit for their participation.

Electrophysiological Recordings

Electrophysiological recordings were measured from Ag/AgCl electrodes from (named by the International 10-20 system) Fz, Cz and Pz referenced with an average of RM and LM and grounded at the forehead. Pz is the typical electrode of interest in studies of emotion (e.g. Hajcak, MacNamara, & Olvent, 2010). EEG were recorded with a SynAmps 2 amplifier and headbox and Neuroscan 4.3 software with a sampling rate of 1000 Hz and a .1-100 Hz band pass filter. All experimental procedures were presented to the participant via E-Prime software on a 17 inch flatscreen monitor approximately 60 cm away.

Procedure

Participants had their brainwaves recorded while completing the modified delayed-match-to-sample task. To establish a baseline, participants first passively viewed a set of each emotional image, each presented for 1000 ms, in a random order and repeated five times. In the experimental paradigm, the initial probe image was either positive, neutral, or negative in valence and matched for arousal. The initial image was presented for 1000 ms followed by a 3000 ms delay during which time the participants were asked to maintain their thoughts on the initial image, as in Van Boven (2009). The comparison image, either positive or negative in valence, was then presented for 1000 ms. Participants were prompted to make a behavioral assessment of the emotionality of the second image using the Self-assessment manikin (SAM), a pictorial scale to assess affect/emotionality (Lang, Bradley, & Cuthbert, 2005). Participants indicated the emotionality of the image by pressing a key that corresponded to the appropriate manikin. Finally, participants matched the probe among a set of four images and indicated this with a key press. This procedure repeated for 210 randomly ordered sets (30 of each comparison type).

Participants also completed an n-back task with n's of one and three. There were three trial blocks of 27 images presented randomly. Ten of the 27 images were targets. Participants were scored on correctly identified targets.

The tasks order was randomized. After completing both tasks, participants completed normative ratings of the IAPS images and were debriefed.

Results

EEG Analysis

Data were analyzed offline using Scan 4.3. Raw EEG waves were epoched from -100 to 1000 ms, and subjected to linear detrending for the entire sweep and baseline correction for the prestimulus interval. Artifact rejection was completed on EOG1 and EOG2 for +/- 100 mV and data for trials occurring beyond this window were rejected. Further rejection was assessed after grand averages were computed and are noted. The remaining trials were filtered using a low pass filter at 9 Hz with 24 dB per octave. An offline reference was algebraically computed to include an average of both mastoids. Grand averages were completed for each participant in each condition. I further excluded any condition in which the trials did not meet a minimum average of eight trials accepted per condition. This resulted in 37 subjects lost due to too few trials across conditions and two lost to equipment error. Analyses were completed on the 97.

LPP analysis for each condition

Grand average waveforms were created based on the emotionality of the initial image presented; positive, neutral or negative. Figure 1 shows these waves. Grand averages were also created for each emotional pair presented, resulting in six different waves. These are presented in Figure 2 for the positive second images with the corresponding means and latencies in Table 1. The waves and descriptive statistics for the negative second images are presented in Figure 3 and Table 1.

A 3 (First image: positive, neutral, negative) x 2 (Second image type: positive, negative) repeated-measures ANOVA revealed a significant effect of the second image type on the amplitude of the LPP with negative second images eliciting larger LPP amplitudes ($F(1,97) = 14.43$, $p < .001$, $\eta^2 = .13$). Further, there was a significant interaction between the first and second images, $F(2,194) = 3.04$, $p = .05$, $\eta^2 = .03$. However, there was no influence of the emotion type of the first image presented ($F(1,97) = 0.50$). Post-hoc corrected comparisons showed that there were no differences in the amplitude of the LPP in response to the second positive image. However, the second negative image showed an attenuation of the LPP wave following the positive image compared to the negative image ($t(97) = 2.21$, $p = .029$) and the neutral image ($t(97) = 2.35$, $p = .021$). Additionally, when the first image presented was emotionally negative, the LPP amplitude was greater for the negative compared to positive second image ($t(97) = 4.84$, $p < .001$). The post-hoc tests also confirmed that there were no overall differences between the LPP amplitudes for the second image types following a positive ($p = .13$) or a neutral ($p = .12$) image. Latency analyses revealed that the LPPs in response to a second negative image occurred later that those in response to a positive second image ($F(1,97) = 26.40$, $p < .001$, $\eta^2 = .21$).

Behavioral Data

The mean of the participants ratings were used for each image combination type. Data were rescaled to the same scale (1-5) such that the higher rating, the greater emotionality of the image. The mean ratings are reported in Table 2a and displayed in Figure5. A repeated measures ANOVA on the ratings of emotionality of the images showed a main effect for second image type ($F(1,90) = 93.90$, $p < .001$, $\eta^2 = .90$) as well as for first image ($F(2,180) = 9.05$, $p < .001$, $\eta^2 =.09$). Importantly, there was an interaction between the first and second image types on the reported emotionality of the images ($F (2,180) = 67.91$, $p < .001$, $\eta^2 = .43$). Follow up corrected comparisons showed that a positive image received a more positive rating after viewing either a negative ($t(90) = 7.48$, $p < .001$) or neutral ($t(90) = 4.36$, $p < .001$) first image. A negative first image diminished the rating of a positive second image to an even greater degree than the neutral did ($t(90) = 6.97$, $p < .001$). The negative second image was similarly rated as the most emotional when preceded by a negative image ($t(90) = 7.05$, $p < .001$ compared to positive-negative pair and $t(90) = 6.70$, $p < .001$ when compared to neutral-negative pair). Additionally, differences in reaction times were observed based on the type of image interaction (refer to Table 2b). Overall reaction times for negative images were faster than positive ones ($F(1,93) = 5.56$, $p = .02$, $\eta^2 = .65$). There was an interaction between the emotionality of the first and second image types on the reaction time $F(2,186) = 90.47$, $p < .001$, $\eta^2 = .49$). Follow up post-hoc corrected comparisons showed that reaction time was faster for a negative-negative pair than for a negative-positive pair ($t(97) = 9.62$, $p < .001$). Similarly the positive-positive pair was rated more quickly than the positive-negative one ($t(97) = 7.30$, $p < .001$). There were no differences in reaction times for the ratings of images following a neutral image.

n-back Analysis

The n-back task was scored for the number of targets correctly identified. Participants were excluded if they failed to make a response for more than 75% of the trials; 21 participants were excluded. An additional eleven participants were excluded due to a programming change. The means and proportions of correctly identified targets are presented in Table 3.

Linear Models

It appeared that n-back performance did not predict changes in the amplitude of the LPP. There is only an effect of second image, and just a marginal effect of n-back performance.

Discussion

This study is unique in its use of emotional information as the stimuli for a working memory task. The emotional category of the first image influenced the degree of neuronal response to the second emotional image. Overall, second negative images elicited the greatest activity as measured in larger LPPs. Additionally, there was an accentuation of responses to congruent pairing of negative stimuli and an attenuation of the LPP when the emotionality of the second image was incongruent with the first (i.e. negative imaged followed a positive image).

Emotion and Electrophysiology

Consistent with previous research, negative emotional information appeared to be both more robust and more easily influenced than positive emotional information. The influence of has been observed in reappraisal of negative images (Hajcak & Niewenhuis, 2006) in framing of negative images (Kisley et al, 2011) and in the mere electrophysiological response to the images themselves (Ito & Caccioppo, 1996). The previous studies have relied on cognitive techniques that require working memory, yet are not themselves executive functions. The current study directly employs working memory and adds further evidence to this trend in a novel manner by active engagement based on an emotional comparative evaluation.

The uniqueness of negative information has been well documented and may occur for several reasons. As noted earlier, there are different emotional pathways for negative compared to positive emotional information (Kim & Hamann, 2007). Negative emotional stimuli are more likely processed through the amygdala for fear, the subcollasal cingulated for sadness and basal ganglia for disgust, whereas positive emotional information more generally relies on the basal ganglia (Phan, Wager, Taylor, & Liberzon, 2001). Thus, the ability to influence the affective processing will differ because the neuroanatomical pathways differ. Ito and Caccioppo (1996) called the negativity bias adaptive. The fact that negative information is processed differently than positive information and that negative information was more readily altered may say something about how working memory interacts with the processing systems for emotional information. At a neuronal level, the influences of the cognitive maintenance and manipulation of the comparison of images may be differentially connected to negative emotional systems as compared to positive.

Emotion and Working Memory

Few studies have directly linked emotion to working memory. In the present study, no relationship was found between the behavioral cognitive working memory (as measured by the n-back task) and the electrophysiological emotional working memory task. One reason for this lack of relationship is that the n-back task may not be the best proxy. It is a broad measure of performance of the central executive of working memory and perhaps its breadth obscured the sensitivity necessary to account for an electrophysiological relationship, which will be discussed later. Additionally, emotional processing may involve more than just load and capacity for which the n-back is a good measure. A recent study investigating the role of working memory load and emotional processing found the amplitude of the LPP decreased when under conditions of a higher working memory load conditions (MacNamara, Ferri & Hajcak, 2011). MacNamara and colleagues compared the LPPs in response to neutral and aversive stimuli that interrupted a working memory task. The task was only for maintenance of information rather than manipulation of that information. The addition of a comparison requires both maintenance and manipulation. And in the current study, those with higher capacity (as evidenced by better performance on the higher load condition (3-back)) exhibited no difference on behavioral ratings or on the amplitude of the LPP. Emotional information may move the task beyond that typically measured by working memory. And the introduction of emotional information shows a path divergence in processing that may not be estimated by general working memory.

While there was no direct relationship between the behavioral working memory task and the electrophysiological one, it is clear that the inherent working memory embedded in the electrophysiological task influenced outcome measures. First, there were changes in both the LPP and the waveforms in general. Second, there were changes in the behavioral ratings and their reaction times. These changes suggest that the cognitive comparison reliant on working memory has occurred. It is not clear whether these observed changes relate to more general concepts of working memory and what that relationship may look like. One possibility is that traditional cognitive working memory does not play a role in processing emotional information. The observed effects could be due to something else, such as an overlap in observed electrophysiological processing of emotional information. There is some electrophysiological evidence that supports LPP responses in working memory. Gevins et al (1996) found P3 late positive potential-like waves in response to non-matching stimuli were observed in prefrontal scalp locations on an n-back task. The P3 is similar to an LPP in that it is an evaluative component that is typically elicited for infrequent stimuli. In the Gevins study, this component was interpreted as reflecting tonic processing in the DLPFC. While this is not sufficient to account for trends in the LPP in the current study, it is possible that tonic activity in the DLPFC facilitates comparisons in the delayed match to sample task and influences the LPP.

Several previous studies have investigated dissociations of positive and negative emotional information in memory. Gray (2001) found that negative emotional induction (avoidance states) improved spatial working memory but not verbal, while positive emotional states (approach) showed the opposite influence. Hemisphere specifics were one rationale given to the dissociation, also noted was the possibility of role of mood state. Building on this differentiation of valence, Dolcos (2004) noted that evaluative ratings of emotional images yielded different patterns of brain activation in the PFC depending on the emotionality of those images. This was noted as fitting with a valence hypothesis in which different brain regions served different valence states. Additionally, he proposed that positive information may be used in typical working memory, maintenance and manipulation, while negative information might be subjected to inhibition or avoidance. In terms of the present study, the cross comparison may have more greatly taxed the responses, hence the attenuation of the LPP for incongruent pairs. This may also suggest that within group comparisons would be "easier" because of reliance on only one system. This is exactly what was observed in the reaction time responses; they were faster for congruent than incongruent pairs.

Taken together, past research suggests that emotional processing will differ based on the task requirement of maintenance versus manipulation (Davidson & Irwin, 1999). Further, the neuroanatomy involved in manipulation is more associated with the DL PFC and with positive emotional content (Dolcos et al, 2004) whereas negative emotional content is more associated with inhibition and the VLPFC. The present study required manipulation of both positive and negative information and observed a differential processing in the LPPs for the different types of emotional information. The McNamara (2011) study only required retention, i.e. maintenance, for negative information and found that for maintenance and inhibition higher working memory requirements decreased the ability of emotional processing and there was a diminished LPP. In the present study we also observed this diminished LPP for negative second images after having viewed a positive image. The Dolcos (2004) study required an evaluative emotional rating which required some active processing and revealed underlying neuroanatomical differences. The pattern of results in the current study supports a valence hypothesis. Trials with an initial neutral image serve as a baseline for maintenance processing. The neutral-negative pair reflects processing along the ventral, inhibitory, negative valence line. The neutral-positive pair reflects processing along the dorsal, manipulative, positive line. The LPP is similar for these neutral pairs. For congruent trials, the amplitude of the LPP for negative stimuli is greater than that for positive stimuli. The interaction of the maintenance embedded in the task with inhibitory processes related to more negative information bolsters the response. The negative information may initially provide a heightened response (as in the negativity bias) that serves to focus by gating out other task irrelevant information such that manipulation in the comparison of the images is using amplified and focused responses. The combination of both ventral and dorsal systems is exhibited in the incongruent trials. In this case, the first image would initiate processing along one pathway which would then need to be compared to the other. The observed results arise from the interaction of these systems. The negative system may recruit greater neuronal activity but this effect is diminished with the inclusion of the positive information and the manipulation requirement. The executive processing of negative information is particularly malleable. This may be why the negativity bias exists. The response to negative information is greater, and subsequent negative emotional information is even more damaging. However, if the more dorsal, manipulative positive processing precedes the negative information, the effect can be diminished. Not just that negative emotions uniquely processed, that processing is different. One item of interest here is that although negative information was more relevant electrophysiologically, the behavioral data suggested that positive information was more tractable. While the neuronal responses to negative information may be along a evolutionarily embedded processing stream, the responses to positive information may better integrate later cognitive evaluations, particularly at a behavioral level.

Importantly, Davidson (1999) asked if working memory for emotional information was the same as working memory for cognitive information. Based on these data, the answer appears to be no. The evidence did not support the premise that cognitive working memory was related to affective working memory: something about the addition of emotional information changes the framework. There may still be a relationship between the cognitive and affective components of working memory. One possibility is that both rely on the DLPFC but are served by different connective pathways. Similarly different connective paths serve verbal compared to spatial information. Additionally, the DLPFC is organized along two gradients. The dorsal-ventral gradient serves the task demands and the anterior-posterior serves task complexity or difficulty (Badre, 2008). The type of emotional stimuli may differentiate the brain pathways involved. Just as the central executive shows differences in updating and inhibition, these could extend to emotional pathways. The precise interactions of emotion and working memory are still unclear because it appears that working memory for affective information is different from working memory for cognitive information. The ability to integrate these may be crucial in cognitive control. This raises the question, what is affective working memory and how does it compare to cognitive working memory?

Future Directions

Future research should aim to tease apart the roles of the positive/negative, manipulation/inhibition, and dorsal/ventral processing streams. This could include employing targeted cognitive working memory measures for manipulation and inhibition, and using combinations of valenced stimuli, using additional neuroimaging techniques. Future work could also investigate potential shared components of cognitive and affective working memory, such as electrophysiological markers in cognitive working memory tasks. Two other continuums are still yet unstudied: arousal and valence. These were experimentally held constant in the current study. Using a broader range of positive and negative may expose more about the processing stream (i.e. how positive or negative does information have to be to instantiate one stream? Where does neutral end? Do varying degrees of emotional information perform differently? Interact differently?) The role of arousal may also modify the interactions in these systems.

To summarize, the manipulation of the LPP wave in the present study is different than in previous work with cognitive strategies because here there is an active engagement based on a comparison. This represents a new type of strategy for cognitive control over emotional processing. The results suggest that executive processing for emotional information is different than cognitive working memory. Further, the results support a valence hypothesis with different executive interactions for positive than negative information.

Tables

Second Image	Amplitude		Latency	
First Image	Positive	Negative	Positive	Negative
Positive	4.18 (3.10)	4.75 (2.69)	802.22 (144.75)	866.54 (115.66)
Neutral	4.20 (3.05)	4.81 (2.74)	810.18 (139.36)	862.12 (134.32)
Negative	3.90 (2.57)	5.49 (3.18)	811.38 (138.85)	865.35 (144.17)

Table 1. LPP amplitude and latency.

Means and standard deviations of the LPP amplitude and latency. Overall, negative images elicited greater amplitudes.

First Image	Second Image Type Positive	Negative
Positive	4.18 (0.47)	3.16 (0.56)
Neutral	3.93 (0.49)	3.30 (0.46)
Negative	3.39 (0.87)	3.60 (0.53)

Table 2a. Mean behavioral ratings of emotionality of the viewed images.

Means and standard deviations, in parentheses, of the emotionality of the second image after having viewed the first.

First Image	Second Image Type Positive	Negative
Positive	1803.65(770.21)	2264.48(873.70)
Neutral	2050.44(801.97)	2026.90(878.85)
Negative	2369.52(1105.33)	1634.05(751.91)

Table 2b. Mean reaction times (in ms) of behavioral ratings of image emotionality.

Means and standard deviations, in parentheses, of the reaction times in rating the emotionality of the second image after having viewed the first.

	Number Correct	Proportion Correct
1-back	22.66 (7.05)	0.76 (.24)
3-back	14.94 (8.79)	0.50 (.29)
Overall	37.60 (13.21)	0.63 (.22)

Table 3. N-back scores

Means and standard deviations, in parentheses, of the number and percent of correctly identified targets.

Figures

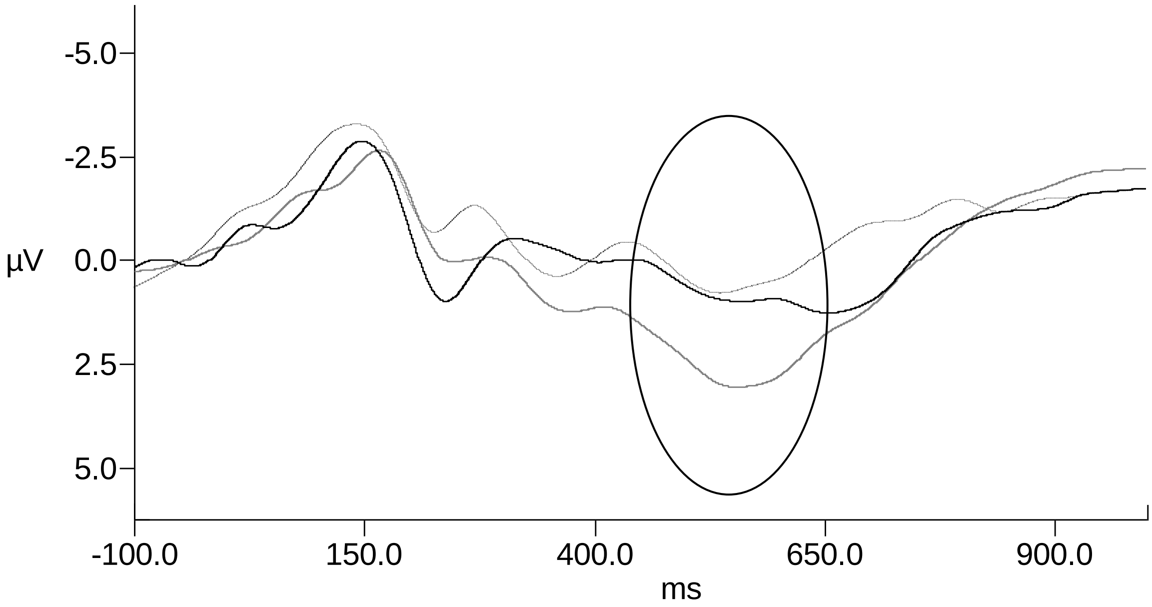

Figure 1. Grand Average waveforms for the LPP in response to the initial image.

The waveform of the second positive image following a positive first image is represented by the black line, a neutral first image is represented by the dashed-dotted line, and a negative first image in light gray.

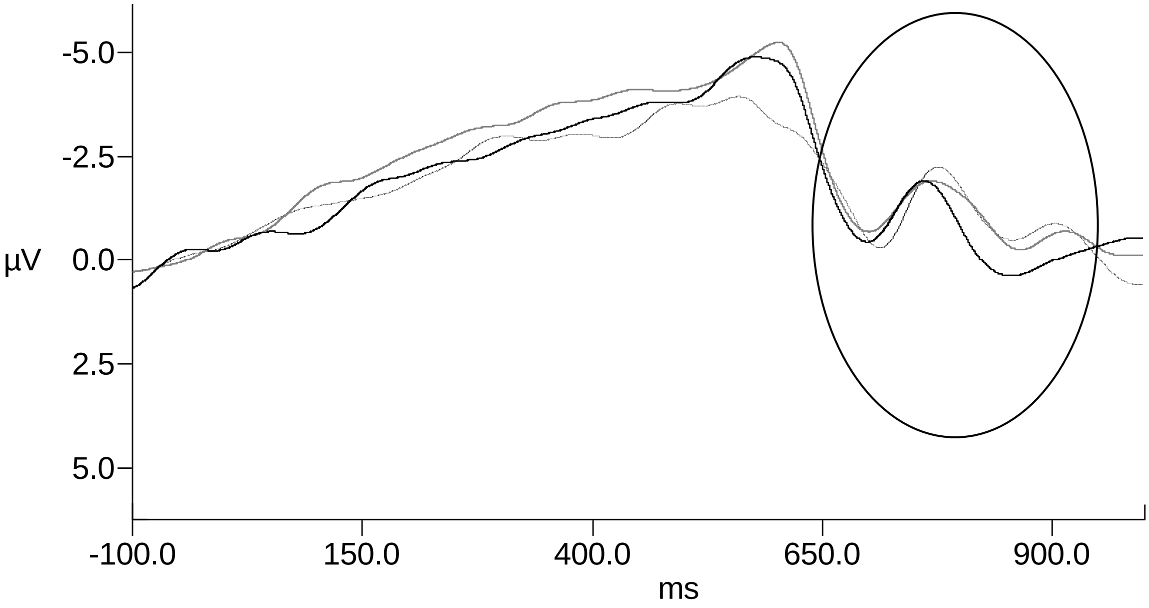

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Figure 2. Grand Average waveforms for the LPP in response to the positive second image.

he waveform of the second positive image following a positive first image is represented by the black line, a neutral first image is represented by the dashed-dotted line, and a negative first image in light gray.

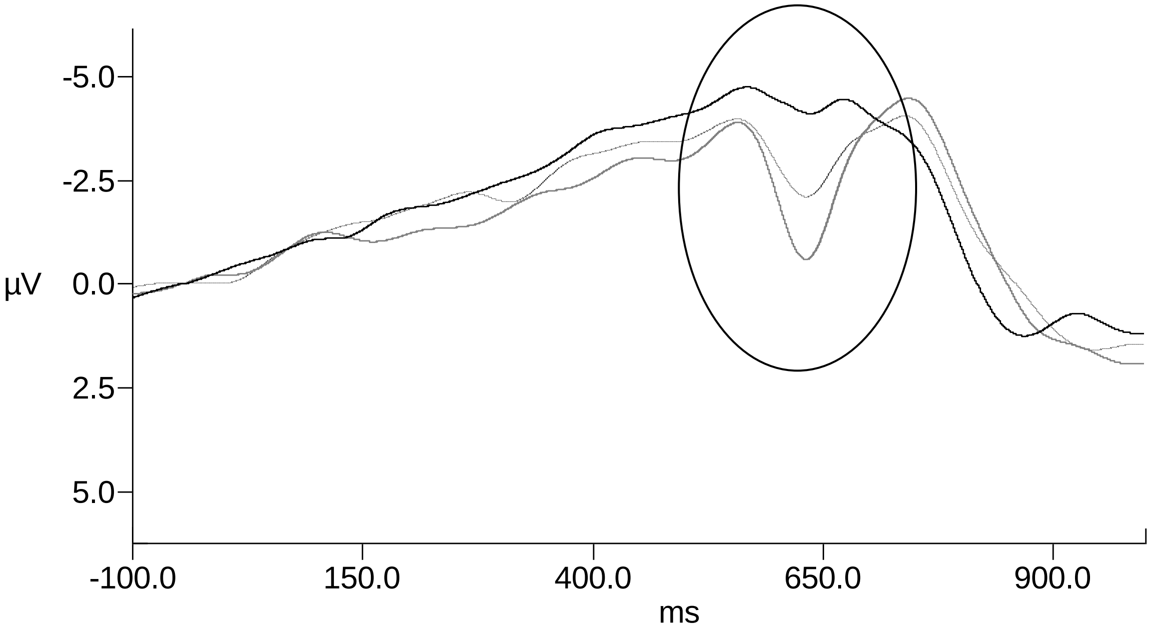

Figure 3. Grand Average waveforms for the LPP in response to the negative second image.

The waveform of the second negative image following a positive first image is represented by the black line, a neutral first image is represented by the dashed-dotted line, and a negative first image in light gray.

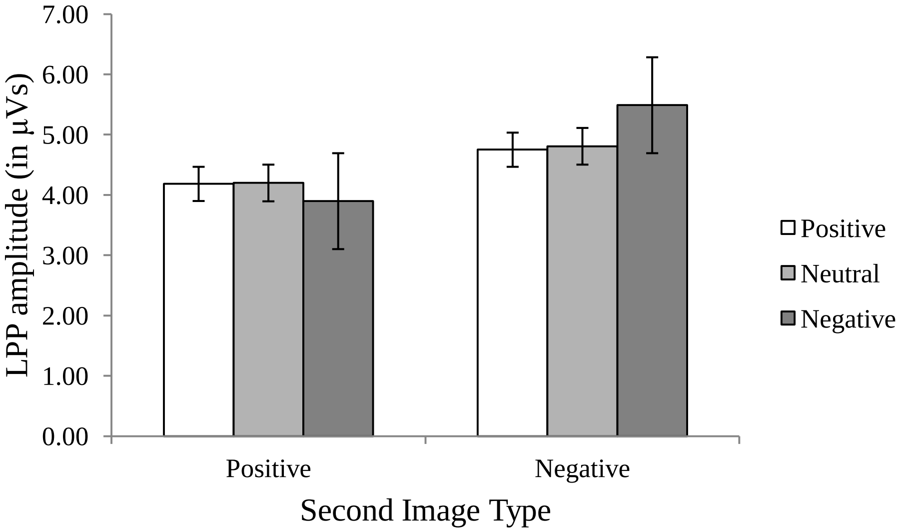

Figure 4. Amplitudes of the LPP waves.

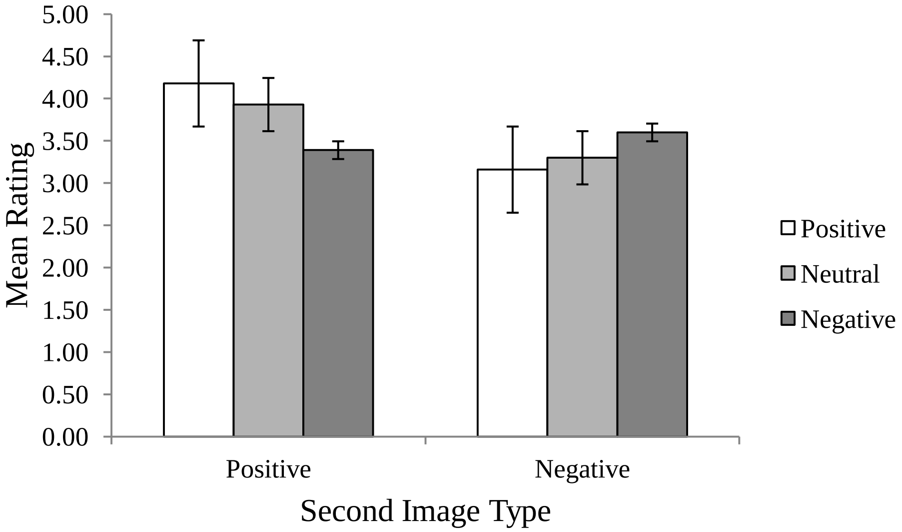

Figure 5. Mean ratings of the second image after viewing either a positive, neutral or negative first image.

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