THE INTERPLAY OF COGNITION AND EMOTION: DOES INCIDENTAL COGNITVE PROCESSING INFLUENCE SUBSEQUENT EMOTIONAL RESPONDING?

A Dissertation

by

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ABSTRACT

A series of four experiments tested the effects of performing executive functioning tasks on subsequent emotional responses. Inspired by dual process theories of mind I hypothesized that performing an incidental executive functioning task would diminish subsequent negative emotional responding. Study 1 (*N* = 47) examined the effects of a working-memory task on subsequent self-reported emotions to emotional videos and found engaging in a prior cognitive task reduced subsequent negative emotional reactions. Study 2 (*N* = 89) and Study 3 (*N* = 214) examined the effects of engaging in a cognitive control task (i.e., a flanker task) on subsequent self-reported emotions to images, and found engaging in a prior cognitive task reduced subsequent negative emotional reactions especially after controlling for trait anxiety. Study 4 (*N* = 171) was similar to the design of Study 3 but incorporated electroencephalography (EEG) to assess both self-reported and neural indices of emotional responding and found no effect of completing a flanker task before viewing emotional images on self-reported emotions. However, contrary to expectations, a neural indicator of attention to and processing of images known as the late positive potential (LPP) was enhanced during negative images after completing the flanker task. Further analyses revealed an interaction between self-reported arousal during negative pictures and condition to predict later LPP amplitudes such that completing the flanker task first disrupted the usual positive relationship between LPP amplitudes and arousal, suggesting that completing the flanker task first changed later attention to and processing of negative stimuli. Implications for dual-process theories of cognition and emotion regulation are discussed.

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Contributors

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All work conducted for the dissertation was completed by the student, under the advisement of Professor Schmeichel of the Department of Psychological and Brain Sciences.

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INTRODUCTION

Theorists and philosophers have long divided human mental life into the broad categories of emotion and cognition. Epstein (1973, 1985) formalized this distinction in his Cognitive-Experiential Self Theory (CEST), which grouped mental faculties into either cognitive, rational processes or emotional, experiential processes. Other similar “dual process” theories have been articulated, including Stanovich and West’s (2000) distinction between System 1 and System 2 processes, and Evans and Over’s (1996) distinction between implicit and explicit processes. Although labels and more fine-grained details may vary across the different models, they all generally assume that cognitive and emotional systems of the brain and mind interact to produce human behavior and experience.

Dual process models of mind predict bidirectional interactions between systems, but the vast majority of empirical work has examined how emotion, or activity in the experiential system, influences the operation of the more cognitive, rational system. The general result of this work has been to demonstrate how seemingly irrational emotional states influence otherwise rational thought processes. For example, the experience of fear increases pessimism in estimates of risk, whereas anger increases optimism (Lerner & Keltner, 2001), and both positive and negative emotions have been found to reduce performance on logic tasks (Blanchette & Richards, 2009). More generally, emotions induce changes in multiple forms of cognition, thereby providing clear evidence of the impact of experiential processes on more rational processes (e.g., Clore & Huntsinger, 2007; Lench, Flores, & Bench, 2011). Comparatively little work has examined the reverse pattern: the influence of rational processing on subsequent emotional responding.

This dissertation examines the effects of performing cognitive tasks on subsequent emotional responses. The hypothesis was that engaging the rational system influences the operation of the emotional system, even if activation of the rational system is incidental to (i.e., is extrinsic to or precedes) the emotional event. The present research focused specifically on the impact of performing executive functioning tasks. Executive functioning refers to cognitive processes that allow individuals to work toward their goals by holding information in working memory, inhibiting non-goal relevant automatic responses, and flexibly shifting attention and focus (Miyake et al., 2000). Performing tasks that require executive functioning is assumed to engage rational (System 2, explicit) processing. Focusing on executive functions also narrowed the search for appropriate cognitive tasks amenable to the examination of neural activity underlying task performance to measure possible neural mechanisms for effects of incidental rational processing on subsequent emotional responding.

Below I review the neuroanatomy thought to underlie emotional processes and executive functioning before reviewing research examining the impact of incidental emotions on executive functioning. Then I review evidence that cognition can influence emotional responding, beginning with cognitions directly related to emotional events, followed by a review of studies hinting that performing incidental cognitive tasks can influence subsequent emotional responding. I also highlight findings from neuroimaging and psychophysiological research relevant to the interaction between cognition and emotion.

Neuroanatomy Underlying Dual Process Models

Historically, emotional or affective processing has been associated with limbic areas of the brain, including the amygdala, insula, basal ganglia, and ventral striatum, whereas cognitive processing, especially executive functioning, has been linked to higher cortical areas such as the anterior cingulate cortex and prefrontal cortex (Cohen & Henik, 2012; Darlow & Sloman, 2010; Oschner & Gross, 2005; Pessoa, 2008; Pessoa, 2009). These brain regions are active in both cognitive and emotional processes and are joined together in highly connected circuits, suggesting that bidirectional effects between cognition and emotions are not only physically possible but likely (Pessoa, 2008). Areas of the prefrontal cortex implicated in executive functioning have been linked to emotion regulation (e.g., Ochsner, Silvers, & Buhle, 2012). For example, activity in the prefrontal cortex during instructions to engage in cognitive reappraisal (a specific emotion regulation strategy) has been found to predict negative affect in daily life (Bastiaansen et al., 2018). Furthermore, researchers have found increased resting state connectivity between the amygdala and dorsal anterior cingulate cortex following a negatively valenced video, suggesting these connected areas of emotional and cognitive systems interact even after an emotional event has ended (van Marle, Hermans, Qin, & Fernandez, 2010). Additionally, activity in the anterior cingulate cortex has been related to processes as diverse as emotional responses to errors, goal congruency of actions, and successful performance of cognitive tasks requiring inhibition and action monitoring (Carter & van Veen, 2007).

Taken together, the overlap and interconnection between emotional and cognitive areas of the brain suggests that bidirectional effects can occur between the two systems. Recent neuroimaging data reviewed below suggests that such bidirectional interactions are common, and that these interactions give rise to complex interactions between cognitive and emotional processing in both related (integral) and unrelated (incidental) tasks.

Incidental Emotions Influence Cognitive Processing

A large body of evidence has observed that incidental emotions influence a variety of complex cognitive processes, from performance on logic problems (Blanchette & Richards,

2009) to risk estimates (Lerner & Keltner, 2001). One study even found evidence that emotions impact performance on a short-term memory task in nonhuman primates (Blanchette, Marzouki, Claidière, Gullstrand, & Fagot, 2017). A number of studies have examined the impact of incidental emotions specifically on executive functioning and have found that emotions influence performance on executive functioning tasks. Additionally, neuroimaging work has begun to elucidate the neural underpinnings of these effects.

Emotions impair executive functioning. Multiple lines of evidence suggest that incidental emotions can impair executive functioning. For instance, emotional images shown briefly before cognitive task trials have been found to impair inhibition on a stop signal task (Verbruggen & De Houwer 2007), attention alerting as measured by the Attention Network Task, (Dennis, Chen, and McCandliss, 2008), and conflict adaptation during Stroop-like tasks (Padmala, Bauer, & Pessoa, 2011). Disruptions in executive functioning have been found following both positive and negative emotional stimuli (e.g., Verbruggen & De Houwer 2007). Neuroimaging research has suggested that emotional stimuli presented directly before an executive functioning task trial impair performance because emotions and amygdala activity disrupt task-related prefrontal cortex activity, perhaps due to emotional events diverting resources toward affective processing or emotion regulation and away from cognitive task performance (Mitchell et al., 2008; Hart, Green, Casp, & Belger, 2010; Sagaspe, Schwartz, & Vuilleumier, 2011).

Emotions enhance executive functioning. Other researchers have found that both positive and negative emotions can enhance executive functioning, including speeded reaction times on incongruent trials of an auditory Simon task when the targets are emotional compared to neutral words (Kanske & Kotz, 2011b, 2011d), speeded reaction times on incongruent trials of a modified flanker task using emotional words (Kanske & Kotz, 2010), and facilitated conflict processing of complex audio/visual stimuli (Zinchenko et al., 2015; Zinchenko et al., 2017). Similarly, when participants are instructed to increase their negative affect to images shown before Stroop trials, performance is enhanced relative to trials where participants are instructed to decrease their negative affect (Sullivan & Strauss, 2017). Neuroimaging and electroencephalography work has suggested that large areas of the anterior cingulate cortex are active during incongruent trials with negative stimuli compared to neutral stimuli, implying that emotional trials enhance executive functioning by boosting activity in areas associated with conflict processing (Kanske & Kotz, 2010; Kanske & Kotz, 2011a, 2011b, 2011c, 2011d).

Reconciling effect of emotions on executive functioning. The research reviewed above appears contradictory: How can emotions both impair and enhance executive functioning? As Kanske (2012) noted, most studies that found emotions impair executive functioning have used task-irrelevant emotional stimuli as distractors, whereas most studies that conclude emotions enhance executive functioning have used emotional stimuli within the task. Thus, emotional events appear to disrupt performance when they are incidental to the cognitive task but may enhance performance when they are a part of (i.e., integral to) the cognitive task.

Integral Cognitions Influence Emotion

Research on appraisals and cognitive reappraisals has indicated that cognitions integral to emotional events influence emotional responses. How individuals think about emotional stimuli influences the strength of their emotional response (Smith, Haynes, Lazarus, & Pope, 1993). For example, participants are able to decrease or increase their emotional responses to negative images after being instructed to use cognitive reappraisal to change their emotions or to think about emotional events in a different way (Ochsner et al., 2004; Hajcak & Nieuwenhuis, 2006;

MacNamara, Foti, & Hajcak, 2009). Cognitive reappraisal has been associated with increased activation in prefrontal cortex and anterior cingulate cortex and reduced activity in amygdala when participants attempt to down-regulate their responses (Oschner et al., 2004), and increased prefrontal activity during reappraisal is associated with less negative affect in daily life (Bastiaansen et al., 2018). Thus, cognitions related to emotional events influence emotional responses at both the self-report level and the neural level, and these cognitions are typically associated with activity in the prefrontal cortex.

Cognitive processes integral to emotional events may change emotional responding even in the absence of explicit instructions to regulate emotional responding. For instance, when participants are instructed to label the emotion displayed on a face, neural activity suggests emotional responses are reduced and prefrontal activity is increased compared to trials which participant are asked if the face matches a target face (Hariri, Bookheimer, & Mazziotta, 2000). Even though labeling emotions requires participants to focus on emotional stimuli, the cognitive task of selecting a label for an emotional face apparently engages cognitive processes that down-regulated amygdala activity. Similarly, when participants in another study were instructed to view emotional stimuli as part of a recognition task, activity in the left prefrontal cortex was inversely related to amygdala function compared to when participants simply rated their emotional responses (Liberzon et al., 2000).

Thus, when participants engaged with emotional stimuli within the context of a cognitive task, even without explicit instructions to reappraise the content of the emotional stimuli, patterns of brain activation associated with emotional responses were reduced and patterns of activation associated with emotion regulation or cognitive processing were enhanced. However, these studies on the influence of integral cognitive processes on emotional responses are not directly comparable to the primary focus of the current research—the possibility that incidental cognitions influence emotion.

Incidental Cognitive Tasks Influence Emotion Processing

Compared to research examining the influence of incidental emotions on cognitive processes, there is a paucity of research examining the effects of incidental cognitive processes on emotions. However, research on the impact of working memory load on emotional responding and research on the impact of a cognitive task interspersed between emotional stimuli provides hints that incidental cognitive tasks do indeed influence emotional processing. This section reviews existing evidence suggesting prior cognitive tasks (i.e., incidental cognition) can influence emotional responses.

Incidental cognitive load and emotions. A few studies have examined the impact of incidental cognitive load on concurrent emotional processing. For instance, one study found that completing a math problem immediately after viewing a negative image caused participants to report less negative mood compared to no intervening cognitive task or completing an easier math problem (Van Dillen & Koole, 2007). Another study found that completing a math task between image viewing and emotional ratings reduced negative affect during passive picture viewing but had no effect when participants were instructed to maintain their emotional response (DeFraine, 2016). A follow-up study found that activity in the amygdala during passive viewing of the negative images was reduced during the math task, and this reduction in amygdala activity correlated with an increase in activity in the dorsal-lateral prefrontal cortex (Van Dillen, Heslenfeld, & Koole, 2009). Hence, activating brain areas associated with more rational processing was associated with reductions in activity in brain regions associated with more emotional processing.

Other researchers have examined the effects of working memory load on emotional processes and found that higher working memory load reduces indices of emotional responding, including less emotional interference as measured with reaction times (Van Dillen & Derks, 2012), reduced limbic activity for emotional stimuli (Erk, Kleczar, & Walters, 2007; McRae et al., 2009), and reduced neural indices of emotional processing and attention, including the N2 and late positive potential (LPP; MacNamara, Ferri, & Hajcak, 2011; Van Dillen & Derks, 2012). Taken together, it appears that incidental cognitive load can reduce emotional reactions. However, it is unclear if these reductions happen because prefrontal activity directly suppresses activity in emotional brain areas or if the reductions can be explained by participants being distracted from the emotion inductions (e.g., McRae et al., 2009).

Incidental cognitive tasks and emotions. Other researchers have examined the effects of cognitive tasks interspersed between emotional events. Generally these studies involve participants completing a cognitive task and viewing an emotional image in between each cognitive task trial. Studies using this approach have compared emotional reactions to stimuli immediately preceded by a cognitive task trial that contains conflict (such as an incongruent Stroop trial or a stop trial during a stop-signal task) versus emotional reactions to stimuli immediately preceded by a cognitive task trial without conflict (such as a congruent Stroop trial, or a normal trial during a stop-signal task).

Emotional images preceded by an incongruent trial appear to elicit a smaller emotional response, as indexed by performance on the subsequent trial of the cognitive task (Cohen, Henik, & Mor, 2011; Kalanthroff, Cohen, & Henik, 2012) and by reductions in amygdala activity (Etkin et al., 2006; Blair et al., 2007). Furthermore, connectivity analysis suggested that activity in the lateral frontal cortex during a number Stroop task was positively related to activity in regions of the middle frontal cortex, which in turn related to a reduction in activity in the amygdala. This pattern suggests that prefrontal cortex activity during incongruent trials of a cognitive task indirectly modulates emotional activity through areas of the brain implicated in emotion regulation, particularly the middle frontal cortex (Blair et al., 2007). Similarly, other researchers have found that conflict on preceding trials dampened amygdala activity indirectly through activation in the prefrontal cortex via the anterior cingulate cortex (Etkin et al., 2006; Kanske & Kotz, 2011b). However, other researchers have found an enhancement of the LPP (a neural marker of emotion and attention) after incongruent trials on a flanker task compared to congruent trials (Ligeza & Wyczesany, 2017). None of these studies using an interleaved trial paradigm to measure the influence of incidental cognitive processing on emotional responses have actually measured self-reported emotional responses, which leaves ambiguity as to how closely if at all the behavioral and neural responses are tracking subjective emotional experiences.

Goals of Current Research

Extant research has observed that incidental emotions have an impact on cognitive processing and that integral cognitive processes have an impact on emotional responding. The literature also hints that incidental cognitive processes—operationalized as either concurrent cognitive load (e.g., MacNamara, Ferri, & Hajcak, 2011) or an incongruent trial immediately preceding an emotional stimulus (e.g., Cohen, Henik, & Mor, 2011)—can impact emotional responding, and that these effects may be due to the recruitment of middle frontal cortex to dampen activity in affective regions of the brain (e.g., Etkin et al., 2006; Blair et al, 2007). However, it is unclear if these effects are due to the distracting nature of cognitive load or the recruitment of cognitive processes related to emotion regulation, and the duration of the influence of cognitive task performances on emotional responses remains unknown. The current research addressed these uncertainties using a novel paradigm to examine the effects of a completely independent and unrelated cognitive task on responding to emotional stimuli. The current research addressed the following questions:

- Can completely incidental cognitive tasks influence subsequent responding to emotional stimuli?
- Do incidental cognitive tasks influence self-reported emotional experiences?
- Do incidental cognitive tasks influence subsequent EEG measures of emotional responding (i.e., N1, P2, N2, early posterior negativity, and late positive potential)?
- Does neural activity during the incidental cognitive task (i.e., incongruent-elicited N2 and P3, error related negativity, and error positivity) correlate with subsequent emotional reductions?
- How are self-reported emotional experiences related to EEG measures of emotional responding, and does this relationship differ if the cognitive task is performed first?

Methods

This dissertation consists of four studies. The first three studies tested the hypothesis that incidental cognitive tasks impact subsequent emotional responding with self-reported emotional responses serving as the primary outcome measure. The fourth study incorporated EEG measures and assessed both self-reported and neural indices of emotional responding as well as neural responses during the cognitive task to gauge the extent to which neural measures of cognitive task engagement and effort predict subsequent emotional responses.

STUDY 1

The first study examined the effect of prior cognitive tasks on emotional reactivity with a working memory task (e.g., the operation span task, or OSPAN; Turner & Engle, 1989) as the cognitive task and self-reported emotional reactions to short film clips as the outcome measure. Participants were randomly assigned to complete the working memory task first or the film task first, and emotional reactions to the film clips were compared between the two orders. I predicted that individuals who completed the working memory task first would show a reduced emotional response to the film clips compared to individuals who completed the film task first.

Method

Participants. Forty-seven undergraduate students (27 women; age *M* = 19.06, *SD* = 0.94) participated in exchange for credit toward a course requirement. Data from all participants were included in all analyses reported below.

Procedure. Participants were randomly assigned between two experimental conditions—*films task first* or *memory task first*. The experiment began with a brief description of the two tasks to be performed by the participants, which were characterized as "related to emotions" and "related to memory," respectively. More thorough instructions were provided immediately prior to each task. At the end of the experiment participants completed a follow-up questionnaire asking them to rate the difficulty of watching the film clips and the difficulty of the memory task (both ratings made on a scale where 1 = *not at all* to 7 = *very*), as well as a general demographic form, the Rosenberg Self-Esteem Scale (Rosenberg, 1979) and the Berkley Expressivity Questionnaire (Gross & John, 1997). Last, participants were debriefed and thanked for their participation.

Working memory task. The operation span (OSPAN) task consisted of two separate tasks performed concurrently (Turner & Engle, 1989). One task required participants to calculate mathematical equations and decide whether the answer provided was correct. For example, participants saw "(9 X 3) – 1 = 2", and had to indicate (by saying "Yes" or "No") whether the given answer was correct ("No"). The second aspect of the OSPAN is a memory span task in which participants read a word to be recalled a short time later. One target word was presented after each mathematical equation. Thus, participants read and evaluated an equation, read a target word, and then advanced to the next equation/word pairing. After two to five equation/word pairings, participants were prompted to recall the preceding set of target words. There were 15 sets of equation/word combinations in all, presented in the same order for all participants. The OSPAN was administered on a computer and participants controlled the presentation of stimuli with their responses. Participants were guided though a short practice run in order to ensure familiarity with the task, and when they indicated that they fully understood the procedure, the task began. The experimenter surreptitiously recorded how long it took each participant to complete the OSPAN and tracked participants' "Yes" or "No" evaluations of the math equations.

Emotional film viewing task. Prior to viewing the film clips, all participants were told they would be watching two short clips that tend to elicit emotional reactions in college students, and that they should watch the clips carefully. Participants in the film-clip first condition were assured that the memory portion of the experiment would not involve memory for the content of the film clips. They also learned that as they watched the clips their face would be videotaped "for record keeping purposes." Participants were told to "watch the clips as if you were at home watching TV – if you feel anything as you watch I want you to express it in whatever way is natural and normal for you." One clip showed jokes and comedy routines from a popular latenight talk show, and the other depicted gruesome scenes from an animal slaughterhouse (see Schmeichel, Demaree, Robinson, & Pu, 2006). Both clips lasted exactly two minutes, for a total of four minutes of film viewing; the clips were shown in counterbalanced order. Both immediately before and immediately after watching the film clips, participants completed a state measure of mood (the PANAS; Watson, Clark, & Tellegen, 1988) to track changes in mood state due to the films. The dependent measures of interest were changes in negative and positive affect scores from before to after the film clips. I expected that individuals who completed the working memory task first would show reduced emotional responses to the film clips compared to individuals who completed the film viewing task first, both in overall levels of emotion as well as less change in emotions before and after film viewing.

Results

Working memory performance. I assessed several indices of working memory performance from the OSPAN (Conway et al., 2005), and none of them indicated an effect of experimental condition. As shown in Table 1, regardless of whether participants performed the OSPAN before or after watching the film clips, participants recalled just as many words correctly, took just as long to complete the test, and performed just as well on the math portion of the test. Therefore, the emotion task appeared to have little or no effect on working memory capacity.

Table 1

Study 1: Working Memory Scores as a Function of Condition

OSPAN Measure	Films-First (*n* = 22)	Memory-First (*n* = 25)	*t* (45)	*p*	Cohen's *d*
Number of incorrect math responses	1.68 (1.21)	2.04 (2.05)	0.72	.478	0.21
Time to complete OSPAN (seconds)	386.00 (38.88)	375.44 (72.55)	0.63*	.531	0.18
Longest span correct	3.09 (0.75)	3.04 (0.89)	0.21	.834	0.06
Number of sets recalled	5.23 (1.97)	5.28 (2.26)	0.09	.933	0.02
Number of words recalled from correct sets	12.55 (6.22)	12.68 (7.11)	0.07	.946	0.02
Total number of words recalled	34.09 (3.87)	32.68 (5.62)	0.99	.328	0.29

* corrected for inequality of variances, df = 37.64

Note: Descriptive statistics reported as mean (standard deviation).

Emotional reactivity. First, I analyzed PANAS negative affect in a 2 (Task Order: films first or memory first) × 2 (Time: before films or after films) mixed-model analysis of variance (ANOVA), and found a main effect of time, such that negative affect increased from before to after the film clips, F (1, 45) = 10.49, p = .002, *partial* η^2 = 0.19. The main effect of task order was non-significant, F (1, 45) = 0.08, p = .778, *partial* η^2 = 0.002. More importantly, the key Task Order × Time interaction was significant and in the predicted direction, F (1, 45) = 7.49, p = .009, *partial* η^2 = 0.14. See Table 2. Among participants who viewed the film clips at the start of the study, negative affect increased from before to after the films; for these participants the film clips functioned as a negative mood induction. For participants who viewed the film clips after taking the working memory test, however, the film clips did not increase negative affect.

Negative affect did not differ between the groups before the film, *t* (36.50) = 1.54, *p* = .131 (corrected for unequal variances). See Figure 1.

I repeated the same analyses using the positive affect subscale of the PANAS and found only a main effect of time, such that positive affect decreased from before to after the film clips, *F* (1, 45) = 13.55, *p* = .001, *partial* η^2 = 0.23. Neither the task order between-subjects main effect nor the Task Order × Time interaction was statistically significant, *F*s < 1.06, *p*s > .30, *partial* η^2s < 0.03, nor was there a difference in positive affect between the groups before the film, *t* (45) = 0.44, *p* = .66. See Table 2 and Figure 2.

Table 2

Study 1: PANAS Scores Before and After Film Task as a Function of Condition

PANAS Score	Films-First (*n* = 22)	Memory-First (*n* = 25)	Across Conditions
Negative affect, pre-film	12.59 (2.61)	14.40 (5.16)	13.55 (4.22)
Negative affect, post-film	17.36 (6.81)	14.80 (5.68)	16.00 (6.30)
Positive affect, pre-film	27.00 (7.89)	26.04 (7.16)	26.49 (7.44)
Positive affect, post-film	24.41 (7.97)	21.44 (7.17)	22.83 (7.62)

Note: Descriptive statistics reported as mean (standard deviation).

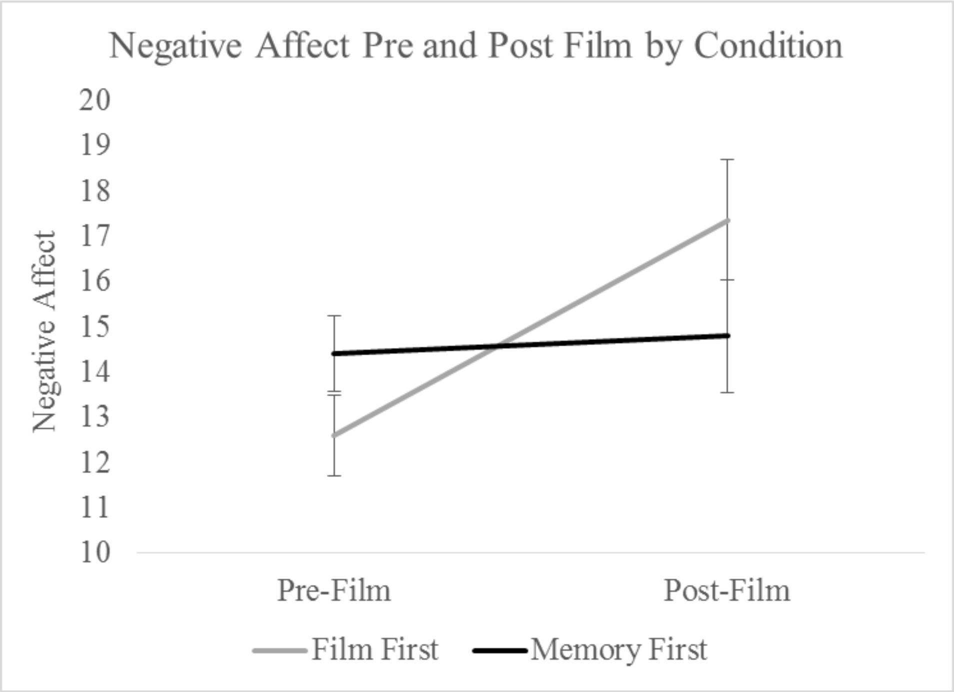

Figure 1. Study 1, negative affect pre and post film as a function of order condition (with standard error bars).

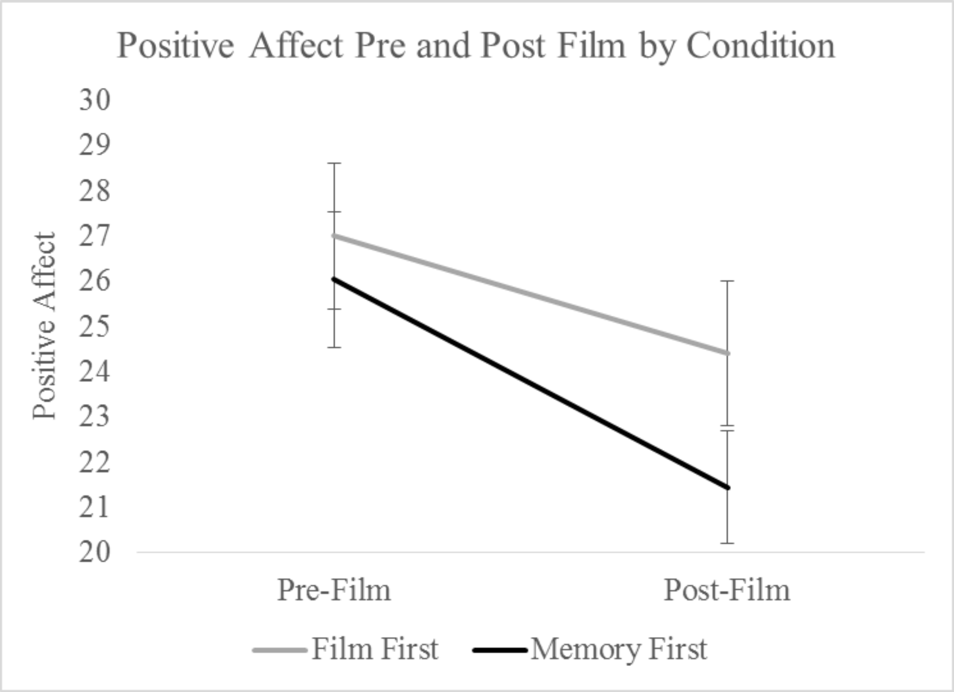

Figure 2. Study 1, positive affect pre and post film as a function of order condition (with standard error bars).

Discussion

This first study provided initial evidence for the hypothesis that engaging in a prior, incidental cognitive task blunts negative emotional reactivity. Specifically, the film task induced a change in negative affect, but only for participants in the film first condition. For participants who completed the cognitive task first, viewing the films did not increase negative affect.

However, the first study was limited by having a relatively small sample size, testing one specific type of cognitive task (the OSPAN), and measuring emotional reactivity only after participants had viewed both the positive and negative film clips. Therefore, it is unclear if the effect of a prior cognitive task is specific to negative emotions, or if the negative film clip overwhelmed the effects of viewing the positive film clip (e.g., Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001). It is also unclear if the effect is specific to completing a working memory task, or if completing other cognitive tasks that require executive functioning would have a similar blunting effect on subsequent emotional responses.

Further, this study used a between-subjects design, and individuals in the films first conditions had not been in the lab or engaged in experimental tasks as long as the individuals in the cognitive first conditions had been when they encountered the emotion task. It is thus plausible that, rather than providing evidence that engaging complex cognition temporarily suppresses emotional reactivity, the results could be accounted for by a relatively more mundane explanation regarding time spent in the lab (e.g., participants become less emotionally reactive the longer they spend time in the laboratory). I am not aware of a theory that would make such a prediction, but nonetheless for Study 2 I sought to address this potential confound with a within-subjects design that used a more versus less cognitively demanding version of the same task to be performed before emotional image viewing, to assess the impact of completing a prior cognitive task (one hard, one easy) on emotional responses.

STUDY 2

For the within-subjects design in Study 2, I modified an existing cognitive task to create more versus less cognitively demanding versions to be completed before emotional image viewing. I chose to adapt the flanker task (Eriksen & Eriksen, 1974), which taps executive functioning in the form of resisting response interference from irrelevant stimuli. To make a less cognitively demanding version of the task, I removed all incongruent trials. Thus, this version of the task did not require participants to inhibit the conflicting response activated by incongruent flanking arrows, and therefore this all-congruent flanker task lacked the important executive functioning element hypothesized to reduce subsequent emotional reactivity.

In this design, the first flanker task was completed without a prior picture-viewing task, which is unusual because the majority of research on the interplay between executive functioning and emotions has examined the impact of emotions on later executive functioning. However, Study 1 found no effect of film viewing task on working memory performance, and because the effect of emotions on cognitive task performance was not of interest in the current line of research, I did not include a picture-viewing task prior to the first cognitive task in Study 2.

For Study 2, I predicted that participants would report less emotional responses (i.e., higher valence ratings and lower arousal ratings for negative images, and lower valence ratings and lower arousal ratings for positive images) to pictures that follow the mixed flanker task compared to the congruent flanker task. I did not predict an effect on neutral images.

Method

Participants. A priori power analysis with crossed random effects for a counterbalanced design (Westfall, Kenny, & Judd, 2014) indicated the need for at least 91 participants to achieve

80% power to detect a small effect of *d* = 0.25. To account for exclusions I over sampled and one-hundred-and-seventeen undergraduate students participated in exchange for credit toward a course requirement. A total of 23 participants failed to respond on all trials during at least one flanker task and were excluded from analysis. An additional 5 participants were excluded from analyses for being more than 3 *SD*s above the mean on the number of non-responses (i.e., more than 66 non-responses on the easy flanker, *n* = 2; more than 41 non-responses on the hard flanker, *n* = 1) or number of errors (i.e., more than 29 errors on the easy flanker, *n* = 1; more than 58 errors on the hard flanker, *n* = 1), indicating they were not fully engaged with the task, leaving a final sample of 89 students (63 women; 57 white; age *M* = 19.50, *SD* = 1.03). An additional 2 participants completed the study but were excluded because of a computer error.

Procedure. Participants were randomly assigned to one of four counterbalanced orders to ensure there was no effect of picture set (Set A or Set B presented first or second) or task order (all-congruent flanker first or mixed-congruency flanker first) on emotional reactivity. Participants reported individually to a laboratory for an experiment on how different thought processes and emotions relate to each other. After providing informed consent, participants completed the Rational-Experiential Inventory (Pacini & Epstein, 1999). Then, participants completed two different counterbalanced blocks of a modified flanker task followed by counterbalanced blocks of images. Because the picture-viewing task always occurred after a flanker task, the study design was a 2 (Prior Flanker Task: all-congruent vs. mixed-congruency) × 3 (Image Type: positive, negative, and neutral) within-subjects design with self-reported emotional responses to the images as the dependent measure. After viewing the last block of images, participants completed a final set of questionnaires including: Need for Cognition (Cacioppo, John, Petty, & Richard, 1982), Trait Self Control (Tangney, Baumeister, & Boone, 2004), Trait Anxiety (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), BIS/BAS (Carver & White, 1994), Approach and Avoidance Temperament Questionnaire (Elliot & Thrash, 2010), and demographic questionnaires. The trait measures were included for exploratory purposes. Last, participants were thanked for their participation and debriefed.

Flanker task. Participants completed two blocks of a modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974) that used arrows as stimuli. On each trial, participants saw either congruent (“<<<<<” or “>>>>>”) or incongruent (“<<><<” or “>><>>”) arrow stimuli centered on a 20 inch computer monitor in white font against a black background. Participants responded to the direction of the center arrowhead by pressing a key labeled left or right. Flanker arrows appeared approximately 150 ms prior to the target stimulus (center arrowhead), which remained on screen for another 150 ms (South, Larson, Krauskopf, & Clawson, 2010). Participants had 800 ms to respond, and intertrial intervals varied randomly at 800 ms, 900 ms, 1000 ms, and 1100 ms. Participants began the first flanker task (regardless of condition) with 8 all congruent practice trials, followed by 220 test trials. Every 20 trials, the message “Try to be as fast and accurate as possible with your responses” appeared onscreen. In the *all-congruent* flanker task, participants saw only congruent flanker trials. In the *mixed-congruency* flanker task, participants saw congruent arrows on 85% of trials and incongruent arrows on the other 15% of trials. Incongruent trials required participants to inhibit responding to the conflicting flanking arrows and instead respond to the central arrow. Which flanker task participants completed first was counterbalanced across participants.

Emotional image viewing task. Immediately after each flanker task participants viewed a block of 60 images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) selected based on normed data to elicit high arousal, high valence (i.e., positive images), high arousal, low valence (i.e., negative images), and low arousal, middling valence (i.e., neutral images), respectively.[1] Image-viewing trials consisted of a 1.5 second fixation cross, followed by a picture for 6 seconds. Immediately after each image, participants rated their emotional responses using self-assessment manikins (SAMs; Bradley & Lang, 1994) for valence from 1 (*unhappy)* to 7 (*happy*) and arousal from 1 (*calm)* to 7 (*excited*). Participants were instructed to view each image and "rate how it made you feel using the scale provided." Participants viewed two blocks of pictures in all (in a counterbalanced order), one after each flanker task. Each picture block included 20 images of each type (i.e., positive, negative, neutral), and the two image sets were matched on content, valence, and arousal. The dependent measures of interest were the valence and arousal ratings of emotional responses.

Results

Flanker task performance. I assessed several indices of flanker performance, including overall average reaction time and error rates for both the all-congruent and mixed-congruency tasks. Additionally, for the mixed-congruency task, I assessed post error slowing by calculating

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[1] Set A consisted of positive images (IAPS numbers: 1463, 4220, 4608, 4651, 4652, 4659, 4670, 4681, 4694, 5621, 5623, 5910, 7200, 7330, 7402, 7460, 7480, 8031, 8161, 8502) with a normed average valence of *M* = 7.08, *SD* = 0.52, and a normed average arousal of *M* = 5.93, *SD* = 0.82; negative images (IAPS numbers: 1052, 1220, 1300, 2095, 3071, 3150, 3230, 3250, 3550, 6230, 6250.1, 6510, 6560, 6838, 7380, 8485, 9340, 9405, 9530, 9911) with a normed average valence of *M* = 2.58, *SD* = 0.59, and a normed average arousal of *M* = 6.16, *SD* = 0.65; and neutral images (IAPS numbers: 2200, 2215, 2383, 2397, 2440, 2480, 2485, 2506, 2513, 2575, 2745.1, 2850, 6150, 7004, 7006, 7009, 7041, 7056, 7059, 7100) with a normed average valence of *M* = 5.10, *SD* = 0.35, and a normed average arousal of *M* = 3.13, *SD* = 0.65. Set B consisted of positive images (IAPS numbers: 1710, 4607, 4611, 4656, 4658, 4680, 4689, 4695, 5600, 7260, 7350, 7390, 7470, 7481, 8186, 8200, 8260, 8300, 8370, 8501) with a normed average valence of *M* = 7.12, *SD* = 0.54, and a normed average arousal of *M* = 5.90, *SD* = 0.71; negative images (IAPS numbers: 1050, 1205, 1270, 1301, 2811, 2900, 3000, 3130, 3301, 3400, 3530, 6260, 6360, 6550, 9040, 9300, 9490, 9520, 9902, 9921) with a normed average valence of *M* = 2.49, *SD* = 0.74, and a normed average arousal of *M* = 6.20, *SD* = 0.76; and neutral images (IAPS numbers: 2038, 2102, 2190, 2214, 2305, 2385, 2393, 2487, 2514, 2516, 2570, 5534, 7000, 7025, 7035, 7053, 7161, 7185, 7236, 7493) with a normed average valence of *M* = 5.06, *SD* = 0.24, and a normed average arousal of *M* = 3.13, *SD* = 0.47 (Lang, Bradley, & Cuthbert, 2005). None of the valence categories differed between sets (*t*s < 0.40, *p*s > 0.650) and the overall normed valence and arousal ratings of each image valence type collapsed across sets did not differ from the average ratings for each image type from Study 2 (*t*s < 1.40, *p*s > 0.150).

the reaction time for correct trials immediately after an error minus reaction time for correct trials immediately before an error (higher positive numbers indicate better cognitive control; Dutilh et al., 2012), flanker interference by calculating the reaction time for correct incongruent trials minus reaction time for correct congruent trials (higher positive numbers indicate more interference), and accuracy during incongruent trials by counting the number of errors during incongruent trials. For all flanker indices, reaction times faster than 200 ms were removed from analyses.

As shown in Table 3, reaction times were faster and error rates were lower for the all-congruent flanker task, suggesting that this task was indeed easier than the mixed-congruency flanker task. None of the mixed-congruency performance measures revealed an effect of flanker order, indicating that the order in which participants completed the flanker tasks did not influence performance.

Table 3

Study 2: Flanker Performance as a Function of Condition

Overall Flanker Performance	All-Congruent	Mixed-Congruent	*t* (88)	*p*	Cohen's *d*
Overall RT	273.68 (29.41)	320.57 (42.31)	13.14	< .001	1.23
Overall Error Rate	4.28 (4.74)	17.94 (7.97)	17.06	< .001	2.01
Mixed-Congruency Flanker Performance	All-Congruent First (*n* = 34)	Mixed-Congruent First (*n* = 55)	*t* (87)	*p*	Cohen's *d*
Post-error slowing	-9.03 (29.27)	4.52 (63.69)	1.17	.247	0.26
Interference score	137.22 (39.36)	124.22 (41.54)	1.46	.148	0.32
Incongruent trial accuracy	13.65 (4.93)	13.31 (5.21)	0.31	.759	0.07

Note: Descriptive statistics reported as mean (standard deviation).

Emotional reactivity. First, I examined self-reported valence and arousal for each emotional picture type (positive, negative) in separate 2 (Flanker Task) × 2 (Task Order) × 2 (Picture Sets) within-subjects repeated measures ANOVAs. I did not analyze neutral images as I did not predict that flanker condition would influence self-reports during neutral images and there was no evidence of a significant difference between prior flanker block and valence ratings for neutral images, *t* (88) = 1.73, *p* = .087, *d* = 0.17, or arousal ratings for neutral images, *t* (88) = 1.07, *p* = .290, *d* = 0.07. Picture set had no effect on the outcomes reported below and was dropped from analyses.

Negative images. Performing the all-congruent versus mixed-congruency flanker task did not influence self-reported valence (all-congruent *M* = 2.05, *SD* = 0.68; mixed-congruent *M* = 2.06, *SD* = 0.69) or arousal (all-congruent *M* = 3.96, *SD* = 1.39; mixed-congruent *M* = 3.97, *SD* = 1.32) responses to negative images. I observed a non-significant trend for the interaction between order and flanker task on valence, *F* (1, 87) = 2.34, *p* = .130, with valence means in the predicted direction when the mixed-congruent task was completed first (all-congruent *M* = 1.98, *SD*= 0.68; mixed-congruent *M* = 2.04, *SD* = 0.68), but in the opposite direction when the all-congruent flanker task was completed first (all-congruent *M* = 2.16, *SD* = 0.69; mixed-congruent *M* = 2.08, *SD* = 0.73).

Similarly, for self-reported arousal the means were in the predicted direction in the all-congruent first condition (all-congruent *M* = 3.86, *SD* = 1.27; mixed-congruent *M* = 3.72, *SD* = 1.38), but in the opposite of the predicted direction in the mixed-congruent first condition (all-congruent *M* = 4.02, *SD* = 1.47; mixed-congruent *M* = 4.12, *SD* = 1.28). However, the Order × Flanker task interaction was non-significant, *F* (1, 87) = 3.36, *p* = .070. See Table 4.

Table 4

Study 2: Self-reported Valence and Arousal in Response to Negative Images as a Function of Flanker Task (All-Congruent or Mixed-Congruent) and Task Order (All-Congruent First or Mixed-Congruent First)

Valence				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Flanker Task	0.05	(1, 87)	.821	0.001
Flanker Task × Task Order	2.34	(1, 87)	.130	0.026
Between-Subjects Effects				
Task Order	0.51	(1, 87)	.444	0.007
Arousal				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Flanker Task	0.06	(1, 87)	.806	0.001
Flanker Task × Task Order	3.36	(1, 87)	.070	0.037
Between-Subjects Effects				
Task Order	0.953	(1, 87)	.332	0.011

Positive images. Self-reported responses to positive images did not differ as a function of preceding flanker task for valence (all-congruent *M* = 4.86, *SD* = 0.75; mixed-congruent *M* = 4.94, *SD* = 0.68) or arousal (all-congruent *M* = 4.13, *SD* = 1.21; mixed-congruent *M* = 4.21, *SD* = 1.25). There were no indications of potential interaction effects due to order. See Table 5.

Table 5

Study 2: Self-reported Valence and Arousal in Response to Positive Images as a Function of Flanker Task (All-Congruent or Mixed-Congruent) and Task Order (All-Congruent First or Mixed-Congruent First)

Valence				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Flanker Task	1.93	(1, 87)	.168	0.02
Flanker Task × Task Order	1.06	(1, 87)	.305	0.01
Between-Subjects Effects				
Task Order	0.20	(1, 87)	.652	0.002
Arousal				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Flanker Task	1.04	(1, 87)	.312	0.01
Flanker Task × Task Order	1.93	(1, 87)	.168	0.02
Between-Subjects Effects				
Task Order	0.242	(1, 87)	.624	0.003

Exploratory analyses controlling for trait anxiety. I explored the extent to which controlling for individual differences in emotion-related traits influenced the predicted effect. These exploratory analyses revealed that trait anxiety mattered. Prior research on emotional responding has observed that state and trait levels of anxiety may influence participants' emotional responses (e.g., MacNamara & Hajcak, 2009, 2010). Additionally, trait and state anxiety have been found to influence emotional responding in the context of a cognitive task (e.g., Kanske & Kotz, 2012; MacNamara, Ferri, & Hajcak, 2011). Therefore, I re-ran the repeated measures ANOVAs on valence and arousal with trait anxiety (M = 2.24, SD = 0.50) as a covariate. Task order was not a significant predictor in this analysis (p > .100) so it was dropped from the model. The repeated measure ANOVA on valence and arousal responses to negative images including trait anxiety as a covariate is reported in Table 6. When controlling for trait anxiety, the effect of flanker task on valence responses to negative images was significant, such that valence was higher (less negative) after the mixed-congruent flanker task (*M* = 2.06, *SD* = 0.69) compared to the all-congruent flanker task (*M* = 2.05, *SD* = 0.69).

Table 6

Study 2: Self-reported Valence and Arousal in Response to Negative Images as a Function of Flanker Task (All-Congruent or Mixed-Congruent), Controlling for Trait Anxiety

Valence				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Flanker Task	4.11	(1, 87)	.046	0.045
Flanker Task × Trait Anxiety	4.44	(1, 87)	.038	0.049
Between-Subjects Effects				
Trait Anxiety	< 0.001	(1, 87)	.998	< 0.001
Arousal				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Flanker Task	0.01	(1, 87)	.930	< 0.001
Flanker Task × Trait Anxiety	0.002	(1, 87)	.961	< 0.001
Between-Subjects Effects				
Trait Anxiety	7.16	(1, 87)	.009	0.076

Discussion

Study 2 failed to support the hypothesis that completing a more (versus less) demanding cognitive task blunts subsequent emotional responding. However, post-hoc exploratory analyses revealed the predicted effect of performing a prior cognitive task on emotional responding after controlling for individual differences in trait anxiety. Hence, completing a mixed-congruency flanker task reduced negative emotional responding compared to completing an all-congruent flanker task, but only after trait anxiety was taken into account. However, we had not predicted that controlling for trait anxiety would be crucial for uncovering the effect of prior cognitive task performance, and the effect in this study was smaller than the conceptually similar effect observed in Study 1.

Therefore, I conducted a third study to examine again the effects of performing a mixed-congruency flanker task on subsequent emotional responding, this time with a between-subjects design. This design was more in line with the design of Study 1 and avoided potential order effects that can influence within-subjects designs, in the hopes that this would allow a more precise assessment of whether performing a demanding flanker task alters subsequent emotional responding. I also wanted to test the extent to which controlling for trait anxiety is crucial for uncovering the effect of performing a prior flanker task on subsequent emotional responding.

STUDY 3

I conducted a third study to examine the effects of performing a cognitive task using a between-subjects design similar to Study 1. Participants completed a flanker task that had both incongruent and congruent trials and reported their emotional responses to positive, negative, and neutral images. Participants were randomly assigned to complete the *flanker task first* or the *image task first*, and emotional reactions to each image type were compared across orders for a 2 (Order) × 2 (Image Valence; positive, negative, neutral) mixed design. I anticipated that participants in the flanker first condition would report less negative emotional responses (i.e., higher valence ratings, lower arousal ratings) to negative pictures compared to participants in the image first condition. I also examined the effect of order on positive pictures to ensure the effect of cognitive task on emotional responses was specific to negative emotions. I did not predict any difference in emotional responding as a function of task order for neutral images. Further, following up the exploratory finding from Study 2, I predicted that the effect of cognitive task performance on subjective emotional experience would emerge above and beyond the influence of trait anxiety.

Method

Participants. Prior to beginning this study I planned to sample two hundred participants. Two-hundred-and-twenty-six undergraduate students participated in exchange for credit toward a course requirement. Twelve participants were excluded from analyses for being more than 3 *SD*s above the mean on the number of non-responses (i.e., more than 56 non-responses; *n* = 4) or number of errors (i.e., more than 134 errors; *n* = 8) on the flanker task, indicating they were not fully engaged with the task. After these exclusions the final sample included 214 students (134 women; 129 white, age *M* = 18.73, *SD* = 1.47). An additional 16 participants completed the study but were excluded because of a computer error (*n* = 8), failure to follow task instructions (*n* = 7) or for not completing all experimental tasks due to experimenter error (*n* = 1).

Procedure. Participants reported individually to a laboratory for an experiment on how different thought processes and emotions relate to each other. They were randomly assigned between two experimental conditions—flanker first or image first. After providing informed consent, participants completed the Rational-Experiential Inventory (Pacini & Epstein, 1999). Next, participants completed the flanker task and the image-viewing task, with task order depending on experimental condition. Because participants were randomly assigned to one of two orders, the experiment was a 2 (Order: flanker first vs. image first) × 3 (Image Type: positive, negative, and neutral) mixed design, with self-reported emotions elicited by the images as the dependent measure. After completing both tasks, participants completed a final set of questionnaires, including: Need for Cognition (Cacioppo et al., 1982), Trait Self Control (Tangney et al., 2004), Trait Anxiety (Spielberger et al., 1982), Affect Intensity Measure (Larsen & Diener, 1987), BIS/BAS (Carver & White, 1994), Approach and Avoidance Temperament Questionnaire (Elliot & Thrash, 2010) and demographic questionnaires. Last, participants were thanked for their participation and debriefed.

Flanker task. The cognitive task in Study 3 was nearly identical to the mixed-congruent flanker task used in Study 2. The flanker task began with 30 practice trials, followed by 330 test trials. Every 30 trials, the message "Try to be as fast and accurate as possible with your responses" appeared onscreen. Participants saw congruent arrows on 90% of trials and incongruent arrows on the other 10% of trials. All other task parameters were the same as Study 2.

Emotional image-viewing task. Participants viewed 56 images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) and rated their emotional responses to each image using self-assessment manikins for valence and arousal (SAMs; Bradley & Lang, 1994). The images were selected based on normed data to elicit high arousal, high valence (i.e., positive images, 19 images), high arousal, low valence (i.e., negative images, 19 images), and low arousal, middling valence (i.e., neutral images, 18 images).[2] Image-viewing trials and instructions were identical to Study 2. The dependent measures of interest were participants' self-reports of valence and arousal in response to the images.

Results

Flanker task performance. I assessed the same indices of flanker performance as in Study 2, including post-error slowing calculated as the reaction time for correct trials immediately after an error minus reaction time for correct trials immediately before an error (higher positive numbers indicate better cognitive control; Dutilh et al., 2012), flanker interference calculated as the reaction time for correct incongruent trials minus reaction time for correct congruent trials (higher positive numbers mean more incongruent interference), and accuracy during incongruent trials calculated as the number of errors during incongruent trials. For all flanker indices, reaction times faster than 200 ms were removed from analyses. As shown in Table 7, none of the indices revealed an effect of experimental condition. Hence, post-error

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[2] Positive images (IAPS numbers: 4608, 4651, 4656, 4658, 4659, 4670, 4681, 4695, 5621, 7200, 7260, 7350, 7390, 7460, 7470, 8031, 8161, 8186, 8260) with normed average valence of *M* = 6.90, *SD* = 0.36, and normed average arousal of *M* = 5.96, *SD* = 0.84. Negative images (IAPS numbers: 1052, 1205, 1270, 1300, 2811, 3000, 3022, 3071, 3130, 3150, 3250, 3400, 3550, 6230, 6550, 6560, 7380, 9300, 9405) with normed average valence of *M* = 2.63, *SD* = 0.77, and normed average arousal of *M* = 6.44, *SD* = 0.64. Neutral images (IAPS numbers: 2190, 2393, 2394, 2397, 2506, 2516, 2850, 5534, 7000, 7009, 7025, 7035, 7053, 7100, 7161, 7180, 7185, 7236) with normed average valence of *M* = 5.08, *SD* = 0.32, and normed average arousal of *M* = 3.03, *SD* = 0.43 (Lang, Bradley, & Cuthbert, 2005).

slowing, flanker RT interference, and accuracy during incongruent trials were similar regardless of whether participants completed the flanker task first or viewed emotional pictures first.

Table 7

Study 3: Flanker Performance as a Function of Condition

Flanker Performance	Images-First (n = 105)	Flanker-First (n = 109)	t (212)	p	Cohen's d
Post-error slowing	34.28 (40.78)	35.91 (27.77)	0.34*	.732	0.05
Interference score	67.46 (29.75)	67.26 (39.60)	0.04	.966	0.006
Incongruent trial accuracy	12.11 (5.18)	11.60 (4.94)	0.74	.462	0.10

* corrected for inequality of variances, df = 182.64

Note: Descriptive statistics reported as mean (standard deviation).

Emotional reactivity. As in Study 2, to quantify emotional reactivity I averaged participants' valence and arousal responses separately for positive, negative, and neutral images. I did not predict an effect for neutral images, and condition had no effect on valence self-reports, t (212) = 0.84, p = .402, d = 0.11, or arousal self-reports, t (212) = 0.11, p = .916, d = 0.01, in response to neutral images. Thus, I examined emotional reactivity in two separate 2 (Task Order: image first or flanker first) × 2 (Image Type: positive or negative) mixed-model ANOVAs, one for valence and one for arousal. See Table 8 and Table 9.

Valence. As predicted, I found an effect of condition on self-reported emotional valence, F (1, 212) = 5.21, p = .023, $partial\ \eta^2$ = 0.02. Please see Table 8. Planned-comparisons found the predicted difference between conditions for valence during negative images, t (212) = 2.28, p = .023, d = 0.31, such that negative images elicited less negative valence in the flanker first condition (*M* = 2.12, *SD* = 0.69) compared to the image first condition (*M* = 1.92, *SD* = 0.58). Self-reported valence did not differ in response to positive images, *t* (212) = 0.96, *p* = .336, *d* = 0.13, between the flanker first (*M* = 4.68, *SD* = 0.65) versus image first (*M* = 4.59, *SD* = 0.71) conditions. See Figure 3.

Table 8

Study 3: Self-reported Valence as a Function of Condition (Image First or Flanker First) and Image Type (Positive or Negative)

Valence				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Image Type	1658.20	(1, 212)	< .001	0.89
Image Type × Condition	0.73	(1, 212)	.393	0.003
Between-Subjects Effects				
Condition	5.21	(1, 212)	.023	0.02

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

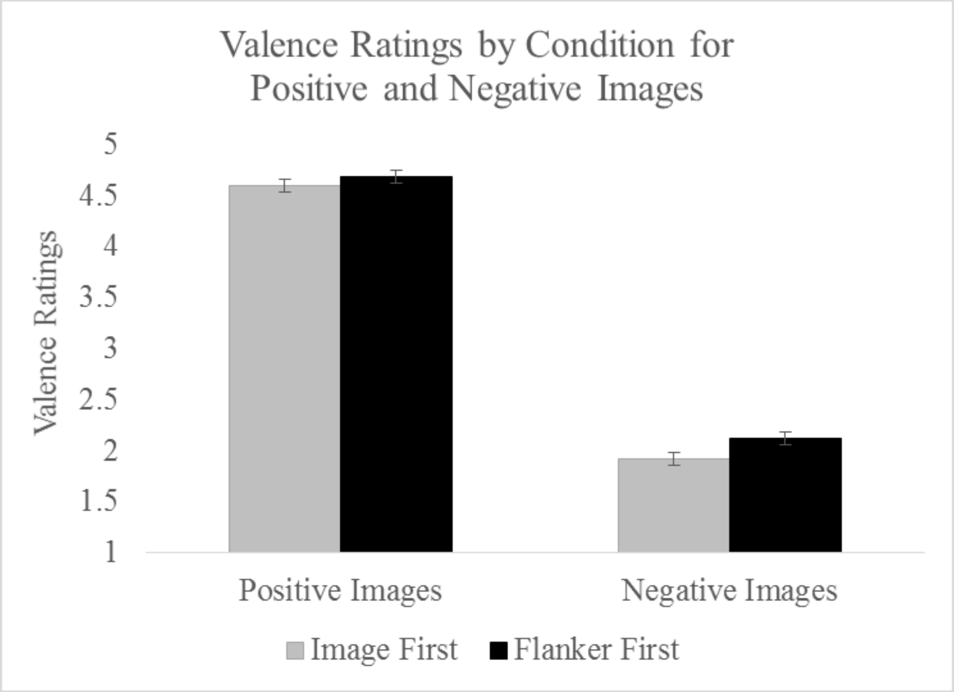

Figure 3. Study 3, self-reported valence as a function of order condition, image type (positive or negative), with standard error bars.

Arousal. As shown in Table 9, I found a picture type by condition interaction on self-reported arousal, Greenhouse-Geisser corrected F (1.00, 212.00) = 4.08, p = .045, *partial* η^2 = 0.03. Descriptively, negative images elicited less arousal in the flanker first condition (M = 4.26, SD = 1.13) compared to the image first condition (M = 4.54, SD = 1.08). However, planned comparisons failed to find a difference between task orders for arousal during negative images, t (212) = 1.88, p = .061, d = 0.26. Arousal did not differ for positive images, t (212) = 0.17, p = .863, d = 0.02, between the image first (M = 4.24, SD = 1.04) and flanker first (M = 4.26, SD = 1.02) conditions. See Figure 4.

Table 9

Study 3: Self-reported Arousal as a Function of Condition (Image First or Flanker First) and Image Type (Positive or Negative)

Arousal				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Image Type	5.67	(1, 212)	.018	0.03
Image Type × Condition	4.08	(1, 212)	.045	0.02
Between-Subjects Effects				
Condition	1.38	(1, 212)	.241	0.006

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

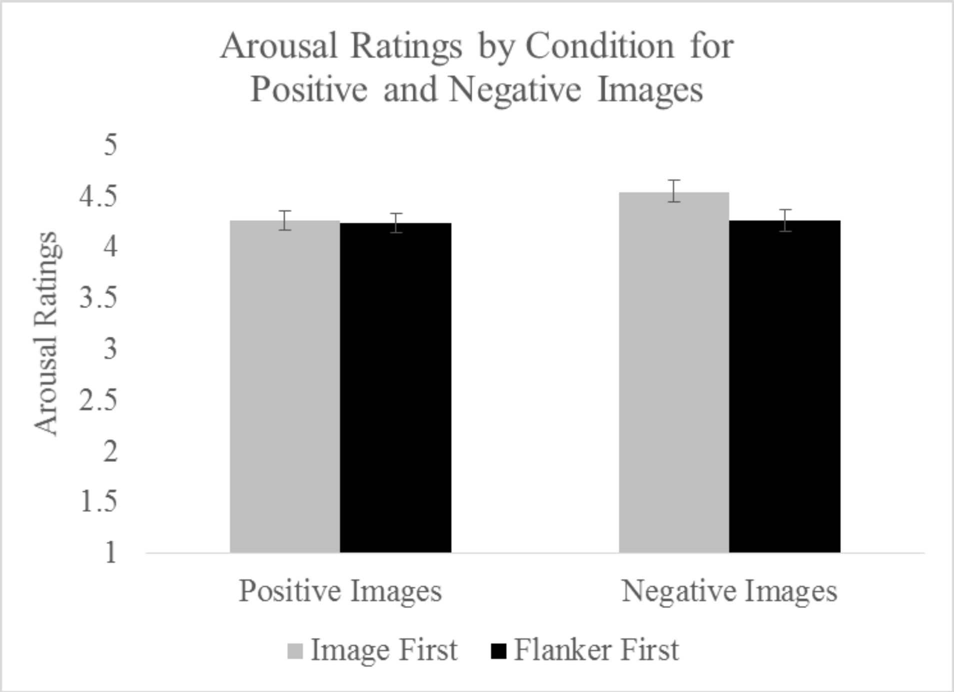

Figure 4. Study 3, self-reported arousal ratings by order condition, positive and negative images, with standard errors.

Trait anxiety as a covariate. Next, I conducted individual one-way ANOVAs to examine the effect of condition on negative valence and arousal controlling for trait anxiety. This is a parallel analysis to the exploratory analysis reported in Study 2. After controlling for trait anxiety, condition was still significant, $F(1,211) = 5.13$, $p = .025$, partial $\eta^2 = 0.024$, such that self-reported valence during negative images differed as a function of experimental condition, such that valence was higher (less negative) in the flanker first condition ($M = 2.12$, $SD = 0.89$) compared to the image first condition ($M = 1.92$, $SD = 0.92$). For arousal, the effect of condition fell just short of conventional levels of statistical significance, $F(1,211) = 3.86$, $p = .051$, partial $\eta^2 = 0.018$, but descriptively the arousal ratings were in the predicted direction and higher in the image first condition ($M = 4.55$, $SD = 1.57$) compared to the flanker first condition ($M = 4.25$, $SD = 1.54$).

Discussion

The third study provided additional evidence for the hypothesis that engaging in a prior incidental cognitive task blunts negative emotional reactivity. Specifically, participants who completed the flanker task first showed a reduction in self-reported negative valence and arousal in response to negative images compared to participants who viewed the images first, prior to completing the flanker task. Furthermore, self-reported emotional responses to positive images were in the hypothesized direction of reduced positive valence, but this difference was not statistically significant. Additionally, the key effect on negative valence remained significant after controlling for trait anxiety, consistent with the exploratory analyses reported in Study 2.

Altogether, the first three studies provided support for the hypothesis that incidental cognitive task performance influences subsequent emotional responding. However, the first three studies relied solely upon self-reported emotional responses. The fourth study extended the previous findings by assessing the effects of incidental cognitive task performance on neural indices of emotional responses in addition to self-reports.

STUDY 4

The first three studies found effects of prior cognitive task performance on negative emotional reactivity as measured by self-reports. However, self-reports of emotional responding have shortcomings, including but not limited to demand characteristics and participants' inability or unwillingness to report their emotions accurately. My fourth study expanded upon the previous findings by adding physiological measures of emotional responses. Specifically, the design was similar to Study 3, but participants only viewed negative and neutral images. In addition to collecting self-report emotional responses, I also measured neural activity using electroencephalography (EEG). I specifically looked at known neural markers of responding to emotional stimuli, including the N1, P2, N2, early posterior negativity (EPN), and late positive potential (LPP). I selected these particular event-related potentials (ERPs) because they appear to be reliably moderated by emotional content in prior research (see Hajcak, Weinberg, MacNamara, & Foti, 2012, for an overview of emotion-modulated ERPs). I predicted changes in emotion-modulated ERPs indicative of lowered reactivity to negative images among participants who complete the flanker task first compared to viewing the images first.

I also recorded neural activity during the flanker task to examine neural markers of cognitive functioning and inhibition, including the error related negativity (ERN) and error positivity (Pe) to response errors, as well as the N2 and P3 to incongruent trials. I predicted that task order would have no effect on flanker ERP magnitudes or performance, consistent with the behavioral results from the previous studies. I tested possible moderating effects of cognitive task ERPs on subsequent emotional responding. I expected that individuals who exhibited stronger neural responses to errors and incongruent stimuli would show larger reductions in subsequent emotion-modulated ERPs.

By examining ERPs during both the cognitive and the emotional tasks, I was able to probe the relationship between cognition and emotion at the neural level. I also compared behavioral performance and self-report measures with neural indices of the underlying processes to further pinpoint why incidental cognitive processes impact subsequent emotional responses. I again used trait anxiety as a covariate in analyses for Study 4, to be consistent with the analyses conducted for Studies 2 and 3. Moreover, prior research has found that the ERN is enhanced in individuals high in anxiety, errors are aversive to anxious individuals (Hajcak, McDonald, & Simons, 2003; Weinberg, Riesel, & Hajcak, 2012), and ERP measures of emotional response are influenced by trait and state levels of anxiety (e.g., MacNamara & Hajcak, 2009, 2010). Therefore, it may be especially necessary to control for individual differences in trait anxiety when examining neural responses to errors and emotional images.

Method

Participants. Prior to beginning this study, I planned to sample two hundred participants by the end of Fall 2018. Two hundred students participated in exchange for credit toward a course requirement. For the behavioral analyses, three participants were excluded for missing picture and/or flanker data, and twenty-six participants were excluded for not being fully engaged with the tasks (i.e., having all non-responses on the flanker task, n = 18; rating negative emotional images as highly positive in valence, *n* = 1). Further, I excluded outliers, defined as more than 3 *SD*s above the mean, on non-responses (more than 126 non-responses), *n* = 5 and errors (more than 93 errors), *n* = 2, leaving a final sample of 171 students (107 women, 4 not reported; 110 white, 4 not reported; age *M* = 18.82, *SD* = 0.97). For the EEG analyses, an additional 11 participants were excluded for having unusable EEG data for either the flanker or picture viewing task, resulting in a final sample of 160 students (101 women, 4 not reported; 102 white, 4 not reported; age *M* = 18.80, *SD* = 0.0.97).

Procedure. The procedure was nearly identical to Study 3. The primary differences were the removal of positive images during the picture viewing task and the addition of attaching an EEG cap to participants heads at the beginning of the study, and recording EEG during all tasks as well as during a short (approximately 5 minute) resting recording at the beginning and end of the study.

Participants reported individually to a laboratory for an experiment on how different thought processes and emotions relate to each other. They were randomly assigned to one of two experimental conditions—flanker first or image first. After providing informed consent, participants had an EEG cap attached while completing the Rational-Experiential Inventory (Pacini & Epstein, 1999), Affect Intensity Measure (Larsen & Diener, 1987), Trait Self Control (Tangney et al, 2004), and demographic questionnaires. Then, participants completed the flanker task and the image-viewing task, with task order depending on experimental condition. After completing both tasks participants completed additional questionnaires, including Need for Cognition (Cacioppo et al., 1982), Trait Anxiety (Spielberger et al, 1983), BIS/BAS (Carver & White, 1994), Approach and Avoidance Temperament Questionnaire (Elliot & Thrash, 2010), in addition to answering questions about their experience during the flanker task. Last, they were thanked for their participation and debriefed about the purpose of the study.

EEG data collection. The experimenter attached sensors to participants' heads using 59 tin electrodes in a stretch-lycra electrode cap (Electro-Cap International, Eaton, OH, USA). Electrodes were also placed on participants' earlobes for offline re-referencing. EEG electrode impedances were kept below 5000 kΩ, and differences in impedances at homologous sites were kept below 1000 kΩ. EEG signals were amplified with Neuroscan SynAmps2 (El Paso, TX, USA) and recorded with Curry 7.0.6 acquisition software with 200 Hz lowpass filter and digitized at 500 Hz. All sites were referenced online to the left earlobe (M1), and re-referenced offline to the linked earlobes (M1, M2).

Flanker task. The flanker task was identical to the one used in Study 3. During the flanker task, EEG data was recorded to quantify the N2 and P3 to congruent and incongruent trials, as well as the Pe and ERN to incorrect compared to correct trials, respectively. EEG data was analyzed offline using Curry 7.0.12 S software and re-referenced offline to the average of the earlobes before being bandpass filtered (high pass cut-off of 0.1 Hz, 12 dB slope; low pass cut-off 30 Hz, 12 dB slope; Luck 2014) with a constant baseline correction. Noisy blocks were hand removed before a regression based ocular correction was applied (Semlitsch, Anderer, Schuster, & Presslich, 1986) using a supraorbital electrode. Stimulus locked epochs were created 200 ms before to 500 ms after the central flanker arrow appeared for the N2 and P3, as well as response locked epochs for the ERN and Pe from 200 ms before to 500 ms after the participant responded. After applying a pre-trigger baseline correction, bad epochs were rejected based on voltages exceeding +/- 75 µV on good midline channels (Bartholow et al., 2010). Last, stimulus-locked ERPs windows were determined by examining the peaks in grand average to incongruent correct trials over the midline, and response-locked ERPs windows were determined by the peaks in grand average to incorrect responses over the midline. Specifically, the N2 was quantified as the mean amplitude between 250 and 350 ms after stimulus onset, the P3 was quantified as the mean amplitude between 350 and 450 ms after stimulus onset, the ERN was quantified as the mean amplitude between 20 and 100 ms after response, and the error positivity was quantified as the mean amplitude between 150 and 250 ms after response.

Emotional image viewing task. The image viewing task was nearly identical to the ones used in Study 2 and 3, except that participants only viewed negative and neutral images. Participants viewed 60 images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) selected based on normed data to elicit high arousal, low valence (i.e., negative images, 30 images) and low arousal, middling valence (i.e., neutral images, 30 images).[3] Image viewing trials and instructions were identical to Studies 2 and 3. Participants rated their emotional responses to each image using self-assessment manikins (SAMs; Bradley & Lang, 1994) while EEG data was collected. EEG data was analyzed offline using Curry 7.0.12 S software and re-referenced offline to the average of the earlobes before being low pass filtered (cut-off of 16 Hz, 12 dB slope; Hajcak, Weinberg, MacNamara, & Foti, 2012) with a constant baseline correction. Noisy blocks were hand removed before a regression based ocular correction was applied (Semlitsch, Anderer, Schuster, & Presslich, 1986) using a supraorbital electrode. Stimulus locked epochs were created 100 ms before to 6000 ms after image onset. After applying a pre-trigger baseline correction, bad epochs were rejected based on voltages exceeding +/- 100 µV on good midline channels (adapted from Bartholow et al., 2010 to account for long epoch length). Last, stimulus-locked ERPs windows were determined by the peaks in grand average to all images over the midline. Specifically, the N1 was quantified as the mean amplitude between

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[3] Negative images (IAPS numbers: 1052, 1220, 1270, 1300, 2095, 2900, 3000, 3071, 3130, 3150, 3230, 3250, 3301, 3400, 3550, 6230, 6250.1, 6510, 6560, 6838, 7380, 8485, 9040, 9300, 9340, 9405, 9490, 9520, 9530, 9911) with normed average valence of $M = 2.49$, $SD = 0.66$, and normed average arousal of $M = 6.08$, $SD = 0.73$. Neutral images (IAPS numbers: 2038, 2102, 2190, 2214, 2215, 2305, 2383, 2393, 2397, 2440, 2480, 2485, 2506, 2513, 2516, 2570, 2575, 2850, 6150, 7000, 7025, 7035, 7041, 7053, 7053, 7059, 7100, 7161, 7236, 7493) with normed average valence of $M = 5.09$, $SD = 0.33$, and normed average arousal of $M = 3.09$, $SD = 0.44$ (Lang, Bradley, & Cuthbert, 2005).

50 and 100 ms after image onset, the P2 was quantified as the mean amplitude between 100 to 200 ms after image onset, the N2 and EPN were quantified as the mean amplitude between 200 and 320 ms after image onset, and the LPP was quantified into nine separate 500 ms chunks starting at 500 to 1000 ms through 4500 to 5000 ms after image onset.

Results

First, I analyzed the self-reported and behavioral results consistent with the analyses conducted for Studies 2 and 3. Then I ascertained where on the scalp the relevant ERP signals emerged (see Appendix) before analyzing the ERPs during the picture viewing and flanker tasks by condition. I also examined moderating effects of flanker ERPs on emotional ERPs. Last, I examined how the ERP mean amplitudes corresponded to the self-reported and behavioral results.

Flanker task performance. As before, I assessed several indices of flanker performance, including post-error slowing, flanker interference, and accuracy on incongruent trials. For all flanker indices, reaction times faster than 200 ms were removed from analyses. As shown in Table 10, none of the indices revealed an effect of experimental condition. Hence, post-error slowing, flanker RT interference, and accuracy during incongruent trials were similar regardless of whether participants completed the flanker task first or viewed emotional pictures first.

Table 10

Study 4: Flanker Performance as a Function of Condition

Flanker Performance	Images-First (n = 79)	Flanker-First (n = 91)	t (168)	p	Cohen's d
Post-error slowing	80.09 (65.83)	76.05 (62.16)	0.41	.682	0.06
Interference score	154.98 (43.12)	157.28 (48.03)	0.33	.745	0.05
Incongruent trial accuracy	5.89 (4.99)	6.57 (4.42)	0.95	.344	0.14

Note: Descriptive statistics reported as mean (standard deviation).

Self-reported emotional reactivity. To quantify emotional reactivity I again averaged participants' valence and arousal ratings separately for negative and neutral images. I examined emotional reactivity in two separate 2 (Task Order: image first or flanker first) × 2 (Image Type: neutral or negative) mixed-model ANOVAs, one for valence and one for arousal. See Table 11 and Table 12.

Valence. I did not find the predicted effect of condition on self-reported emotional valence, F (1, 168) = 0.13, p = .715, *partial* η^2 = 0.001; valence in response to negative images was comparable in the flanker first (M = 2.08, SD = 0.59) and image first (M = 2.10, SD = 0.68) conditions, as was valence in response to neutral images (flanker first M = 4.15, SD = 0.45; image first M = 4.17, SD = 0.39). See Table 11.

Table 11

Study 4: Self-reported Valence as a Function of Condition (Image First or Flanker First) and Image Type (Neutral or Negative)

Valence Within-Subjects Effects	F	*df*	*p*	*partial η^2*
Image Type	1152.45	(1, 168)	< .001	0.87
Image Type × Condition	0.001	(1, 168)	.973	< 0.001
Between-Subjects Effects				
Condition	0.13	(1, 168)	.715	0.001

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

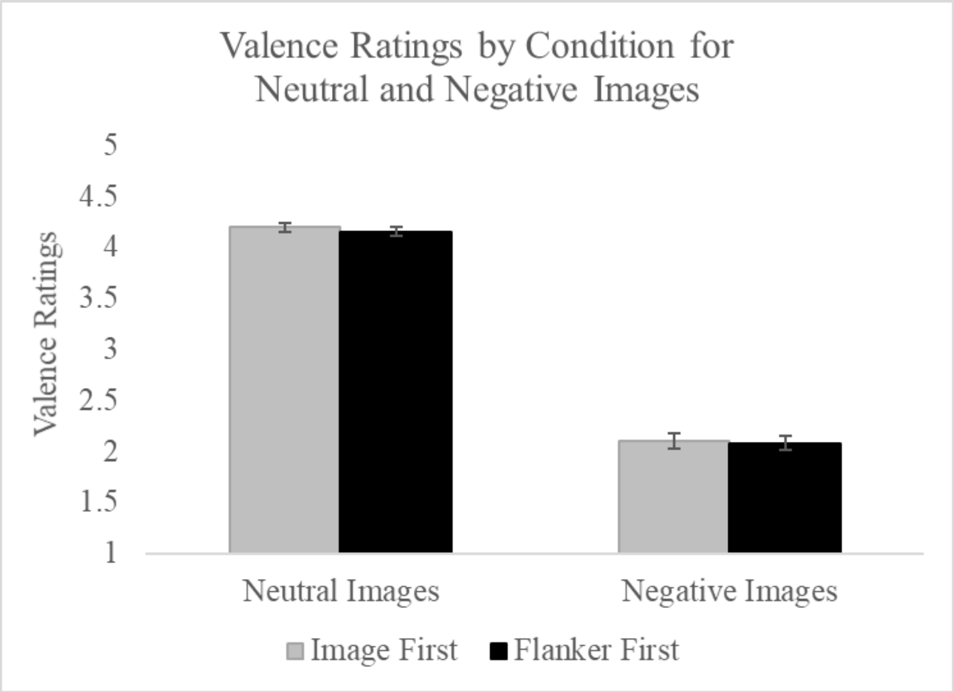

Figure 5. Study 4, valence ratings by order condition, neutral and negative images, with standard errors.

Arousal. As shown in Table 12, I found no effect of condition, nor a picture type by condition interaction, *p*s > .140, on self-reported arousal. Descriptively, arousal was slightly higher in the flanker first condition during both negative (*M* = 4.21, *SD* = 1.11) and neutral images (*M* = 2.55, *SD* = 0.92) relative to the image first condition (negative *M* = 4.02, *SD* = 1.08; neutral *M* = 2.37, *SD* = 0.88).

Table 12

Study 4: Self-reported Arousal as a Function of Condition (Image First or Flanker First) and Image Type (Positive or Negative)

Arousal Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Image Type	378.79	(1, 168)	< .001	0.693
Image Type × Condition	< .001	(1, 168)	.998	< 0.001
Between-Subjects Effects				
Condition	2.12	(1, 168)	.147	0.012

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

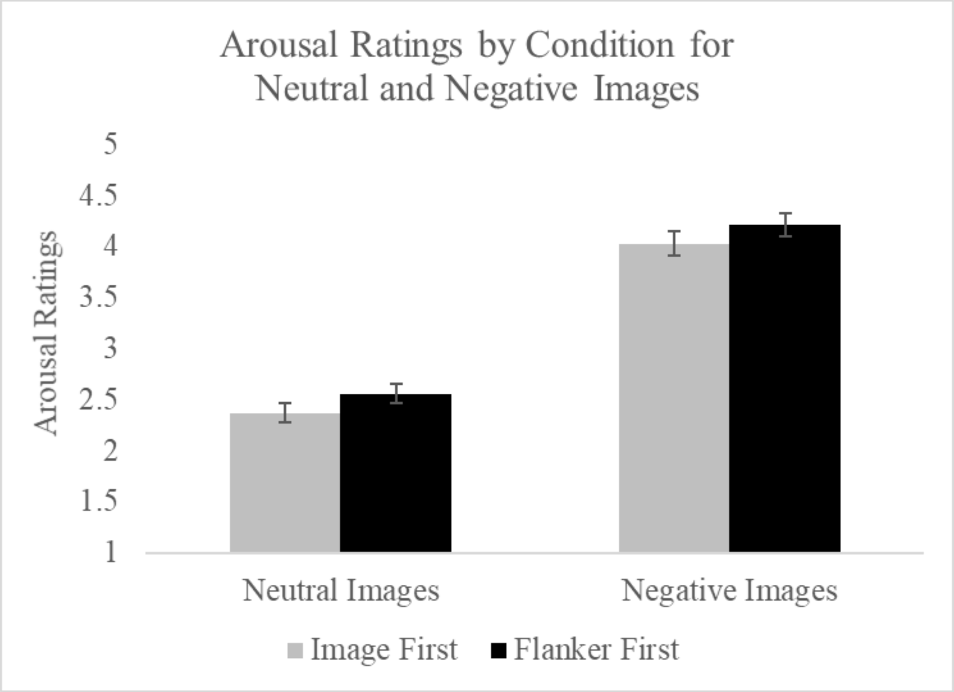

Figure 6. Study 4, arousal ratings by order condition, neutral and negative images, with standard errors.

Trait anxiety as a covariate. Next, I conducted individual one-way ANOVAs to examine the effect of condition on negative valence and arousal controlling for trait anxiety. After controlling for trait anxiety, condition was still a non-significant predictor of valence, F (1, 167) = 0.03, $p = .802$, *partial* $\eta^2 < 0.001$, and arousal, F (1, 167) = 1.00, $p = .318$, *partial* $\eta^2 = 0.006$, responses to negative images.

Flanker task ERPs by condition. I assessed the effects of condition on neural responses to incongruent versus congruent stimuli (i.e., N2 and P3 mean amplitudes) as well as the neural responses after correct and incorrect responses (i.e., ERN and Pe mean amplitudes) at the midline electrode site where each ERP was maximal (see Appendix for analyses regarding maximal electrode sites).

Flanker N2 by Condition. To examine the impact of condition on the flanker N2s, I conducted a 2 (Stimulus Type: congruent or incongruent) × 2 (Condition: image first or flanker first) mixed RM ANOVA N2 amplitudes at electrode site FCz. As shown in Table 13, only a significant effect of stimulus type emerged, F (1, 158) = 502.68, $p < .001$, *partial* $\eta^2 = 0.761$. Consistent with prior research (Clayson & Larson 2011), the N2 was more negative on incongruent trials ($M = -2.825$, $SD = 2.128$) than congruent trials ($M = 0.634$, $SD = 1.150$). This suggests that incongruent trials elicited more early neural indicators of cognitive conflict and control compared to congruent trials, but that this did not differ by condition. See Figure 7.

Table 13
Study 4: Mean Flanker Stimulus Locked N2 Amplitude as a Function of Trial Type (Congruent or Incongruent) and Condition (Image First or Flanker First) at FCz

N2 at FCz				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Trial Type	502.68	(1, 158)	< .001	0.761
Trial Type × Condition	0.14	(1, 158)	.707	0.001
Between-Subjects Effects				
Condition	0.91	(1, 158)	.342	0.006

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

Flanker P3 by Condition. To examine the impact of condition on the flanker P3s, I conducted separate 2 (Stimulus Type: congruent or incongruent) × 2 (Condition: image first or flanker first) mixed RM ANOVA on flanker P3 mean amplitudes at electrode sites Cz and CPz. As shown in Table 14, only a significant effect of stimulus type emerged at both electrode sites, ps < .001, such that the P3 was more positive on incongruent trials (at Cz, $M = 5.65$, $SD = 3.12$;

at CPz, *M* = 5.60, *SD* = 2.91) than on congruent trials (at Cz, *M* = 1.26, *SD* = 1.40; at CPz, *M* = 1.69, *SD* = 1.38). This suggests that incongruent trials elicited more early neural indicators of attentional resource allocation and response inhibition compared to congruent trials, consistent with prior research (Clayson & Larson, 2011), but this pattern did not differ by condition. See Figure 7.

Table 14

Study 4: Mean Flanker Stimulus Locked P3 Amplitude as a Function of Trial Type (Congruent or Incongruent) and Condition (Image First or Flanker First) at Cz and CPz

P3 at Cz				
Within-Subjects Effects	F	*df*	*p*	*partial η²*
Trial Type	411.07	(1, 158)	< .001	0.722
Trial Type × Condition	1.78	(1, 158)	.184	0.011
Between-Subjects Effects				
Condition	1.03	(1, 158)	.313	0.006
P3 at CPz				
Within-Subjects Effects	F	*df*	*p*	*partial η²*
Trial Type	387.73	(1, 158)	< .001	0.714
Trial Type × Condition	2.681	(1, 155)	.104	0.017
Between-Subjects Effects				
Condition	2.68	(1, 155)	.104	0.017

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

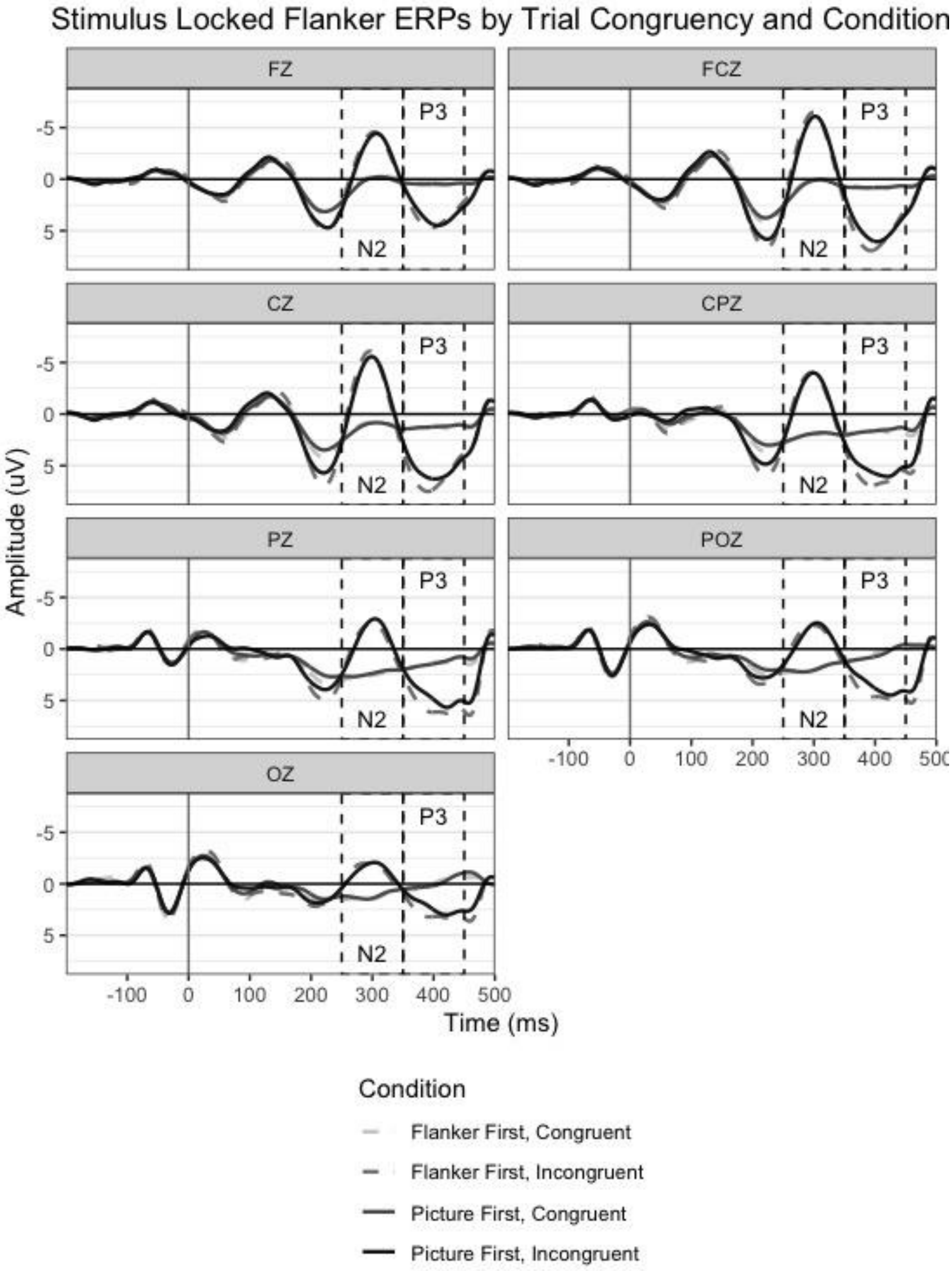

Figure 7. Stimulus locked flanker ERPs by trial type and condition at midline sites.

Flanker ERN by Condition. To examine the impact of condition on the ERN, I conducted a 2 (Response Type: correct or incorrect) × 2 (Condition: image first or flanker first) mixed RM ANOVA ERN mean amplitudes at Cz. As shown in Table 15, only a significant effect of response type emerged, F (1, 155) = 200.85, $p < .001$, *partial* $\eta^2 = 0.564$, such that the ERN was more negative for incorrect trials ($M = -6.049$, $SD = 5.06$) than for correct trials ($M = -0.30$, $SD = 1.07$). This pattern is consistent with prior research and indicates that incorrect trials elicited more post error neural activity compared to congruent trials, but this difference did not differ by condition. See Figure 8.

Table 15

Study 4: Mean Flanker Response Locked ERN Amplitude as a Function of Response Type (Correct or Incorrect) and Condition (Image First or Flanker First) at Cz

ERN at Cz				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Response Type	200.85	(1, 155)	< .001	0.564
Response Type × Condition	0.01	(1, 155)	.979	< 0.001
Between-Subjects Effects				
Condition	0.05	(1, 155)	.829	< 0.001

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

Flanker response locked Pe by condition. To examine the impact of condition on the flanker response locked Pe, I conducted a 2 (Response Type: correct or incorrect) × 2 (Condition: image first or flanker first) mixed RM ANOVA on flanker Pe amplitudes at electrode site Cz. As shown in Table 16, only a significant effect of response type emerged, F (1,

156) = 311.33, $p < .001$, *partial* $\eta^2 = 0.66$, such that the Pe was more positive on incorrect trials ($M = 4.28$, $SD = 3.38$) than on correct trials ($M = -0.83$, $SD = 1.19$). Consistent with prior research, this pattern indicates that incorrect trials elicited more post trial adjustment of neural activity compared to congruent trials, but this difference did not differ by condition. See Figure 8.

Table 16

Study 4: Mean Flanker Response Locked Pe Amplitude as a Function of Response Type (Correct or Incorrect) and Condition (Image First or Flanker First) at Cz

Pe at Cz				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Response Type	200.85	(1, 155)	< .001	0.564
Response Type × Condition	0.01	(1, 155)	.979	< 0.001
Between-Subjects Effects				
Condition	0.05	(1, 155)	.829	< 0.001

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

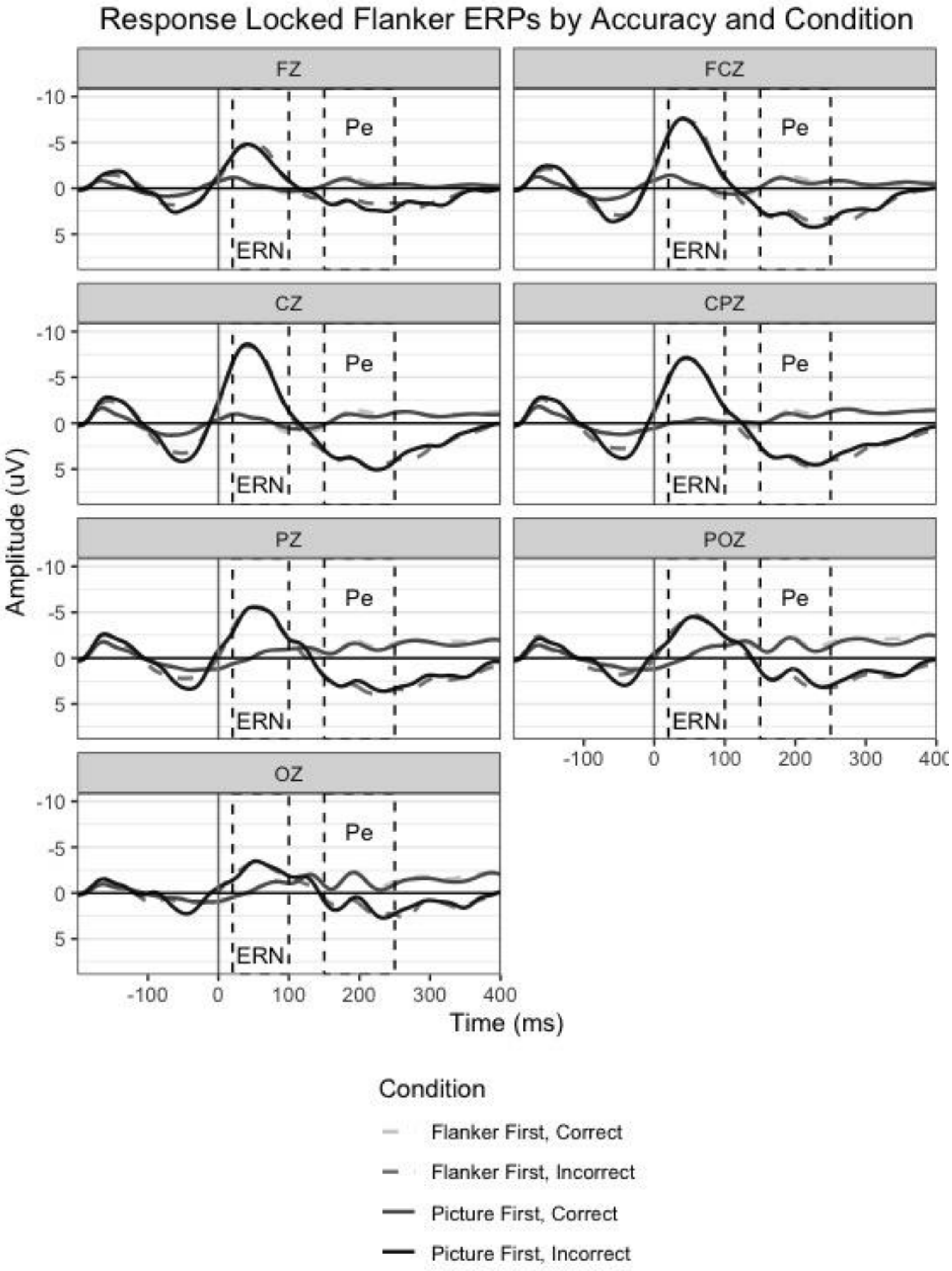

Figure 8. Response locked ERPs by accuracy and condition at midline sites.

Image viewing task ERPs by condition. Next, I assessed the effects of condition on early (i.e., N1, P2, N2 mean amplitudes) and late (i.e., LPP mean amplitudes) neural responses to neutral and negative images at the midline electrode site where each ERP was maximal, and on occipital neural responses (i.e., EPN), with and without controlling for trait anxiety (see Appendix for analyses regarding maximal electrode sites).

Image task N1 by condition. To examine the impact of condition on the image N1, I conducted 2 (Image Type: negative or neutral) × 2 (Condition: image first or flanker first) mixed RM ANOVA with and without trait anxiety as a covariate on image stimulus locked N1 mean amplitude at electrode site Cz. As shown in Table 17, neither image type nor condition influenced N1 amplitudes either with or without controlling for trait anxiety. This suggests that neither condition nor emotional image type influenced early neural indices of selective attention during the image viewing task, contrary to prior evidence that the N1 may be enhanced in response to emotional compared to neutral images (Foti, Hajcak, & Dein 2009; Weinberg & Hajcak, 2010). See Figure 9.

Table 17

Study 4: Mean Image N1 Amplitude as a Function of Image Type (Neutral or Negative) and Condition (Image First or Flanker First) at FCz and Cz, With and Without Trait Anxiety as a Covariate

N1 at FCz				
Within-Subjects Effects	F	*df*	*p*	*partial η^2*
Image Type	0.34	(1, 151)	.564	0.002
Image Type × Condition	2.29	(1, 151)	.132	0.015
Between-Subjects Effects				
Condition	2.58	(1, 151)	.110	0.017
N1 at FCz, With Trait Anxiety				
Within-Subjects Effects	F	*df*	*p*	*partial η^2*
Image Type	0.23	(1, 149)	.634	0.002
Image Type × Trait Anxiety	0.17	(1, 149)	.682	0.001
Image Type × Condition	1.69	(1, 1x)	.196	0.011
Between-Subjects Effects				
Trait Anxiety	0.92	(1, 149)	.339	0.006
Condition	2.26	(1, 149)	.135	0.015
N1 at Cz				
Within-Subjects Effects	F	*df*	*p*	*partial η^2*
Image Type	0.12	(1, 153)	.731	0.001
Image Type × Condition	1.60	(1, 153)	.208	0.010
Between-Subjects Effects				
Condition	0.11	(1, 153)	.742	0.001
N1 at Cz, With Trait Anxiety				
Within-Subjects Effects	F	*df*	*p*	*partial η^2*
Image Type	0.13	(1, 151)	.722	0.001
Image Type × Trait Anxiety	0.12	(1, 151)	.730	0.001
Image Type × Condition	1.075	(1, 151)	.308	0.007
Between-Subjects Effects				
Trait Anxiety	1.58	(1, 151)	.210	0.010
Condition	0.03	(1, 151)	.856	< 0.001

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

Image task P2 by condition. To examine the impact of condition on the image P2, I conducted 2 (Image Type: negative or neutral) × 2 (Condition: image first or flanker first) mixed RM ANOVA with and without trait anxiety as a covariate on image P2 amplitudes at Pz. As shown in Table 18, no significant effects of image type or condition emerged either with or without controlling for trait anxiety. Hence, neither condition nor emotional image type influenced early neural indices of visual attention during the image viewing task, contrary to prior research on emotional modulation of the P2. See Figure 9.

Table 18

Study 4: Mean Image P2 Amplitude as a Function of Image Type (Neutral or Negative) and Condition (Image First or Flanker First) at Pz, With and Without Trait Anxiety as a Covariate

P2 at Pz				
Within-Subjects Effects	F	*df*	*p*	*partial η²*
Image Type	0.24	(1, 149)	.628	0.002
Image Type × Condition	0.09	(1, 149)	.762	0.001
Between-Subjects Effects				
Condition	0.96	(1, 149)	.328	0.006
P2 at Pz, With Trait Anxiety				
Within-Subjects Effects				
Image Type	0.89	(1, 147)	.348	0.006
Image Type × Trait Anxiety	0.38	(1, 147)	.382	0.005
Image Type × Condition	0.16	(1, 147)	.689	0.001
Between-Subjects Effects				
Trait Anxiety	0.21	(1, 147)	.648	0.001
Condition	0.92	(1, 147)	.339	0.006

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

Image task N2 by condition. To examine the impact of condition on the image N2, I conducted 2 (Image Type: negative or neutral) × 2 (Condition: image first or flanker first) mixed RM ANOVA with and without trait anxiety as a covariate on image stimulus locked N2 mean amplitude at FCz and Cz. As shown in Table 19, there was no significant effect of image type or condition with or without controlling for trait anxiety. This suggests that neither condition nor emotion influenced this index of visual attention allocation while viewing images, contrary to prior research that has found the N2 to be enhanced in response to negative images (Lithari et al., 2010). See Figure 9.

Table 19

Study 4: Mean Image N2 Amplitude as a Function of Image Type (Neutral or Negative) and Condition (Image First or Flanker First) at FCz and Cz, With and Without Trait Anxiety as a Covariate

N2 at FCz				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Trial Type	0.06	(1, 151)	.813	< 0.001
Trial Type × Condition	0.54	(1, 151)	.463	0.004
Between-Subjects Effects				
Condition	0.51	(1, 151)	.476	0.003
N2 at FCz, With Trait Anxiety				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Image Type	1.05	(1, 149)	.306	0.007
Image Type × Trait Anxiety	1.18	(1, 149)	.280	0.008
Image Type × Condition	0.37	(1, 149)	.544	0.002
Between-Subjects Effects				
Trait Anxiety	2.09	(1, 149)	.151	0.014
Condition	0.50	(1, 149)	.481	0.003
N2 at Cz				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Trial Type	0.06	(1, 151)	.806	< 0.001
Trial Type × Condition	0.66	(1, 151)	.419	0.004
Between-Subjects Effects				
Condition	< 0.001	(1, 151)	.988	< 0.001
N2 at Cz, With Trait Anxiety				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Image Type	2.24	(1, 149)	.136	0.015
Image Type × Trait Anxiety	2.10	(1, 149)	.150	0.014
Image Type × Condition	0.45	(1, 149)	.502	0.003
Between-Subjects Effects				
Trait Anxiety	1.88	(1, 149)	.173	0.012
Condition	< 0.001	(1, 149)	.990	< 0.001

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

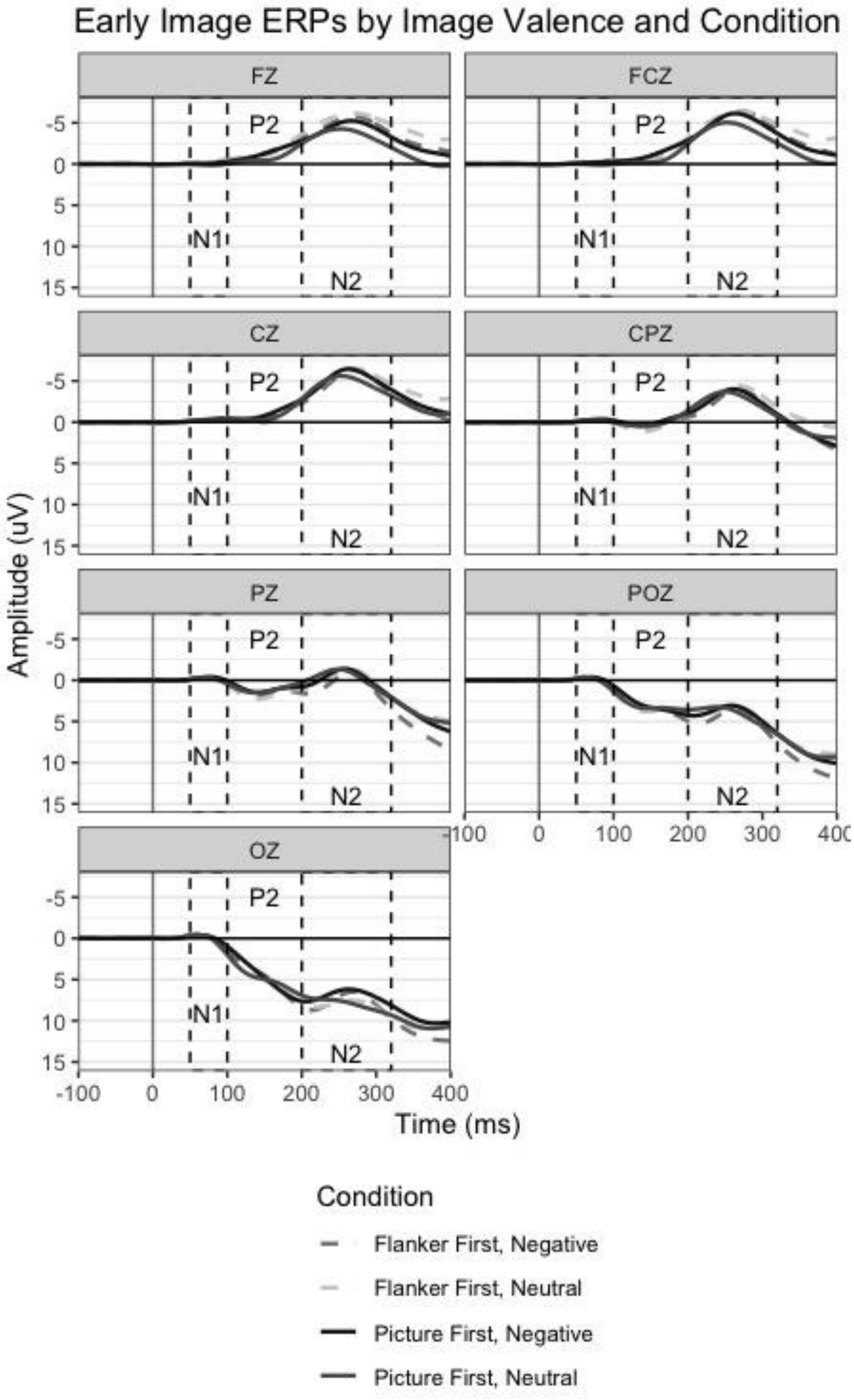

Figure 9. Early image midline ERPs by image type and condition at midline sites.

Image task LPPs by condition. To examine the impact of condition on the LPP, I conducted separate 2 (Image Type: negative or neutral) × 2 (Condition: image first or flanker first) mixed RM ANOVA with and without trait anxiety as a covariate on LPP mean amplitudes for each of the nine 500 ms windows. Table 20 depicts the analyses without trait anxiety as a covariate, and Table 21 depicts the analyses with trait anxiety as a covariate.

As shown in Table 21, trait anxiety was not a significant predictor at any time window, *p*s > 0.055, but it did reduce the effect of image type to non-significance for all but the 500-1000 ms window. As shown in Tables 20 and 21, negative images elicited a larger LPP at all time windows except 4500-5000 ms after stimulus onset. This suggests that for the first 4.5 seconds into picture viewing, participants processed negative images more deeply than neutral images, consistent with prior research (Hajcak, Weinberg, MacNamara, & Foti, 2012). Additionally, for the first two time windows (500-1000 ms and 1000-1500 ms), a significant interaction of condition and image type emerged, *p*s < 0.040. As depicted in Figure 10, contrary to predictions, participants who completed the flanker task first had larger LPPs to negative images 500-1000 and 1000 to 1500 ms after image onset. This difference got smaller over time. This pattern suggests that participants who completed the flanker first were more engaged with and processed the negative images more deeply early in picture viewing compared with participants who viewed the images first, although, as reported above, self-reported emotional responses did not differ between the two groups.

Table 20

Study 4: Mean Image LPP Amplitude as a Function of Image Type (Neutral or Negative) and Condition (Image First or Flanker First) at Each Time Window

LPP 500-1000 ms at Pz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	125.87	(1, 149)	< .001	0.458
Image × Condition	7.01	(1, 149)	.009	0.045
Between-Subjects				
Condition	4.06	(1, 149)	.046	0.027

LPP 1000-1500 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	37.93	(1, 146)	< .001	0.206
Image × Condition	4.42	(1, 146)	.037	0.029
Between-Subjects				
Condition	3.55	(1, 146)	.062	0.024

LPP 1500-2000 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	38.04	(1, 147)	< .001	0.206
Image × Condition	3.37	(1, 147)	.068	0.022
Between-Subjects				
Condition	2.23	(1, 147)	.137	0.015

LPP 2000-2500 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	35.74	(1, 146)	< .001	0.197
Image × Condition	0.08	(1, 146)	.783	0.001
Between-Subjects				
Condition	1.22	(1, 146)	.271	0.008

LPP 2500-3000 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	15.73	(1, 147)	< .001	0.097
Image × Condition	0.29	(1, 147)	.592	0.002
Between-Subjects				
Condition	1.43	(1, 147)	.235	0.010

LPP 3000-3500 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	7.84	(1, 147)	.006	0.051
Image × Condition	0.07	(1, 147)	.796	< 0.001
Between-Subjects				
Condition	0.60	(1, 147)	.441	0.004

LPP 3500-4000 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	7.38	(1, 147)	.007	0.048
Image × Condition	0.05	(1, 147)	.819	< 0.001
Between-Subjects				
Condition	0.27	(1, 147)	.601	0.002

LPP 4000-4500 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	5.65	(1, 146)	.019	0.037
Image × Condition	1.24	(1, 146)	.268	0.008
Between-Subjects				
Condition	0.31	(1, 146)	.577	0.002

LPP 4500-5000 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	1.84	(1, 146)	.177	0.012
Image × Condition	1.63	(1, 146)	.204	0.011
Between-Subjects				
Condition	0.53	(1, 146)	.467	0.004

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

Table 21

Study 4: Mean Image LPP Amplitude as a Function of Image Type (Neutral or Negative) and Condition (Image First or Flanker First) at Each Time Window, With Trait Anxiety as a Covariate

LPP 500-1000 ms at Pz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	6.95	(1, 147)	.009	0.045
Image × Anxiety	0.03	(1, 147)	.857	< .001
Image × Condition	6.71	(1, 147)	.011	0.044
Between-Subjects				
Anxiety	1.67	(1, 147)	.198	0.011
Condition	3.72	(1, 147)	.056	0.025

LPP 1000-1500 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	2.20	(1, 144)	.140	0.015
Image × Anxiety	0.02	(1, 144)	.889	< .001
Image × Condition	4.41	(1, 144)	.038	0.030
Between-Subjects				
Anxiety	3.67	(1, 144)	.058	0.025
Condition	3.68	(1, 144)	.057	0.025

LPP 1500-2000 ms at Pz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	1.40	(1, 145)	.239	0.010
Image × Anxiety	0.03	(1, 145)	.872	< .001
Image × Condition	3.52	(1, 145)	.063	0.024
Between-Subjects				
Anxiety	3.47	(1, 145)	.065	0.023
Condition	2.35	(1, 145)	.127	0.016

LPP 2000-2500 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	0.50	(1, 144)	.480	0.003
Image × Anxiety	0.37	(1, 144)	.544	0.003
Image × Condition	0.14	(1, 144)	.713	0.001
Between-Subjects				
Anxiety	3.63	(1, 144)	.059	0.025
Condition	1.33	(1, 144)	.250	0.009

LPP 2500-3000 ms at Pz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	1.06	(1, 145)	.306	0.007
Image × Anxiety	0.03	(1, 145)	.858	< .001
Image × Condition	0.38	(1, 145)	.538	0.003
Between-Subjects				
Anxiety	3.32	(1, 145)	.071	0.022
Condition	1.56	(1, 145)	.214	0.011

LPP 3000-3500 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	0.003	(1, 145)	.954	< .001
Image × Anxiety	0.30	(1, 145)	.583	0.002
Image × Condition	0.14	(1, 145)	.712	0.001
Between-Subjects				
Anxiety	3.56	(1, 145)	.061	0.024
Condition	0.70	(1, 145)	.403	0.005

LPP 3500-4000 ms at Pz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	0.92	(1, 145)	.339	0.006
Image × Anxiety	0.15	(1, 145)	.698	0.001
Image × Condition	0.02	(1, 145)	.880	< 0.001
Between-Subjects				
Anxiety	3.39	(1, 145)	.068	0.023
Condition	0.35	(1, 145)	.554	0.002

LPP 4000-4500 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	0.05	(1, 144)	.825	< 0.001
Image × Anxiety	0.08	(1, 144)	.773	0.001
Image × Condition	1.01	(1, 144)	.318	0.007
Between-Subjects				
Anxiety	3.48	(1, 144)	.064	0.024
Condition	0.40	(1, 144)	.528	0.003

LPP 4500-5000 ms at CPz

Within-Subjects	F	*df*	*p*	*partial* η^2
Image	0.01	(1, 144)	.930	< 0.001
Image × Anxiety	0.04	(1, 144)	.842	< 0.001
Image × Condition	1.42	(1, 144)	.236	0.010
Between-Subjects				
Anxiety	3.48	(1, 144)	.064	0.024
Condition	0.67	(1, 144)	.413	0.005

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

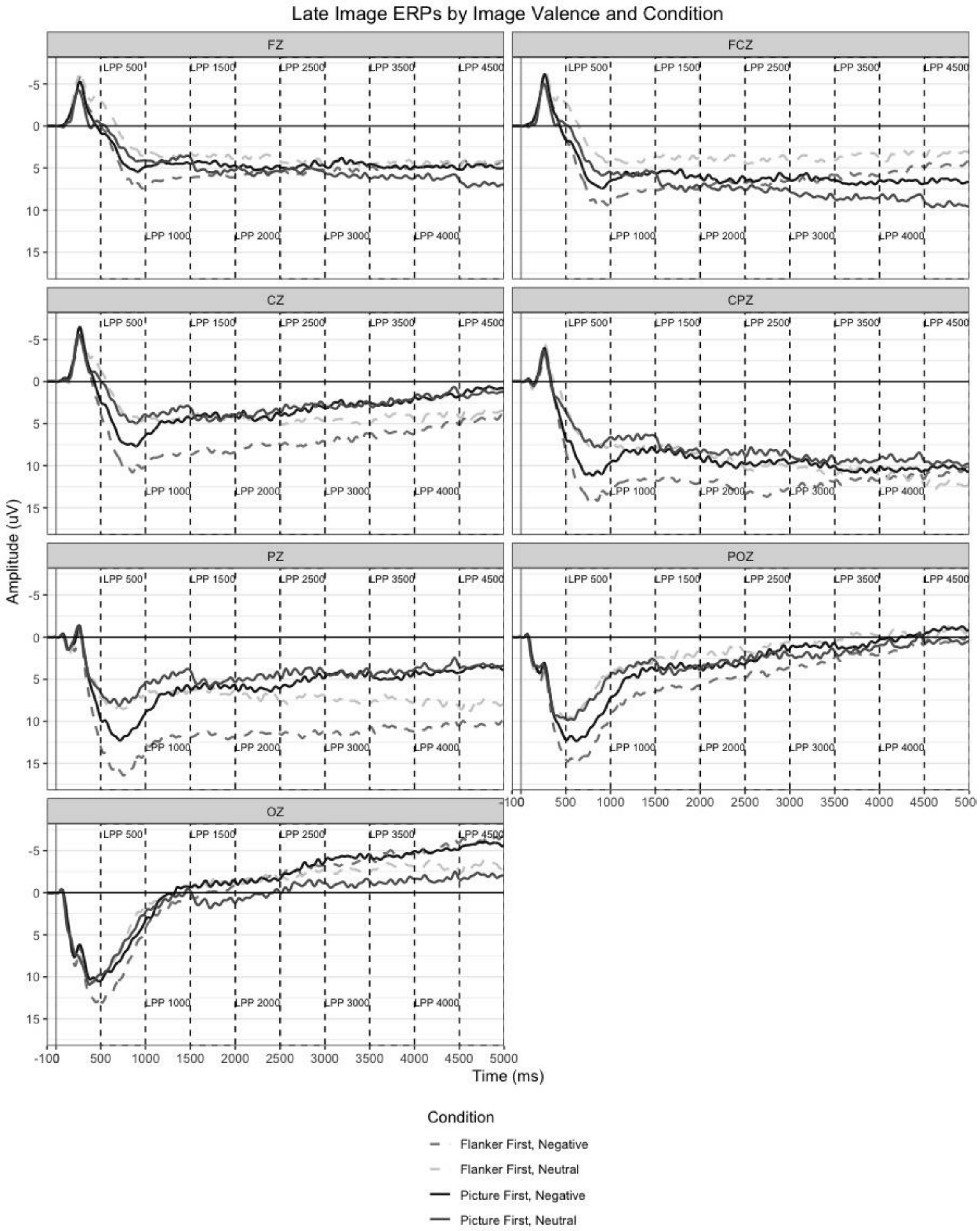

Figure 10. Late image ERPs by image valence and condition at midline sites.

Image task EPN by condition. To examine the impact of condition on the occipital EPN, I conducted 2 (Image Type: negative or neutral) × 2 (Condition: image first or flanker first) mixed RM ANOVA with and without trait anxiety as a covariate on EPN mean amplitudes averaged over O1, Oz, O2, PO5, and PO6. As shown in Table 22, there was no significant effect of image type or condition with or without controlling for trait anxiety. This suggests that neither condition nor emotion influenced early neural indices of visual attention while viewing images, contrary to prior evidence associating with EPN with enhanced visual processing of emotional stimuli (Hajcak, Weinberg, MacNamara, & Foti, 2012; Wheaton et al., 2013; Weinberg & Hajcak, 2010). Additionally, the EPN was positive in mean amplitude over occipital sites. Examination the waveform in Figure 11 reveals that while the overall waveform in the EPN window is positive, with a relative negative deflection consistent with the EPN. However, this pattern was not consistently different across electrode site by image types and conditions.

Table 22

Study 4: Mean Image EPN Amplitude as a Function of Image Type (Neutral or Negative) and Condition (Image First or Flanker First) at Average of Occipital Sites, With and Without Trait Anxiety as a Covariate

EPN at Average Occipital				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Image Type	0.54	(1, 158)	.462	0.003
Image Type × Condition	0.19	(1, 158)	.663	0.001
Between-Subjects Effects				
Condition	2.423	(1, 158)	.121	0.015
EPN at Average Occipital, With Trait Anxiety				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Image Type	0.65	(1, 156)	.423	0.004
Image Type × Trait Anxiety	1.02	(1, 156)	.314	0.006
Image Type × Condition	0.13	(1, 156)	.720	0.001
Between-Subjects Effects				
Trait Anxiety	1.56	(1, 156)	.214	0.010
Condition	2.29	(1, 156)	.133	0.014

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

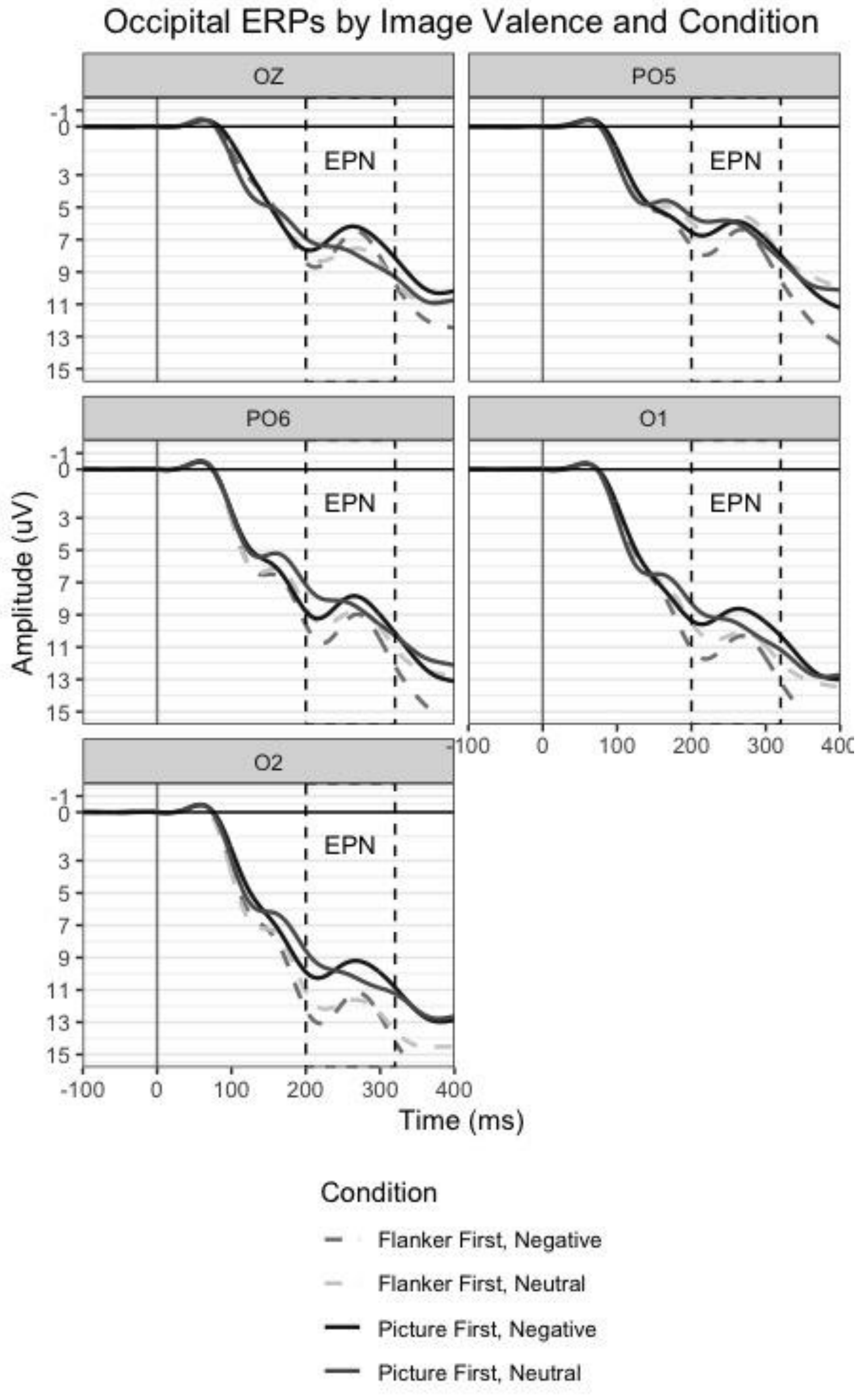

Figure 11. Occipital ERP by image valence and condition.

Moderation of emotional responses and condition by cognitive ERPs. I examined the potential moderating effect of ERPs related to cognitive functioning during the flanker task on indices of emotional responses by centering the flanker N2 and P3 to incongruent trials where the ERPs were maximal and centering the ERN and Pe to incorrect responses where the ERPs were maximal, then running a series of regressions examining the effect of condition, individual ERP mean amplitude, and the condition by ERP interaction term on the emotional ERPs and self-reported valence and arousal to negative images. There were no significant interactions in any of these analyses (*p*s > .08), indicating there was no moderation of emotional responses by condition and cognitive ERPs.

Behavior, self-report, and ERP relationships. I also examined the relationships among the observed ERPs and task-related behaviors. Specifically, I correlated all the flanker ERPs with the flanker behavioral responses and I correlated all the image ERPs with the self reports of valence and arousal across all participants and by condition. Then, I examined how self-reported arousal and condition interact to predict LPP amplitudes during negative picture viewing.

Flanker task ERPs and behavioral responses. As shown in Table 23, the flanker ERPs did not reliably correlate with the behavioral measures of flanker performance, with the exception of the ERN to correct responses (sometimes called the CRN), such that a more negative ERN to correct responses was associated with more post-error slowing and fewer incongruent errors. This pattern was similar across conditions, as shown in Table 24.

Table 23

Study 4: Correlations Between Flanker Behavioral Responses and Flanker ERPs

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Flanker Interference	-											
2. Post-error Slowing	.11	-										
3. Incongruent Accuracy	.31**	-.23**	-									
4. N2 Congruent, FCz	.04	.02	.01	-								
5. N2 Incongruent, FCz	-.11	.004	.02	.43**	-							
6. P3 Congruent, Cz	-.09	-.03	.09	.20*	-.06	-						
7. P3 Congruent, CPz	-.11	-.008	-.006	.08	-.04	.76**	-					
8. P3 Incongruent, Cz	.02	.11	.05	.12	-.33**	.50**	.44**	-				
9. P3 Incongruent, CPz	-.04	.06	-.02	.04	-.31**	.39**	.54**	.92**	-			
10. ERN Correct, Cz	-.01	-.17*	.16*	-.01	-.003	.54**	.44**	.02	-.003	-		
11. ERN Incorrect, Cz	-.04	-.11	.12	.08	.28**	-.01	.004	-.17*	-.15†	.13	-	
12. Pe Correct, Cz	-.05	-.11	.11	-.16*	-.10	.28**	.15†	-.15†	-.22**	.42**	.15†	-
13. Pe Incorrect, Cz	-.003	-.02	-.05	.01	-.02	.22**	.22**	.28**	.27**	.13†	-.25**	-.01

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table 24

Study 4: Correlations Between Flanker Behavioral Responses and Flanker ERPs by Condition

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Flanker Interference	-	.17	.29*	.06	-.16	-.09	-.06	-.02	-.04	.04	.12	.06	-.10
2. Post-error Slowing	.07	-	-.19	.03	.008	-.04	-.12	.11	.03	-.12	-.20†	-.11	.07
3. Incongruent Accuracy	.33**	-.28**	-	.12	.11	.06	-.07	.05	-.03	.17	.17	.19	-.02
4. N2 Congruent, FCz	.02	.02	-.09	-	.33**	.39**	.27*	.27*	.21†	.004	.05	-.18	.06
5. N2 Incongruent, FCz	-.07	.001	-.04	.51**	-	.09	-.03	-.21	-.26*	-.02	.32**	-.005	.004
6. P3 Congruent, Cz	-.09	-.03	.12	.04	-.16	-	.84**	.45**	.37**	.49**	-.03	.12	.36**
7. P3 Congruent, CPz	-.13	.09	.05	-.07	-.05	.70**	-	.43**	.47**	.35**	-.06	.03	.26*
8. P3 Incongruent, Cz	.05	.11	.04	-.01	-.42**	.54**	.45**	-	.95	-.05	-.25	-.20†	.40**
9. P3 Incongruent, CPz	-.03	.10	-.01	-.12	-.34**	.41**	.60**	.90**	-	-.11	-.27*	-.31*	.36**
10. ERN Correct, Cz	-.05	-.21†	.16	-.02	.02	.59**	.51**	.07	.09	-	.15	.32**	.18
11. ERN Incorrect, Cz	-.16	-.02	.08	.10	.26*	.009	.006	-.10	-.05	.11	-	.14	-.26*
12. Pe Correct, Cz	-.12	-.11	.06	-.16	-.18†	.40**	.26*	-.10	-.13	.51**	.15	-	.09
13. Pe Incorrect, Cz	.06	-.08	-.09	-.04	-.04	.12	.18†	.08	.21†	.10	-.25*	-.08	-

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Note: Image first above the diagonal, flanker first below the diagonal.

Image viewing ERPs and self-reports. As shown in Table 25, the negative image ERPs were mostly uncorrelated with self-reported valence. Self-reported arousal to negative images was marginally related to LPP mean amplitude during the 500-1000 ms window, $r(151) = 0.14$ $p = .095$, such that individuals who rated negative images as more arousing had slightly larger LPPs during the 500-1000 ms window, smaller in magnitude but consistent with prior research (Cuthbert et al., 2000; Yen, Chen, & Liu, 2010). Split across conditions, for negative images arousal was non-significantly positively correlated with arousal at all time points in the image first condition, but in the flanker first condition arousal was non-significantly negatively related with LPPs after 2000 ms, as shown in Table 26. This pattern suggests that completing the flanker task first disrupted the relationship between self-reported arousal and LPP amplitudes compared to participants who viewed the images first.

Table 25

Study 4: Correlations Between Self-Reported Emotions and Image ERPs, Negative Images Only

Negative Images	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1. Valence	-															
2. Arousal	-.42**	-														
3. N1, FCz	.05	.004	-													
4. N1, Cz	.01	.06	.93**	-												
5. P2, Pz	-.08	.02	.38**	.45**	-											
6. N2, FCz	-.09	.05	.30**	.30**	.61**	-										
7. N2, Cz	-.10	.08	.23**	.31**	.66**	.96**	-									
8. LPP 500, Pz	-.10	.14†	.03	.07	.49**	.42**	.48**	-								
9. LPP 1000, CPz	.04	.11	.13	.08	.23**	.22**	.22**	.64**	-							
10. LPP 1500, CPz	.05	.08	.12	.12	.16†	.12	.13	.52**	.95**	-						
11. LPP 2000, CPz	.04	.04	.13	.12	.09	.06	.05	.43**	.87**	.95**	-					
12. LPP 2500, CPz	.02	.05	.14	.13	.08	.02	.02	.38**	.83**	.92**	.98**	-				
13. LPP 3000, CPz	.03	.03	.10	.08	.08	.02	.02	.39**	.81**	.89**	.95**	.98**	-			
14. LPP 3500, CPz	.001	-.005	.10	.08	.06	.01	.003	.34**	.77**	.86**	.93**	.95**	.91**	-		
15. LPP 4000, CPz	-.003	.007	.10	.07	.04	-.005	-.02	.33**	.75**	.83**	.91**	.94**	.97**	.99**	-	
16. LPP 4500, CPz	-.02	.07	.07	.07	.05	-.01	-.02	.30**	.71**	.80**	.88**	.92**	.95**	.97**	.99**	-
17. EPN, Avg	-.03	.007	.22**	.26**	.66**	.43**	.47**	.54**	.32**	.28**	.26**	.24**	.23**	.20*	.18*	.21**

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table 26

Study 4: Correlations Between Self-Reported Emotions and Image ERPs, Negative Images Only, by Condition

Negative Images	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16	17.
1. Valence	-	-.41**	.03	-.003	.03	-.004	.003	-.06	.07	.07	.008	-.07	-.04	-.07	-.12	-.12	.01
2. Arousal	-.44**	-	.20	.20	.006	-.03	-.07	.08	.12	.14	.16	.23	.17	.16	.21†	.22†	-.03
3. N1, FCz	.07	-.13	-	.93**	.38**	.37*	.28*	.14	.29*	.34**	.33**	.34**	.25*	. 21†	.19	.19	.28*
4. N1, Cz	.03	-.05	.94**	-	.44*	.35**	.40**	.10	.21†	.25*	.21†	.24†	.15	.12	.10	.11	.31*
5. P2, Pz	-.20†	.02	.39**	.46**	-	.70**	.71**	.63**	.28*	.09	.10	.09	.07	.05	.03	.01	.68**
6. N2, FCz	-.15	.10	.27**	.27**	.57**	-	.95**	.41**	.28*	.23†	.18	.18	.16	.17	.16	.17	.52**
7. N2, Cz	-.17	.17	.20†	.25*	.64**	.96**	-	.41**	.19	.14	.08	.09	.07	.07	.07	.08	.54**
8. LPP 500, Pz	-.14	.14	-.05	.04	.37**	.6**	.54**	-	.59**	.51**	.40**	.40**	.42**	.41*	.39**	.36*	.52**
9. LPP 1000, CPz	.02	.08	.02	.08	.20†	. 20†	.25**	.66**	-	.95**	.85**	.83**	.83**	.80**	.78**	.72**	.30*
10. LPP 1500, CPz	.03	.01	-.04	.01	.11	.07	.12	.50**	.95**	-	.94**	.91**	.89**	.86**	.84**	.79**	.23†
11. LPP 2000, CPz	.06	-.06	-.02	.04	.08	-.009	.03	.43**	.88**	.96**	-	.97**	.95**	.92**	.91**	.88**	.19
12. LPP 2500, CPz	.10	-.10	-.003	.04	.07	-.07	-.03	.34**	.83**	.92**	.98**	-	.97**	.95**	.94**	.92**	.19
13. LPP 3000, CPz	.09	-.08	-.03	.02	.08	-.06	-.02	.34**	.81**	.89**	.96**	.98**	-	.99**	.98**	.95**	.15
14. LPP 3500, CPz	.07	-.13	.001	.04	.07	-.08	-.05	.28*	.77**	.86**	.93**	.96**	.98**	-	.99**	.97**	.14
15. LPP 4000, CPz	.10	-.15	.01	.05	.04	-.11	-.07	.27*	.74**	.84**	.91**	.95**	.97**	.99**	-	.99**	.13
16. LPP 4500, CPz	.07	-.13	-.03	.03	.06	-.11	-.08	.23*	.72**	.81**	.90**	.94**	.96**	.97**	.99**	-	.11
17. EPN, Avg	-.07	.02	.19†	.23*	.65**	.39**	.43**	.53**	.31**	.30**	.30**	.25*	.27*	.27*	.25*	.27*	-

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Note: Image first above the diagonal, flanker first below the diagonal.

Table 27 depicts the correlations between neutral image self-reports and ERPs across all participants. Similar to the negative image correlations, neutral image ratings of arousal were positively (but not significantly) related to LPP magnitude, with the stronger correlations occurring earlier in picture viewing. Split across conditions as demonstrated in Table 28, the pattern for neutral image LPPs and self-reported arousal is opposite the pattern for negative images. Specifically, participants in the flanker first condition demonstrated a significant positive correlation between neutral image arousal and neutral image LPP magnitude from 500 to1000 ms and a marginally significant positive correlation from 1000 to 1500 ms. In the image first condition, however, the correlations between arousal and neutral image LPP magnitudes were smaller and non-significant, although they too increased in magnitude over picture viewing. This pattern suggests that completing the flanker task first enhanced the relationship between self-reported arousal and LPP amplitudes during neutral picture viewing.

Table 27

Study 4: Correlations Between Self-Reported Emotions and Image ERPs, Neutral Images Only

Neutral Images	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16
1. Valence	-															
2. Arousal	.009	-														
3. N1, FCz	.007	.03	-													
4. N1, Cz	-.01	.02	.94**	-												
5. P2, Pz	.01	.02	.31**	.40**	-											
6. N2, FCz	-.04	.08	.32**	.29**	.57**	-										
7. N2, Cz	-.04	.09	.25**	.31**	.65**	.93**	-									
8. LPP 500, Pz	.05	.09	.11	.17*	.60**	.48**	.57**	-								
9. LPP 1000, CPz	-.006	.13	-.009	.02	.20*	.27**	.28**	.53**	-							
10. LPP 1500, CPz	-.08	.10	-.12	-.09	.03	.09	.08	.31**	.92**	-						
11. LPP 2000, CPz	-.07	.11	-.07	-.06	.02	.03	.02	.23**	.84**	.95**	-					
12. LPP 2500, CPz	-.05	.08	-.02	-.02	-.002	.01	-.01	.21*	.82**	.92**	.98**	-				
13. LPP 3000, CPz	-.06	.06	-.006	-.001	.02	.02	-.006	.21*	.80**	.89**	.95**	.98**	-			
14. LPP 3500, CPz	-.07	.04	-.03	.02	.01	-.004	-.03	.20*	.78**	.88**	.93**	.96**	.99**	-		
15. LPP 4000, CPz	-.06	-.001	-.02	-.009	.01	-.01	-.04	.17*	.74**	.85**	.92**	.95**	.98**	.99**	-	
16. LPP 4500, CPz	-.10	.04	-.03	-.009	.01	-.02	-.04	.17*	.74**	.85**	.90**	.94**	.97**	.98**	.99**	-
17. EPN, Avg	-.07	.08	.-.02	.02	.53**	.31**	.40**	.44**	.30**	.20*	.16*	.13	.13	.14†	.14†	.12

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table 28

Study 4: Correlations Between Self-Reported Emotions and Image ERPs, Neutral Images Only, by Condition

Neutral Images	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16	17.
1. Valence	-	-.11	.19	.13	.03	.03	.02	.11	.07	-.02	.02	.07	.07	.05	.06	-.006	-.10
2. Arousal	.10	-	.01	-.02	-.11	.008	-.02	.08	.05	.009	.07	.08	.10	.10	.03	.12	.01
3. N1, FCz	-.12	.06	-	.91**	.24†	.38*	.30*	.18	.05	-.01	.003	.06	.10	.08	.06	.06	-.01
4. N1, Cz	-.11	.06	.95**	-	.33**	.37**	.41**	.22†	.05	-.02	-.02	.03	.09	.08	.06	.06	.02
5. P2, Pz	-.005	.09	.43**	.49**	-	.63**	.68**	.75**	.30*	.08	.02	.01	.08	.08	.08	.09	.54**
6. N2, FCz	-.09	.14	.27*	.24**	.54**	-	.94**	.47**	.38*	.22†	.13	.12	.19	.19	.20	.21	.47**
7. N2, Cz	-.09	.18	.23*	.26*	.65**	.93**	-	.53**	.36**	.19	.10	.09	.16	.16	.16	.18	.52**
8. LPP 500, Pz	.009	.23*	.09	.15	.42**	.52**	.61**	-	.54**	.30*	.23†	.27*	.32*	.32*	.29*	.31*	.39**
9. LPP 1000, CPz	-.05	.18†	-.02	.02	.12	. 21†	.22*	.53**	-	.91**	.85**	.85**	.83**	.81**	.80**	.80**	.29*
10. LPP 1500, CPz	-.11	.15	-.17	-.13	-.04	.003	.01	.31**	.92**	-	.96**	.92**	.88**	.87**	.87**	.85**	.18
11. LPP 2000, CPz	-.13	.12	-.10	-.08	-.006	-.03	-.05	.22†	.83**	.95**	-	.97**	.93**	.92**	.92**	.90**	.18
12. LPP 2500, CPz	-.14	.08	-.05	-.03	-.03	-.07	-.09	.16	.80**	.91**	.98**	-	.98**	.97**	.95**	.94**	.18
13. LPP 3000, CPz	-.15	.02	-.07	-.05	-.06	-.12	-.14	.12	.78**	.91**	.96**	.98**	-	.99**	.98**	.97**	.22†
14. LPP 3500, CPz	-.15	<.001	-.09	-.08	-.06	-.15	-.17	.10	.76**	.89**	.94**	.96**	.99**	-	.99**	.98**	.24†
15. LPP 4000, CPz	-.16	-.03	-.06	-.05	-.07	-.17	-.19†	.06	.70**	.84**	.92**	.95**	.98**	.99**	-	.99**	.28*
16. LPP 4500, CPz	-.18	-.03	-.06	-.05	-.07	-.19†	-.21†	.04	.70**	.85**	.91**	.94**	.97**	.98**	.99**	-	.24*
17. EPN, Avg	-.04	.11	-.003	.03	.52**	.20†	.33**	.48**	.30**	.20†	.14	.09	.06	.06	.02	.01	-

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Note: Image first above the diagonal, flanker first below the diagonal.

LPP's and arousal ratings during negative image viewing. To better understand how task order was moderating the relationship between LPP magnitude and self-reported arousal during negative images, I conducted a series of regressions with self-reported arousal (mean-centered), order condition (dummy coded), and the interaction predicting LPP magnitude at each window, with and without controlling for trait anxiety (mean-centered).

As shown in Table 29, consistent with earlier analyses, task order was a significant main effect during early LPP time windows (500-1000 ms, p = .012; 1000-1500 ms, p = .039), such that individuals in the flanker first condition demonstrated larger LPP's than individuals in the image first condition. However, this main effect continued to get smaller across the time windows while the interaction between arousal ratings and conditions grew over time and became significant during the later time windows (4000-4500 ms, p = .033; 4500-5000 ms, p = .038).

Table 29

Study 4: Mean Negative LPP Amplitude Predicted by Negative Arousal Self-Reports and Condition at Each Time Window

LPP 500-1000 ms at Pz				**LPP 1000-1500 ms at CPz**				**LPP 1500-2000 ms at Pz**			
	β	*t*	*p*		β	*t*	*p*		β	*t*	*p*
Condition	0.21	2.55	.012	Condition	0.17	2.08	.039	Condition	0.15	1.81	.073
Negative Arousal	0.08	0.66	.510	Negative Arousal	0.12	0.91	.367	Negative Arousal	0.14	1.06	.290
Arousal × Condition	0.04	0.31	.755	Arousal × Condition	-0.03	0.22	.829	Arousal × Condition	-0.09	0.73	.466
			R^2 = .061				R^2 = .041				R^2 = .032

LPP 2000-2500 ms at CPz				**LPP 2500-3000 ms at Pz**				**LPP 3000-3500 ms at CPz**			
	β	*t*	*p*		β	*t*	*p*		β	*t*	*p*
Condition	0.09	1.03	.307	Condition	0.09	1.15	.253	Condition	0.06	0.73	.468
Negative Arousal	0.16	1.22	.223	Negative Arousal	0.23	1.77	.078	Negative Arousal	0.17	1.35	.179
Arousal × Condition	-0.17	1.29	.200	Arousal × Condition	-0.25	1.93	.055	Arousal × Condition	-0.19	1.49	.137
			R^2 = .021				R^2 = .037				R^2 = .020

LPP 3500-4000 ms at Pz				**LPP 4000-4500 ms at CPz**				**LPP 4500-5000 ms at CPz**			
	β	*t*	*p*		β	*t*	*p*		β	*t*	*p*
Condition	0.03	0.40	.688	Condition	0.02	0.20	.842	Condition	0.06	0.72	.475
Negative Arousal	0.16	1.26	.210	Negative Arousal	0.22	1.70	.092	Negative Arousal	0.22	1.69	.094
Arousal × Condition	-0.22	1.72	.087	Arousal × Condition	-0.28	2.15	.033	Arousal × Condition	-0.27	2.09	.038
			R^2 = .022				R^2 = .032				R^2 = .034

Table 30 reports the regressions controlling for trait anxiety. While trait anxiety was not a significant predictor of LPP magnitude at any time window (*p*s > .08) and the pattern of results did not change, including trait anxiety in the regressions did reduce the interactions to marginally significant. As trait anxiety did not change the pattern of findings, I discuss the interaction pattern for the analyses without trait anxiety below.

Table 30

Study 4: Mean Negative LPP Amplitude Predicted by Negative Arousal Self-Reports and Condition at Each Time Window Controlling for Trait Anxiety

LPP 500-1000 ms at Pz				**LPP 1000-1500 ms at CPz**				**LPP 1500-2000 ms at Pz**			
	β	*t*	*p*		β	*t*	*p*		β	*t*	*p*
Trait Anxiety	0.10	1.21	.227	Trait Anxiety	0.13	1.52	.131	Trait Anxiety	0.14	1.65	.100
Condition	0.20	2.47	.015	Condition	0.17	2.11	.036	Condition	0.15	1.88	.063
Negative Arousal	0.06	0.48	.630	Negative Arousal	0.09	0.68	.500	Negative Arousal	0.11	0.84	.402
Arousal × Condition	0.07	0.55	.586	Arousal × Condition	0.01	0.08	.936	Arousal × Condition	-0.06	0.42	.675
			R^2 = .067				R^2 = .056				R^2 = .051
LPP 2000-2500 ms at CPz				**LPP 2500-3000 ms at Pz**				**LPP 3000-3500 ms at CPz**			
	β	*t*	*p*		β	*t*	*p*		β	*t*	*p*
Trait Anxiety	0.15	1.73	.086	Trait Anxiety	0.11	1.34	.183	Trait Anxiety	0.14	1.73	.086
Condition	0.09	1.11	.270	Condition	0.10	1.23	.221	Condition	0.07	0.83	.407
Negative Arousal	0.13	1.00	.317	Negative Arousal	0.21	1.61	.109	Negative Arousal	0.15	1.15	.251
Arousal × Condition	-0.13	0.96	.337	Arousal × Condition	-0.22	1.68	.095	Arousal × Condition	-0.16	1.19	.238
			R^2 = .042				R^2 = .051				R^2 = .042
LPP 3500-4000 ms at Pz				**LPP 4000-4500 ms at CPz**				**LPP 4500-5000 ms at CPz**			
	β	*t*	*p*		β	*t*	*p*		β	*t*	*p*
Trait Anxiety	0.12	1.44	.151	Trait Anxiety	0.13	1.54	.126	Trait Anxiety	0.12	1.41	.161
Condition	0.04	0.50	.619	Condition	0.03	0.31	.757	Condition	0.07	0.82	.413
Negative Arousal	0.14	1.10	.272	Negative Arousal	0.20	1.54	.126	Negative Arousal	0.20	1.54	.125
Arousal × Condition	-0.19	1.46	.146	Arousal × Condition	-0.25	1.88	.062	Arousal × Condition	-0.24	1.84	.068
			R^2 = .037				R^2 = .050				R^2 = .049

To understand the interaction between task order and self-reported arousal on LPP amplitudes during negative images, I plotted the effects of these predictors during each LPP time window. As shown in Figure 12, early time windows demonstrate a main effect of task order such that individuals who completed the flanker task first demonstrate a larger (more positive) mean LPP amplitude, and a positive relationship between arousal and LPP mean amplitude such that individuals who reported higher arousal during negative images demonstrated a larger initial LPP. However, in later time windows there is an interaction between arousal and task order, such that individuals in the image first condition continue to show a positive relationship between arousal and LPP mean amplitude, but participants in the flanker first condition demonstrate a negative relationship between LPP mean amplitude and arousal. This indicates that in the flanker first condition the later portion of the LPP is sensitive to another part of picture processing than self-reported feelings of arousal, suggesting that completing the flanker task first is changing later stages of image processing in a way that is decoupled from self-reported arousal.

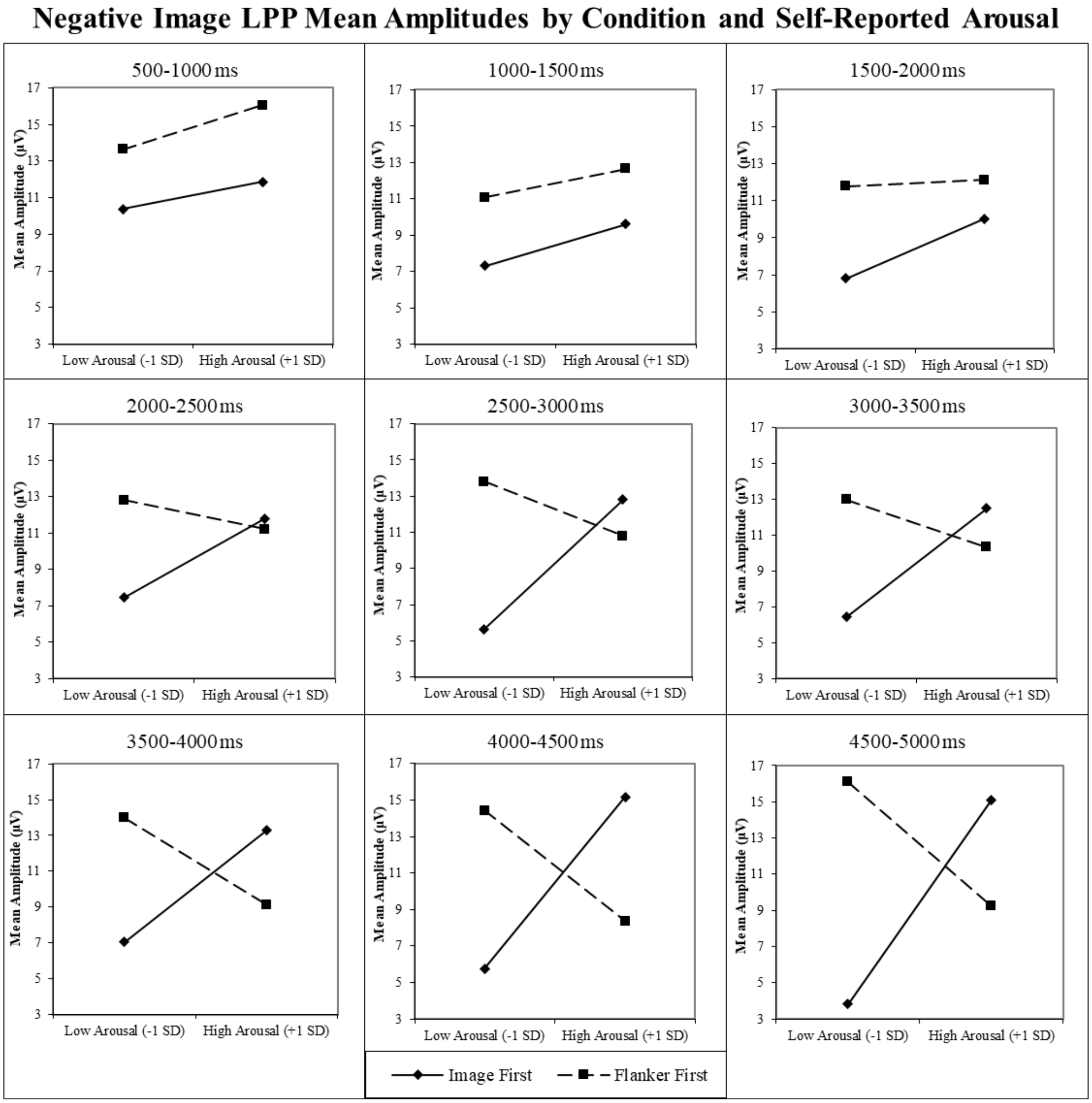

Figure 12. Mean negative LPP amplitude at each time window by self-reported arousal and condition.

Discussion

I had anticipated that the self-reported valence and arousal findings in Study 4 would replicate the findings from Studies 1-3, such that participants who completed the flanker task first would report less negative emotions in response to emotional images compared to those who viewed the images first. Unfortunately, this finding was not replicated, nor did trait anxiety matter as it did in Studies 2 and 3. However, Study 4 had fewer participants than the similarly designed Study 3, limiting the statistical power to find a small effect of task order on self-reported emotional responses. Additionally, the design was different from the earlier studies in that positive images were removed from the image set in Study 4. This change could have influenced how participants reacted to the emotional images given that the context was changed from mixed valence images to negative and neutral images only.

Regarding neural responses to emotional images, I expected to see emotion modulation on a variety of ERPs consistent with prior research, including the N1, P2, N2, EPN, and LPP. However, I only saw an effect of image valence on the LPP consistent with prior research, such that negative images showed an enhanced LPP. Much of the research examining the impact of emotions on ERPs used a range of emotions, which means that the context in which participants viewed images was often variable in valence (see Hajcak, Weinberg, MacNamara, & Foti, 2012 for a review). Not only does this allow researchers to compare the impact of different valences on ERPs, it also shifts the context in which participants view emotional images. It may be that some effects of emotion on ERPs are enhanced in mixed valence contexts compared to blocks or tasks that contain only neutral and negative images. Future work should examine if emotional modulation of ERPs to images is sensitive to the types of valence included in the task or block, as well as determine how robust emotional modulation effects are across tasks.

Task order did have an effect on the early LPP time windows, such that participants who completed the flanker task first had larger LPPs to negative images early on in image viewing (500-1500 ms after image onset) compared to participants who viewed the images first. This result is contrary to my original predictions, insofar as LPP magnitude has been associated with negative emotions. However, recent research found that when neutral and negative images were interspersed between flanker trials designed to enhance cognitive conflict in a similar manner to the current research, LPPs elicited by negative images were enhanced when the negative images came after incongruent trials compared to congruent trials (Ligeza & Wyczesany, 2017). While that study did not measure self-reports of emotion, the researchers argue that cognitive conflict sensitizes attention to be more vigilant towards important information, which leads to enhanced neural markers of attention to negative images (which contain biologically important information regarding potential threats). Without self-reports of emotional responding, however, it is unclear if the increase in LPPs after incongruent trials is due to shifts in attention or shifts in other emotional processes that LPPs index.

The current research added much needed self-reported emotional responses to this conundrum. Paired with the lack of significant differences in self-reported valence and arousal, the current LPP finding suggests that participants who completed the flanker task first processed the images more deeply or attentively compared with participants who completed the image first task, but without exhibiting an increase in negative emotional responding. Some prior research has related LPP magnitudes to memory for images (see Schupp et al, 2006 for a review), so it is possible that completing the flanker task first primed participants to process the images more thoroughly, potentially in a less emotional, more analytical manner. This is consistent with other work that found boosting attention to emotional image stimulus with a mindfulness induction also increased LPP amplitudes to negative images (Egan, Hill, & Foti, 2018).

Additionally, the current evidence that task order changed how self-reported arousal related to LPP amplitude bolsters support for this interpretation. Specifically, while LPP amplitude was positively related to self-reported arousal in early windows in both task orders, this positive relationship was maintained through the first five seconds of picture viewing only in the image first condition. In the flanker first condition, the arousal and LPP relationship was reversed over the course of the first five seconds of picture viewing, suggesting that mean LPP amplitude later in picture viewing was related to something other than self-reported arousal. This finding is consistent with participants in the flanker first condition processing the negative images more deeply without increasing their emotional response, perhaps by approaching the images in a more analytic manner. However, we did not probe participants' memory for the images, administer questionnaires designed to gauge depth of processing, or test if participants considered the images from a more analytic manner after completing the flanker, so it is unclear how much the enhanced LPP amplitudes in the current study indexed emotional responding, enhanced attention, or depth of processing. Future research should replicate the negative image LPP enhancement after incidental cognitive processing and attempt to tease apart the impact of emotions and depth of processing on the LPP through the use of self-reports and memory for images

While I found the typical patterns of conflict detection (flanker N2), attention recruitment (flanker N2), error processing (ERN), and post-error shifts (Pe) in the ERPs during the flanker task, I did not find any effect of order on these processes or behavioral measures of flanker performance, consistent with the findings in Studies 1 through 3. Additionally, none of these cognitive ERPs moderate any self-reported emotional responses or emotional ERP neural responses during picture viewing. Therefore, it is unclear what subcomponent of cognitive processing (if any individual component) during an incidental cognitive task influenced subsequent emotional responses. Future research should examine the impact of other types of cognitive processes on subsequent emotional reactivity to determine if there is a common category of processing that may reliably drive this effect, or if the act of engaging in a cognitive task prior to emotional stimuli is sufficient to see a dampening of negative emotional reactions.

SUMMARY AND CONCLUSIONS

This dissertation provided mixed evidence that incidental cognitive processes influence subsequent emotional responding when the incidental cognitive processing is completely separated from the emotional stimuli. Specifically, Studies 1 through 3 found that earlier cognitive processing dampened negative emotional responding, whereas Study 4 found that incidental cognitive processes had no impact on subjective emotional responses. But neural indices (i.e., LPP mean amplitudes) from Study 4 suggested that individuals who completed the flanker task first engaged more deeply with and paid more attention to negative images than individuals who completed the picture task first. Paired with the lack of changes in self-reported emotions and the apparent shift in the relationship between LPP amplitudes and self-reported arousal after completing the flanker task first, Study 4 suggests that completing an incidental cognitive task before viewing negative images allows deeper engagement with negative images without more emotional distress. This result provides an intriguing hint as to how individuals can be encouraged to engage more deeply and attentively with negative emotional events without experiencing more negative affect. Additional research is needed to follow up on exactly what individuals are doing to allow this deeper engagement without enhanced negative affect.

Taking the research discussed in this dissertation as a whole, it appears that the impact of incidental cognitive processing on subsequent emotional responding goes beyond simple distraction. In particular, the LPP findings are inconsistent with a distraction account, as enhanced LPPs indicate additional attention to and processing of images. Coupled with the lack of increased self-reported negative emotions, future research should examine how exactly participants are implicitly regulating their emotions without explicit instructions from experimenters. Indeed, some researchers argue that the distinction between implicit and explicit emotion regulation is not particularly useful, especially when emotion-regulation in the real world occurs without explicit instructions on how to regulate emotions in dynamic environments filled with competing goals and demands (Bartholomew, Heller, & Miller, 2019). Indeed, a recent study attempted to disentangle explicit instructions on how to down-regulate emotions with instructions to have a goal of down-regulating emotions and found that individuals with only a regulation goal showed similar reductions in corrugator activity and self-reported negative affect as individuals given explicit instructions to reappraise (Tamir et al., 2019). Future research should examine how individuals manage their emotions under conditions that do not involve explicit instructions on how to regulate to see what sorts of contextual factors may enhance successful emotion regulation beyond prior cognitive tasks.

The role that trait anxiety plays in the effects of incidental cognitive processes on emotional responses was also mixed in the current research. Specifically, Study 2 suggested trait anxiety may play an important role, but trait anxiety was not a significant predictor of self-reported emotions in Study 3 or 4. Although trait anxiety was not related to LPP magnitudes, including it in the statistical models in Study 4 eliminated the effect of image valence on LPP magnitudes. Additional research is needed to probe the extent to which trait anxiety in sub-clinical samples relates to self-reported experiences of negative emotions and neural indices of emotional processing such as the LPP, particularly with respect to executive functioning. Indeed, some research hints that increased executive functioning provides a buffering role against anxiety. Specifically, researchers found that more prefrontal cortex recruitment during a working-memory task eliminated the increased risk of anxiety symptoms in individuals who also displayed high levels of amygdala activity during an emotional task (Scult et al., 2017).

Indeed, it may be this buffering effect of higher levels of executive functioning that may be obscuring the moderating effects of cognitive task performance and ERPs on subsequent emotional responding, insofar as individuals who have higher capacities may show better performance and more efficient neural responses and also be better at managing their emotions compared to individuals with lower executive functioning capacities. Future research should attempt to account for the buffering factor that individual differences in executive functioning appear to have on real-world emotion regulation when examining the aftereffects of incidental cognitive processes on subsequent emotional responses.

Unlike prior research, the current results were consistent in finding no evidence of change in cognitive performance after completing an emotional image viewing task. However, the emotional images used in the current studies were not designed to elicit a large, long standing changes in mood, so perhaps it is not surprising that I found no effects of emotional tasks on subsequent cognitive performance. Future research should delineate when prior emotional events change cognitive performance, and when prior emotional events are unlikely to impact performance.

The current research clearly highlights the usefulness of combining both self-reports and neural measures in understanding complex emotional phenomena. Specifically, if the current work had only included self-reported emotions, it would not have been apparent that later neural markers of attention and processing of negative emotional images are boosted after engaging in an executive functioning task, as demonstrated in Study 4. However, if self-reported emotions were not included in conjunction with the EEG recordings, then it would be impossible to tell if completing an executive functioning task before an emotional task increased the experience of negative emotions in addition to attention to and processing of negative stimuli. Indeed, Lieberman (2018) recently argued that emotion is inherently a conscious experience, so self-reported emotional responses should not be overlooked when considering physiological and neural indices of emotions. The best way to elucidate the complex psychological processes underlying the experience and regulation of emotion is to combine evidence from multiple measures, including self-reports and psychophysiology, as the research described in this dissertation demonstrates.

Potential Implications and Future Directions

This dissertation provided modest evidence that the interaction between emotional and cognitive processes is not a one-way street. As predicted by dual process theories of mind and hinted at by neuroanatomy, it appears that incidental cognitive processes can indeed carry over to subsequent emotional responding. Future research is needed to further delineate what types of incidental cognitive processes are most likely to influence subsequent emotional processes, and to delve deeper into the hints that this dampening in experienced emotion is coupled with an increase in neural markers of processing and attention. The current research focused primarily on the portion of executive control related to response conflict and inhibition of competing response tendencies. Future research should examine the impact of other incidental executive control processes on subsequent emotional responses, including attention shifting and working memory (Miyake et al., 2000). By examining additional tasks, a more thorough picture of the relationship between cognitive processes and emotions will develop.

The current research also hints at new ways to help individuals regulate unwanted negative emotions. Many mental health disorders, including depression and anxiety, are marked by negative emotional states and maladaptive emotion regulation. The evidence that engaging in a cognitive task may dampen negative emotional processing without requiring any explicit instructions to regulate emotions provides a promising avenue by which to help individuals successfully manage negative emotions (i.e., by encouraging them to do cognitive tasks). However, the current study tested only a non-clinical sample of typical undergraduate students. Future research should examine if a similar blunting of negative emotional responding is observed in a clinical sample as well. Additionally, the emotional stimuli used in the current research are standard in laboratory-based studies of emotion, but they pale in comparison to real-world emotional events. If the current findings can be replicated across different samples, then additional research should examine if interventions using cognitive tasks can also help individuals manage emotions encountered in daily life. Furthermore, if neural markers of attention to emotional stimuli such as the LPP are boosted by cognitive task performance in clinical samples, without a concomitant increase in the experience of negative emotions (as was found in Study 4), then engaging in cognitive control exercises before therapy sessions may be useful whenever engagement with negative emotional events is conducive to therapeutic goals.

Some recent research provides hints that exposing participants to a cognitive task before a negative emotion can provide a sort of training to increase the use of successful emotion regulation strategies. Specifically, Cohen and Mor (2018) had participants complete a training task wherein either incongruent flanker trials usually preceded negative images (thereby repeatedly pairing executive control with negative emotions) or a control task wherein congruent flanker trials usually preceded negative images. Compared to the control group, participants who received the training reported a higher propensity to use reappraisal and were more successful when instructed to use reappraisal to reduce negative emotions while reflecting on a negative life event. This result suggests that shifts in emotional responding after performing an executive functioning task can be taught to individuals without explicit instructions to regulate emotions through repeated pairings of executive functioning and negative stimuli. Future research should examine how best to implement such an intervention.

Conclusions

Across four studies, this dissertation provided promising but mixed initial evidence that completely incidental cognitive processes influence subsequent emotional responding. The first three studies provided initial evidence that self-reports of emotional responding may be blunted after completing an incidental task that requires cognitive processing. The fourth study did not find a change in self-reported emotions after a cognitive task but did find an enhancement in neural signals of attention to and processing of negative stimuli. Paired with a lack of increase in self-reported emotional responses, Study 4 suggested that individuals who completed a cognitive task first engaged more deeply with negative images without experiencing more emotional distress. This result suggests a way that individuals can engage more deeply with negative emotional events without experiencing more negative affect, and highlights the importance of combining self-reports with psychophysiological measures to understand complex psychological phenomena.

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APPENDIX

MAXIMAL ERP ANALYSES

Maximal ERP locations. Before beginning the ERP analyses, I determined where on the scalp each component was maximal for each task. For the flanker task, I assessed where on the midline the stimulus locked N2 and P3 were maximal, as well as where on the midline the response locked ERN and Pe were maximal. For the picture task, I assessed where on the midline the stimulus locked N1, P2, N2, and LPP in 500 ms windows were maximal. Analyses regarding the EPN were conducted over occipital sites, as described below.

Flanker Stimulus Locked ERPs. I conducted separate 2 (Stimulus Type: congruent or incongruent) by 7 (Midline Site: Fz, FCz, Cz, CPz, Pz, POz, or Oz) RM ANOVA examining stimulus locked N2 mean amplitudes 250 and 350 ms after stimulus onset and stimulus locked P3 mean amplitudes 350 and 450 ms after stimulus to determine where the N2 and P3 were maximal. See Table A1.

The N2 is a negative deflection over frontal-central areas of the scalp and is thought to index early conflict detection on cognitive conflict tasks (Clayson & Larson 2011; Frühholz, Godde, Finke, & Herrmann, 2011). Regarding the N2, there was a significant interaction between trial type and electrode sites, F (2.46, 332.84) = 66.431, $p < .001$, *partial* $\eta^2 = 0.308$, such that incongruent trials elicited a more negative mean amplitude than congruent trials across the midline, and that the most negative deflection during the incongruent trials occurred at electrode FCz (pairwise comparisons *p*s < .001), consistent with prior research (e.g., Clayson & Larson, 2011). Therefore, analyses regarding the flanker stimulus locked N2 used the mean amplitude at FCz. See Figure A1.

The P3 is a central-parietal, positive deflection thought to index early recruitment of attentional resources as well as response inhibition on cognitive conflict tasks (Clayson & Larson, 2011; Polich 2007). Regarding the P3, a significant interaction between trial type and electrode site emerged, *F* (1.75, 259.64) = 46.00, *p* < .001, *partial* η^2 = 0.237, such that incongruent trials elicited a more positive mean amplitude P3 relative to congruent trials across the midline, and the most positive deflection during incongruent trials occurred at Cz and CPz, (pairwise comparison between Cz and CPz *p* = .673, all other pairwise comparisons *p*s < .001). Because the amplitudes were nearly identical at these two sites, analyses regarding the flanker stimulus locked P3 were conducted separately at both Cz and CPz. See Figure A1.

Table A1

Study 4: Mean Flanker Stimulus Locked N2 and P3 Amplitude as a Function of Trial Type (Congruent or Incongruent) and Electrode Site (Fz, FCz, Cz, CPz, Pz, POz, or Oz)

N2				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Trial Type	527.96	(1, 149)	< .001	0.780
Electrode Site	102.63	(2.35, 350.59)	< .001	0.408
Trial Type × Electrode Site	66.43	(2.46, 366.84)	< .001	0.308
P3				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Trial Type	423.16	(1, 148)	< .001	0.741
Electrode Site	115.08	(3.04, 449.50)	< .001	0.437
Trial Type × Electrode Site	46.00	(1.75, 259.64)	< .001	0.237

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

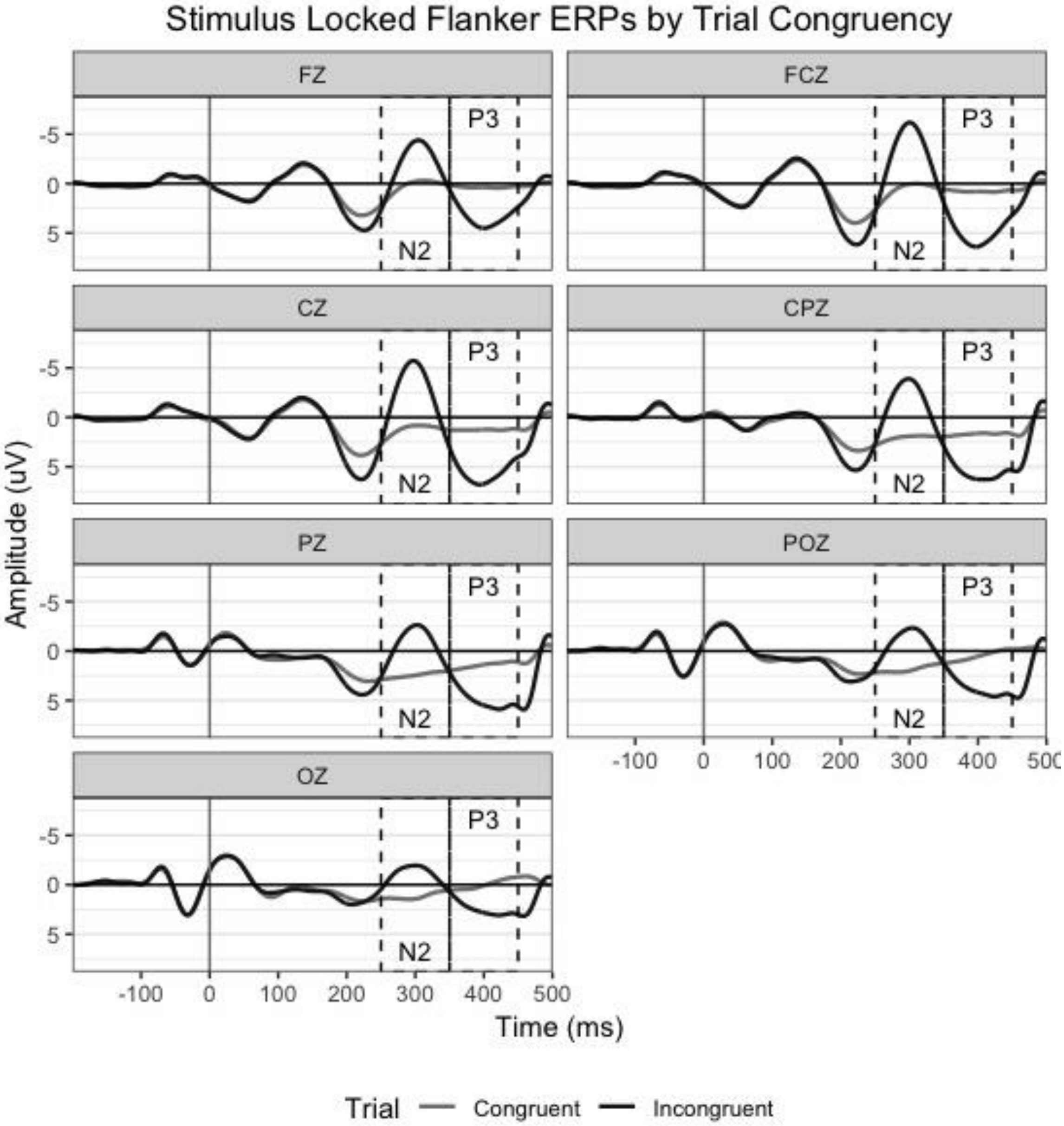


Figure A1. Stimulus locked flanker ERPs by trial congruency over midline sites.

Flanker Response Locked ERPs. I conducted separate 2 (Response Type: correct or incorrect) × 7 (Midline Site: Fz, FCz, Cz, CPz, Pz, POz, or Oz) RM ANOVA examining ERN mean amplitudes 20 and 100 ms after response and Pe mean amplitudes 150 and 250 ms after stimulus to determine where the ERN and Pe were maximal. See Table A2.

The ERN is a neural response to errors characterized by a frontal-central, negative-going deflection after an erroneous response (van Veen & Carter, 2002a). The ERN appears to index conflict generated after an erroneous response and signals the recruitment of additional prefrontal resources of cognitive control for future trials (Carter & van Veen, 2007). Regarding the ERN, there was a significant interaction between response type and electrode sites, F (2.17, 316.21) = 122.76, $p < .001$, *partial* $\eta^2 = 0.457$, such that incorrect responses elicited a more negative mean amplitude than correct responses across the midline. Consistent with prior research, the most negative deflection occurred at electrode Cz (all pairwise comparisons ps < .001), so analyses regarding flanker ERNs used mean amplitudes at Cz. See Figure A2.

The Pe is a central-parietal positive-going deflection in response to errors that appears to be generated by the caudal portion of the anterior cingulate cortex (van Veen & Carter, 2000b) and is hypothesized to relate to post-error adjustment of response strategies and may signal recruitment of additional control resources for subsequent trials (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000). Regarding the Pe, there was an interaction between response type and electrode sites, F (1.950, 284.76) = 75.51, $p < .001$, *partial* $\eta^2 = 0.341$, such that incorrect responses elicited a more positive Pe than correct responses across the midline, and the most positive deflection occurred at electrode Cz (pairwise comparisons ps < .006), consistent with prior research (e.g., van Veen & Carter, 2000b). Therefore, the analyses regarding the flanker response locked Pe used mean amplitudes at Cz. See Figure A2.

Table A2

Study 4: Mean Flanker Response Locked ERN and Pe Amplitude as a Function of Response Type (Correct or Incorrect) and Electrode Site (Fz, FCz, Cz, CPz, Pz, POz, or Oz)

ERN

Within-Subjects Effects	F	*df*	*p*	*partial η^2*
Response Type	162.10	(1, 146)	< .001	0.526
Electrode Site	66.74	(2.22, 324.28)	< .001	0.314
Trial Type × Electrode Site	122.76	(2.17, 316.21)	< .001	0.457

Pe

Within-Subjects Effects	F	*df*	*p*	*partial η^2*
Response Type	303.82	(1, 146)	< .001	0.675
Electrode Site	72.30	(2.11, 308.60)	< .001	0.331
Trial Type × Electrode Site	75.51	(1.95, 284.76)	< .001	0.341

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

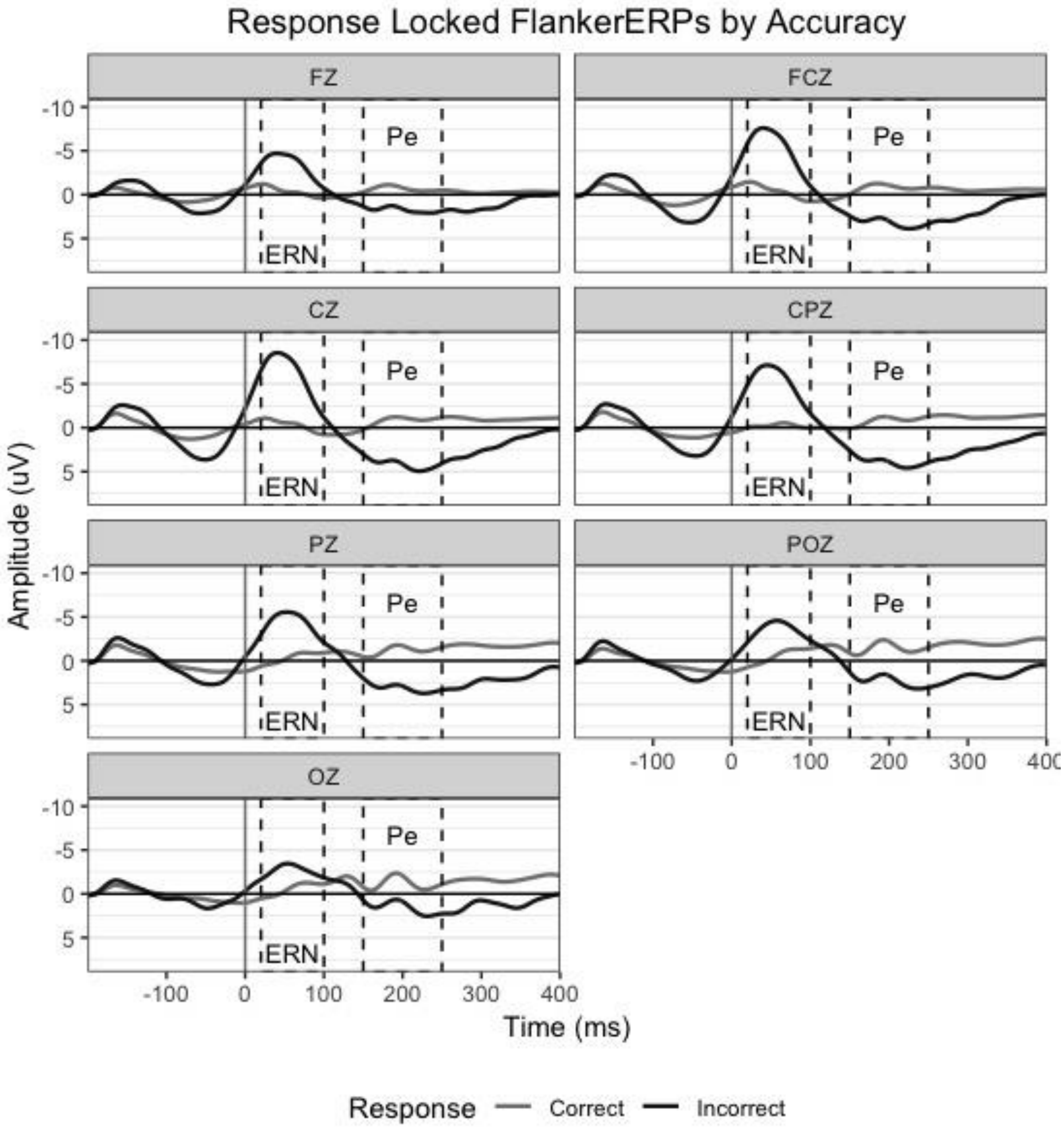


Figure A2. Response locked flanker ERPs by accuracy over midline sites.

Image Viewing Early Midline ERPs. I conducted separate 2 (Image Type: neutral or negative) by 7 (Midline Site: Fz, FCz, Cz, CPz, Pz, POz, or Oz) RM ANOVA examining the early picture ERPS, specifically N1 mean amplitudes between 50 and 100 ms after stimulus onset, P2 mean amplitudes between 100 and 200 ms after stimulus onset, and N2 mean amplitudes between 200 and 320 ms after stimulus onset to determine where the N1, P2, and N2 were maximal. See Table A3.

The N1 is an early central-parietal negative deflection thought to index early visual attention (Hajcak, Weinberg, MacNamara, & Foti, 2012). Regarding the N1, there was a significant interaction between trial type and electrode sites, *F* (1.77, 214.60) = 4.29, $p = .019$, *partial* $\eta^2 = 0.034$, such that negative trials elicited a more positive mean amplitude over frontal sites and more negative amplitude over posterior sites than neutral images, and that the most negative deflection across all trial types occurred at electrode FCz and Cz, (pairwise comparison between FCz and Cz $p = .172$, all other pairwise comparisons *p*s < .035). Therefore, the analyses regarding the image N1 were conducted separately at both FCz and Cz. See Figure A3.

The P2 is an early central-anterior positive deflection thought to index visual attention processes (Hajcak, Weinberg, MacNamara, & Foti, 2012). Regarding the P2, only a significant effect of electrode site emerged, *F* (1.88, 223.43) = 208.60, $p <.001$, *partial* $\eta^2 = 0.637$, such that the most positive amplitudes occurred at electrode Oz (pairwise comparisons *p*s < .001). However, an examination of the waveforms in Figure A3 reveal that the larger amplitude at Oz is due to a larger positive deflection later in the waveform, and instead the P2 appears to be clearest at sites CPz and Pz. The amplitude at Pz is significantly larger than the amplutide at CPZ ($p < .001$). Therefore, analyses regarding the image P2 used the mean amplitude at Pz.

Regarding the N2, there was a significant interaction between trial type and electrode sites, *F* (2.24, 263.78) = 3.74, $p = .021$, *partial* $\eta^2 = 0.031$, such that amplitudes for neutral images were more negative for frontal electrodes but more positive for more posterior electrodes. Additionally, the most negative amplitudes occurred at electrodes FCz and Cz, (pairwise comparison between FCz and Cz *p* = .338, all other pairwise comparisons *p*s < .001). Because the amplitudes were nearly identical at these two sites, analyses regarding the image N2 were conducted separately at both FCz and Cz. See Figure A3.

Table A3

Study 4: Early Image ERP Mean Amplitudes as a Function of Image Type (Neutral or Negative) and Electrode Site (Fz, FCz, Cz, CPz, Pz, POz, or Oz)

N1				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Image Type	0.52	(1, 121)	.473	0.004
Electrode Site	13.54	(1.92, 232.42)	< .001	0.101
Trial Type × Electrode Site	4.29	(1.77, 214.60)	.019	0.034
P2				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Image Type	0.99	(1, 119)	.323	0.008
Electrode Site	208.60	(1.88, 223.43)	< .001	0.637
Trial Type × Electrode Site	1.25	(1.85, 220.53)	.280	0.010
N2				
Within-Subjects Effects	F	*df*	*p*	*partial* η^2
Image Type	0.03	(1, 118)	.860	< 0.001
Electrode Site	341.92	(2.34, 275.52)	< .001	0.743
Trial Type × Electrode Site	3.74	(2.24, 263.78)	.021	0.031

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.

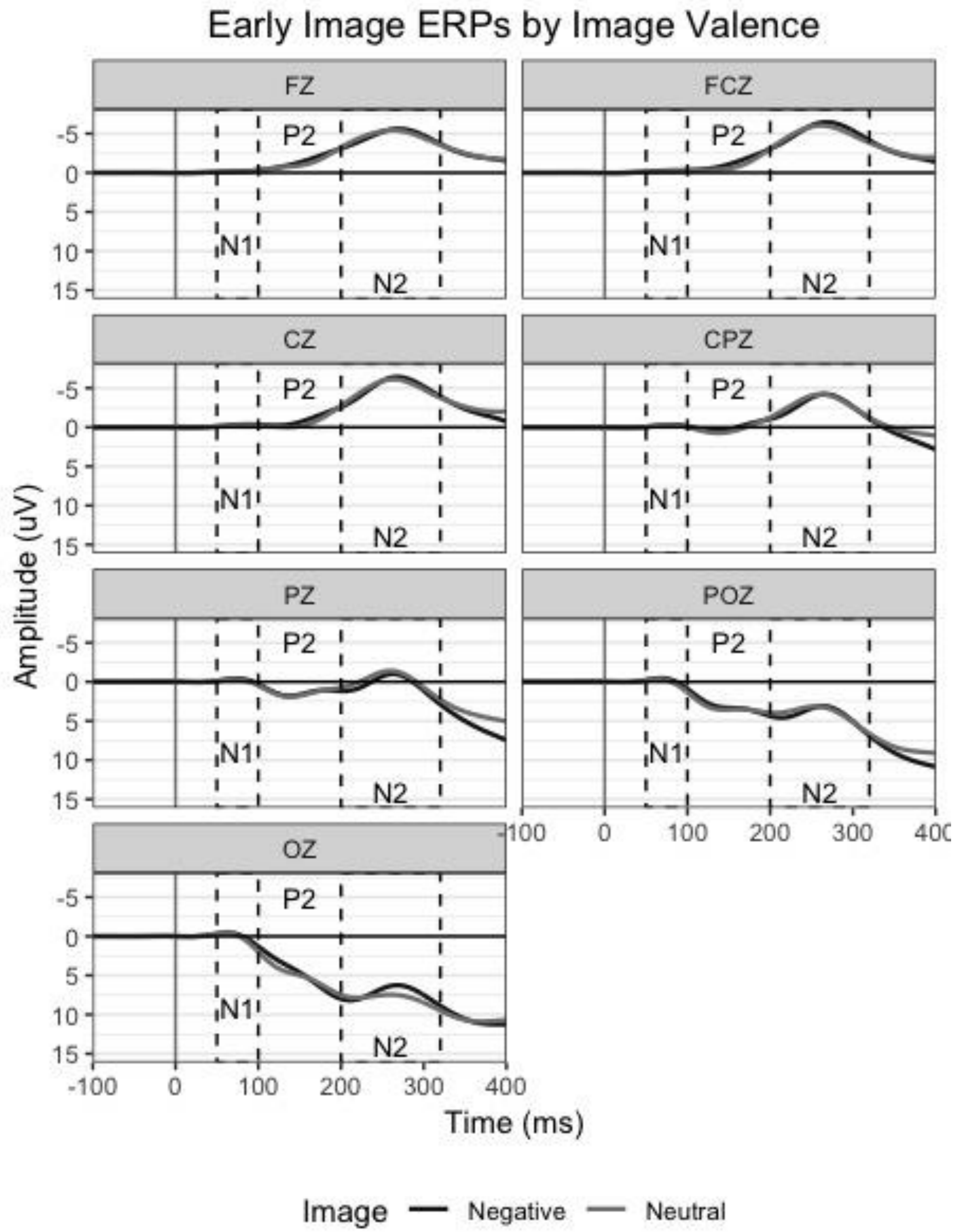


Figure A3. Early image midline ERPs by image valence over midline sites.

Image Viewing Late Midline ERPs. I conducted nine 2 (Stimulus Type: neutral or negative) × 7 (Midline Site: Fz, FCz, Cz, CPz, Pz, POz, or Oz) RM ANOVA examining LPP mean amplitudes in 500 ms chunks starting 500 ms after stimulus onset through 5000 ms after stimulus onset (i.e., 5 seconds into picture viewing) to determine where the LPP was maximal in each window. As shown in Table A4, I found interactions between image type and electrode sites in all time windows, such that amplitudes for negative images were more positive, and this effect was more pronounced over central parietal sites. Consistent with prior research, the LPP shifted toward the front of the scalp over time, such that the LPP was maximal at Pz at 500-1000 ms after stimulus onset, but shifted to CPZ in later time windows. Therefore, analyses for the LPP from 500-1000 ms were conducted at Pz and the rest were conducted at CPz. See Figure A4.

Table A4

Study 4: Late Image ERP Amplitudes as a Function of Image Type (Neutral or Negative) and Electrode Site (Fz, FCz, Cz, CPz, Pz, POz, or Oz) at Each LPP Time Window

500-1000 ms					**1000-1500 ms**				
Within-Subjects	F	*df*	*p*	*partial* η^2	Within-Subjects	F	*df*	*p*	*partial* η^2
Image	65.94	(1, 120)	< .001	0.355	Image	23.19	(1, 120)	< .001	0.162
Electrode	64.37	(3.89, 466.31)	< .001	0.349	Electrode	19.60	(4.94, 592.23)	< .001	0.140
Image × Electrode	22.79	(2.63, 315.06)	< .001	0.160	Image × Electrode	17.14	(3.29, 394.82)	< .001	0.125

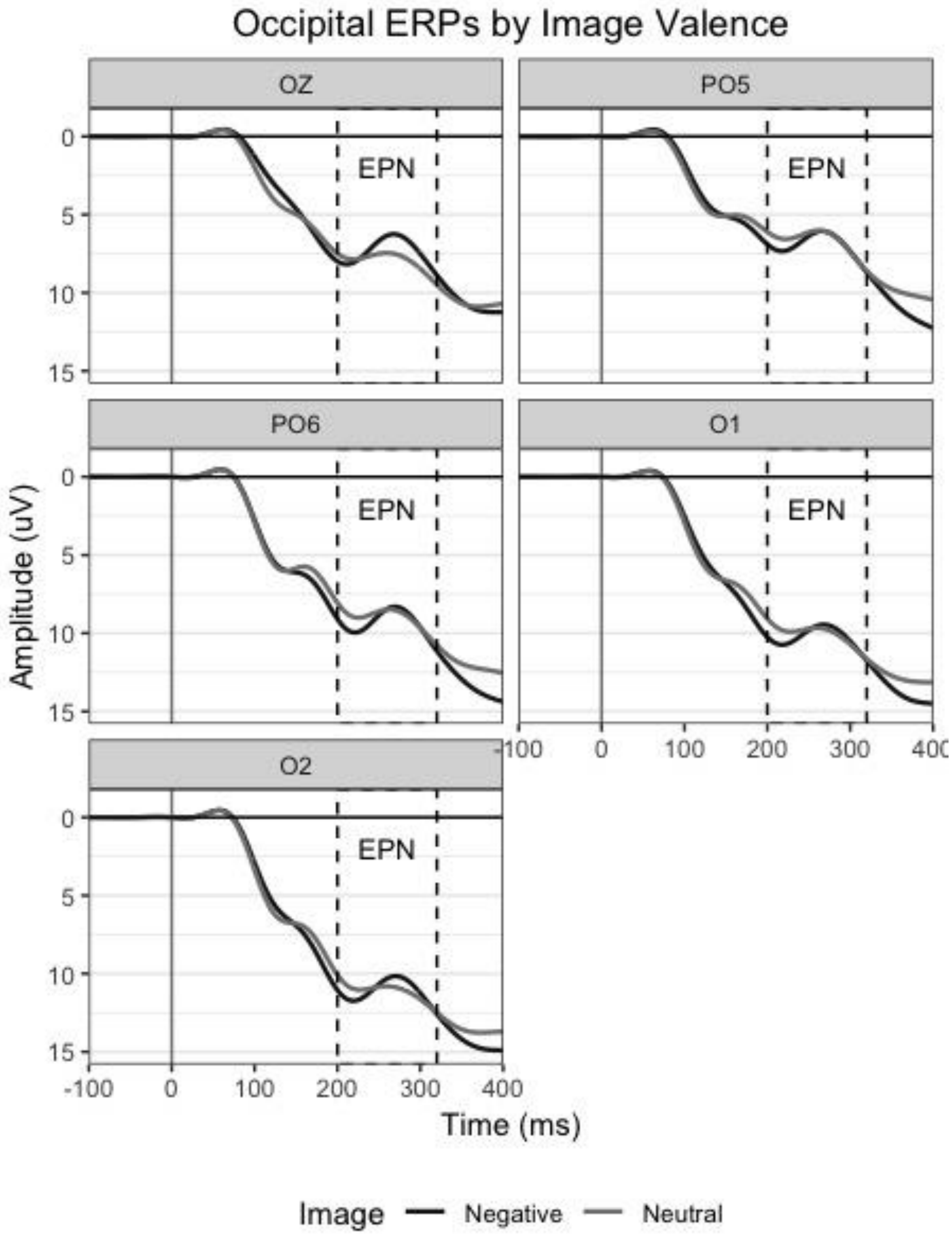
1500-2000 ms					**2000-2500 ms**				
Within-Subjects	F	*df*	*p*	*partial* η^2	Within-Subjects	F	*df*	*p*	*partial* η^2
Image	21.39	(1, 120)	< .001	0.151	Image	16.45	(1, 119)	< .001	0.121
Electrode	16.88	(5.10, 612.35)	< .001	0.123	Electrode	14.11	(5.16, 614.28)	< .001	0.106
Image × Electrode	15.25	(3.73, 447.49)	< .001	0.113	Image × Electrode	11.75	(4.00, 476.51)	< .001	0.090

2500-3000 ms					**3000-3500 ms**				
Within-Subjects	F	*df*	*p*	*partial* η^2	Within-Subjects	F	*df*	*p*	*partial* η^2
Image	5.42	(1, 121)	.022	0.043	Image	1.98	(1, 121)	.162	0.016
Electrode	12.64	(5.29, 639.45)	< .001	0.095	Electrode	11.17	(5.28, 638.97)	< .001	0.084
Image × Electrode	10.18	(4.06, 490.70)	< .001	0.078	Image × Electrode	8.95	(4.47, 144.16)	< .001	0.069

3500-4000 ms					**4000-4500 ms**				
Within-Subjects	F	*df*	*p*	*partial* η^2	Within-Subjects	F	*df*	*p*	*partial* η^2
Image	1.15	(1, 121)	.286	0.009	Image	0.42	(1, 120)	.516	0.004
Electrode	9.64	(5.30, 641.34)	< .001	0.074	Electrode	8.42	(5.30, 636.42)	< .001	0.066
Image × Electrode	7.85	(4.48, 542.49)	< .001	0.061	Image × Electrode	7.78	(4.63, 555.37)	< .001	0.061

4500-5000 ms				
Within-Subjects	F	*df*	*p*	*partial* η^2
Image	0.06	(1, 120)	.801	0.001
Electrode	7.34	(5.32, 638.86)	< .001	0.058
Image × Electrode	7.05	(4.83, 579.22)	< .001	0.055

Note: Greenhouse-Giesser corrected values reported for between-subjects effects. Degrees of freedom may not be whole numbers.


Occipital ERPs by Image Valence
OZ
PO5
PO6
O1
O2
EPN
EPN
EPN
EPN
EPN
0
5
10
15
Amplitude (uV)
-100
0
100
200
300
400
Time (ms)
Image
Negative
Neutral

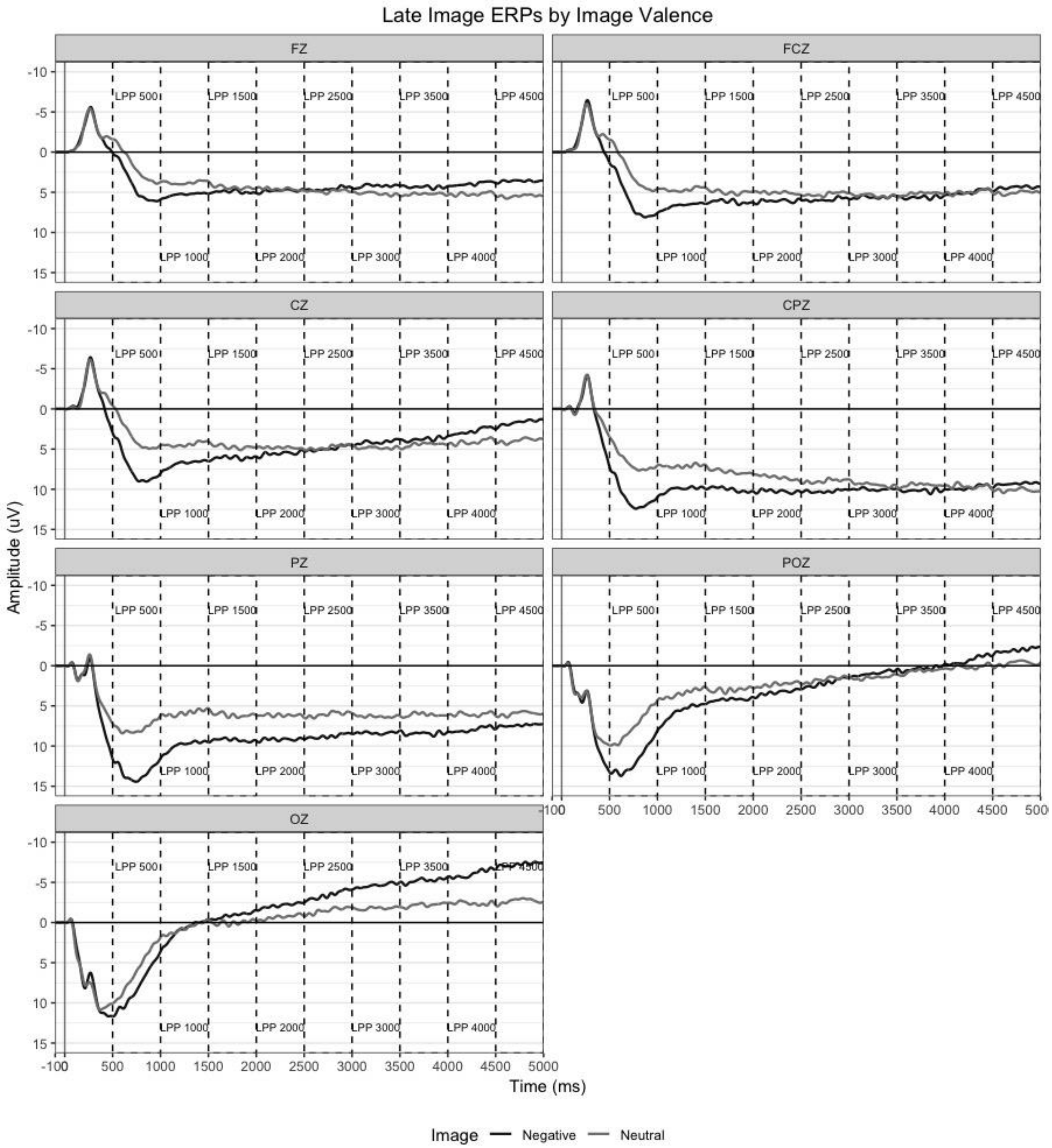


Figure A4. Late image ERPs by image valence over midline sites.

Image Viewing Occipital ERP. The EPN was the only image ERP analyzed that is not maximal along the midline. Instead, prior research has found the EPN to be maximal at occipital sites (Hajcak, Weinberg, MacNamara, & Foti, 2012; Wheaton et al., 2013; Weinberg & Hajcak, 2010). Therefore, I quantified the EPN to be the average of the mean amplitudes between 200 and 320 ms after stimulus onset at O1, Oz, O2, PO5, and PO6. See Figure A5.

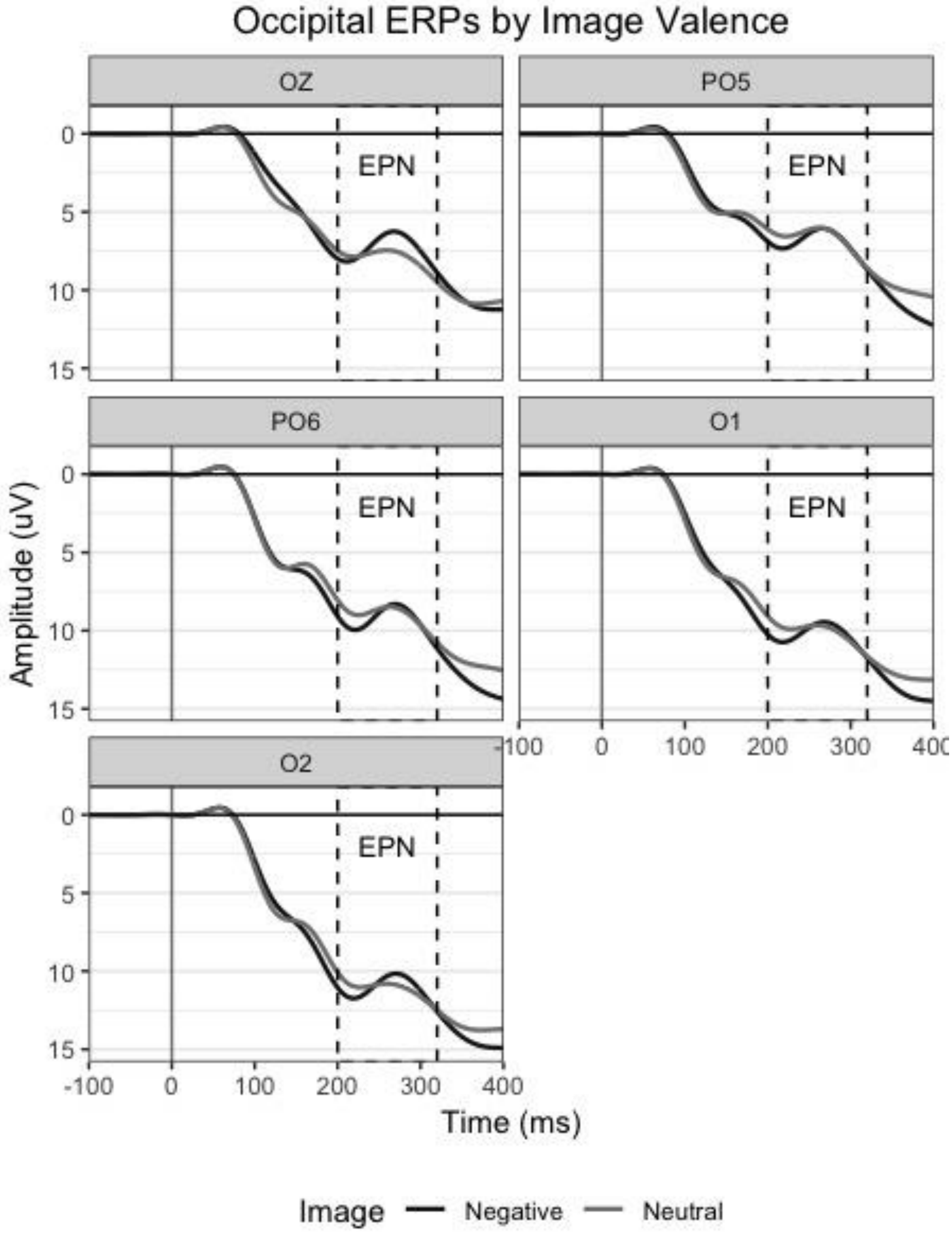


Figure A5. Occipital ERP by image valence.