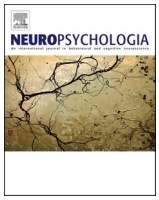
Neuropsychologia 162 (2021) 108031

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia



Impact of emotionally-charged images and trial order on downstream cognitive processing: An ERP study

A. Abid [a], M. Middlebrooks [a], E. Rawls [b], C. Lamm [a,*]

[a] Department of Psychological Science, University of Arkansas, USA
[b] Department of Psychiatry and Behavioral Sciences, University of Minnesota, USA

ARTICLE INFO

Keywords:
Emotion regulation
Cognitive processing
Trial order
N2
LPP
ERP

ABSTRACT

Theories of emotion-cognition interactions suggest that emotional valence can both facilitate or limit cognitive performance. One cause for the mixed findings may be the order (random versus non-random presentation) in which emotional stimuli are presented. To investigate the impact of stimuli order on cognitive control processing, EEG data were recorded as 130 undergraduate students (M age = 22.2, SD = 5.4; 79 female) completed a modified version of the AX-Continuous Performance Task in which the cue was followed by an emotionally-valenced image (positive, negative, and neutral). Specifically, the task was designed so that valenced images were presented in either a block or random order, prior to probe presentation. We examined two event-related potentials (ERPs), the N2, which reflects aspects of cognitive control, and the late positive potential (LPP), which reflects attention allocation to emotional stimuli. We assessed the impact of emotionally oriented attention (LPP) on downstream cognitive control (N2) and how this relationship might differ for a block versus random (order of emotional image) task design. Consistent with the LPP literature, we found a main effect of image valence with the negative trials showing larger LPPs than the positive and neutral trials. For N2s, we found that the negative trials were associated with smaller N2s than both the positive and neutral trials. We observed that as LPP amplitude increased, subsequent N2 amplitude was reduced, specifically for negative trials in the random design. These results suggest an emotion-related depletion of neural cognitive resources. Lastly, we found larger N2s for the block design versus the random design. Together, these results indicate the importance of paying attention to both trial order (block versus random) and within trial stimulus sequence when designing emotion induction tasks.

1. Introduction

Numerous studies have explored the impact of emotion on cognitive processing, including assessing the impact of temporal context on emotional processing (Czekóová et al., 2015), the relationship between goal-directed processing and emotions (Blair et al., 2007), the neural impact of emotional images on cognitive functioning (Pegwal et al., 2019; Raschle et al., 2017) and physiological responses (Fujimura et al., 2013), and the moderation of cognitive load on emotional processing (Van Dillen et al., 2009). Van Dillen et al. (2009) presented neutral or negative images to participants prior to assigning difficult math equations and found that the cognitively demanding task down-regulated the activation of the emotional processing centers. Furthermore, Pegwal et al. (2019) reported that emotionally arousing images, both positive and negative, trigger faster decision-making by improving working memory and attention, suggesting that emotion facilitates cognition. In contrast, Blair et al. (2007) found that both positive and negative images interfered with goal-directed cognitive processing, suggesting a limited resource model. Similarly, Raschle et al. (2017) recently conducted a study revealing that as a task becomes more cognitively demanding, neural activation underlying emotional processing reduces. Moreover, they also found that as negative emotions are aroused, cognitive performance is worsened, again supporting a limited resource model. However, Schupp and colleagues (2000) reported that the processing of an emotional stimulus is independent of the valence of the stimuli preceding it. In contrast, Czekóová et al. (2015) found that the sequence of emotionally triggering images impacts their subjective evaluation. A review by Zinchenko et al. (2020) concluded that emotions (positive and negative) distinctively impact cognitive and emotional control. Thus, it has been strongly suggested that emotional valence impacts (either

* Corresponding author. Department of Psychological Science, University of Arkansas, Fayetteville, USA.
E-mail address: lamm@uark.edu (C. Lamm).

https://doi.org/10.1016/j.neuropsychologia.2021.108031
Received 9 March 2020; Received in revised form 6 September 2021; Accepted 20 September 2021
Available online 23 September 2021

facilitates or limits) subsequent cognitive performance (Blair et al., 2007; Czekóová et al., 2015; Pegwal et al., 2019; Raschle et al., 2017; Van Dillen et al., 2009) and physiological arousal (Fujimura et al., 2013), but results have been inconsistent.

One potential cause of the previously outlined mixed results could be the sequence of stimulus presentation within a block of trials. Many studies present the emotionally-charged images (positive, negative, and neutral) in a random order and then average across the valence of previous trials in an attempt to eliminate the carryover effect of emotional valence onto the present trial. To determine whether emotional stimulus presentation impacts patterns of neural activation underlying cognitive performance, Hilgard et al. (2014) explored the impact of emotionally-charged image order (positive, negative, and neutral) using a variety of paradigms. One of the paradigms used was an oddball paradigm in which the positive and negative images were the infrequent stimuli and the neutral images were the frequent stimuli. Trials consisted of five sequentially presented images in which the fourth or fifth image was the infrequent image (positive or negative) and the remaining four were (frequent) neutral images. They also used two passive viewing paradigms, in which neutral, negative, and positive images were passively viewed and no behavioral response was required. One version of this passive viewing task consisted of emotional images being presented in a block format, while in the other version, emotional images were presented in a random order. They measured late positive potential (LPP) amplitudes, an event-related potential (ERP) with a centroparietal inflection found roughly 250 ms after an emotionally-charged stimulus (Foti and Hajcak, 2008; Hajcak et al., 2007; Keil et al., 2002; Schupp et al., 2000), time-locked to the infrequent image in the oddball paradigm and time-locked to all emotional images in the passive viewing paradigms. They found greater LPP amplitudes for the negative images compared with the positive images only in the blocked passive viewing paradigm. Thus, emotional stimulus order seems to impact neurocognitive function.

The current study aims to extend this body of literature by testing the impact of emotionally-charged images on downstream cognitive processing. In Hilgard et al. (2014), the emotionally-charged images were also the cognitively-demanding events (oddball paradigm), such that the stimulus images require both emotional and cognitive processing. In our study, we build on Hilgard et al. (2014) by presenting cognitively-demanding events roughly 1 s after the emotionally-charged images, and then testing for the impact of block versus random presentation of emotionally-charged images. Furthermore, we examined the impact of emotionally-charged images on two event-related potentials (ERPs; average EEG): the late positive potential (LPP; time-locked to picture) and the N2 (time-locked to cognitively-demanding event).

The LPP component is generally larger following negative or positive stimuli compared to a neutral stimulus (Hajcak et al., 2006; Hajcak and Olvet, 2008; Keil et al., 2002; Schupp et al., 2000) and is considered to be a measure of the attention allocated, i.e., additional neural resources, towards the emotional stimulus where its activation depends on motivational and subjective evaluation of the stimulus (Schupp et al., 2000) but does not depend on task difficulty (Hajcak et al., 2007). Previous research has shown a negativity bias for the LPP, such that the negative stimuli elicit a larger LPP amplitude, compared to both positive and neutral stimuli (Hilgard et al., 2014; Ito et al., 1998; Schupp et al., 2000). These results suggest that negative information requires more attentional neural resources for processing, compared to positive and neutral information. However, not all LPP studies show this clear negativity bias. Instead, some studies show greater LPP amplitudes for both positive and negative images, compared with neutral images (Hajcak and Olvet, 2008; Hajcak et al., 2009; Schupp et al., 2000). Furthermore, Pastor et al. (2008) presented emotional images (pleasant, unpleasant, and neutral), in a block and mixed sequence and reported that no significant differences in LPP amplitude were found in response to emotionally arousing (pleasant and unpleasant) images across the block and mixed designs. Thus, the impact of negative and positive images on LPP amplitude is unclear.

Interestingly, reappraisal studies have reported a decrease in LPP amplitude after participants were instructed to reassess the emotionally arousing images in a less negative way (Hajcak and Nieuwenhuis, 2006), to judge the images as non-affective (Hajcak et al., 2006), or to attend to the less arousing components of an image (Hajcak et al., 2009), suggesting that the level and perception of arousal modulates LPP amplitude. Furthermore, Foti and Hajcak (2008) preceded emotionally-charged images with a neutral or negative description of the image and found that negative images preceded by a neutral description produced lower LPP amplitude, compared to negative images following a negative description, suggesting that cognitive processes can alter emotional processes. A recent study by Weinberg and Hajcak (2010) reported variations of LPP activation within the semantic categories of pleasant, unpleasant, and neutral images, suggesting that each emotionally arousing image is subjective to evaluation. Specifically, they reported that pleasant and unpleasant images produced variable LPP responses, such that “mutilation” and “erotic” images produced the largest LPPs within the unpleasant and pleasant categories, respectively. Meanwhile, “disgusting” and “exciting” images produced the smallest LPPs within the unpleasant and pleasant categories, respectively. Also, within the neutral category, images with people elicited larger LPPs compared to images with objects and without people (Weinberg and Hajcak, 2010). Overall, this suggests that LPP activity is impacted by emotional valence, cognitive demands, and both contextual and presentation features.

The second ERP, the N2, is a mediofrontal deflection peaking 200–400 ms after stimulus presentation (Veen and Carter, 2002) and has been associated with various aspects of cognitive control (Folstein and Van Petten, 2008), such as conflict resolution (Mathalon et al., 2003) and response inhibition (Jodo and Kayama, 1992). The N2 has also been shown to be sensitive to emotionally-charged stimuli (Lewis et al., 2006). In a sample of twenty children, Zinchenko et al. (2019) used a Go/Nogo task with task irrelevant emotional (positive and negative) and neutral faces and reported the greatest go versus nogo difference for the negative stimuli, suggesting higher cognitive control when processing negative emotions. The N2 component is also implicated in conflict processing in both cognitive and emotional domains, as evident by an enhanced N2 activation for incongruent trials, compared to congruent trials in an audiovisual conflict task (Zinchenko et al., 2015). Furthermore, the N2 is larger in the context of reward reduction than reward increase in young children, suggesting that negative emotions associated with reward reduction trigger greater conflict monitoring. Another study by Lewis et al. (2006) also found larger N2s when viewing angry faces compared with neutral images, indicating an increase in attention allocation. To study the underlying neural correlates associated with emotional and unemotional stimuli, van Wouwe et al. (2011) presented a positive affectively-charged video or a relatively neutral video clip to participants just prior to performing a cognitively difficulty task. More specifically, they had participants play an AX-Continuous Performance Task (AX-CPT), which consisted of cues that indicated how a participant should respond (which button to press) on a subsequent probe. They found smaller N2s after watching positively-valenced videos compared with neutral videos. The authors interpreted these results to reflect diminished conflict between behavioral responses brought about by positivity-induced cognitive flexibility. Furthermore, Lamm et al. (2013) also used an AX-CPT paradigm, but their task presented negatively-valenced and relatively neutral images between the cue and probe events rather than videos prior to blocks. Lamm et al. (2013) found larger N2s following negative stimuli, compared to neutral stimuli, also supporting the notion that emotional valence impacts response conflict. Lastly, Todd et al. (2008) explored the impact of emotional faces (angry versus happy) in an inhibitory control task and found that angry faces elicited larger N2s, compared to happy faces, especially in trials that required the inhibition of an automatic response. Together, these studies show that N2 activation is larger for negatively-valenced

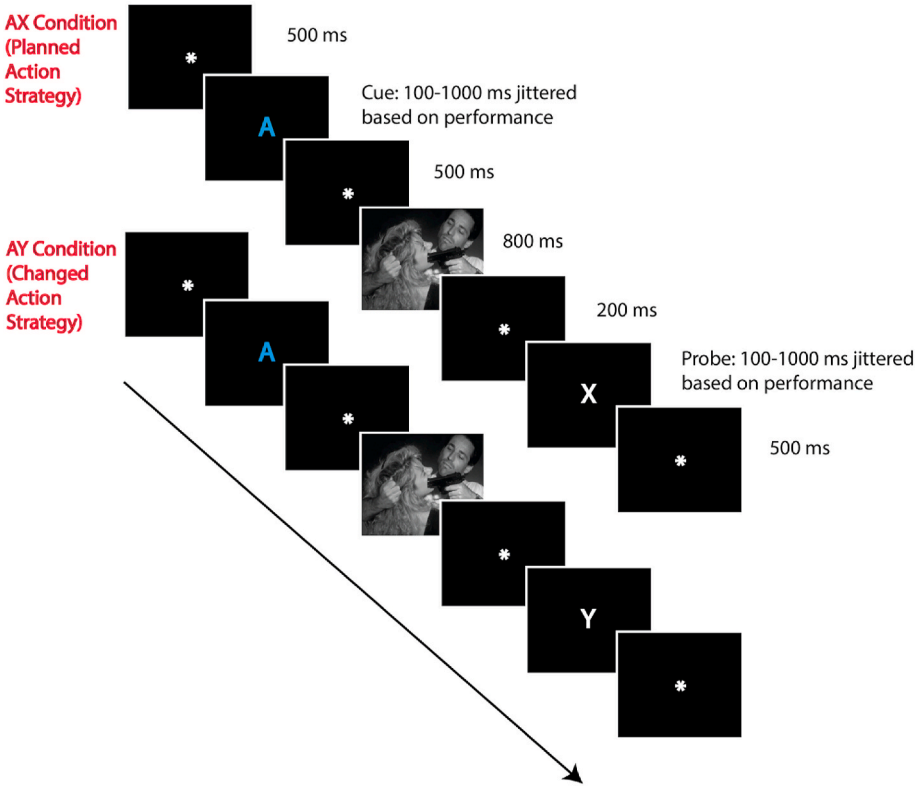


Fig. 1. Modified AX-CPT task diagram.

stimuli and smaller for positively-valenced stimuli with relatively neutral stimuli falling in the middle. Thus, given that N2 reflects aspects of cognitive control, it may be that in the context of negatively-valenced images, we must recruit additional neural resources to both resolve the response conflict and regulate our emotional response.

Additionally, it is still unclear whether N2 activation is dependent on emotional stimuli presentation order. To the best of our knowledge, no studies have examined the impact of trial order of emotionally-charged stimuli (block versus random) on downstream N2 activation. In a behavioral study, Mathalon et al. (2003) used an emotional Stroop task containing threatening and neutral stimuli presented in a pseudorandom order and showed that the reaction time for a negative and neutral stimulus do not vary. However, the response time for the subsequent stimulus is significantly slower following a negative image, suggesting an emotional carry-over effect. Waters et al. (2005) suggested that emotional stimuli (benign and stressful words), when presented in an emotional Stroop task have a carry-over effect, such that the emotional stimulus has an effect on the processing of the subsequent stimulus. Specifically, the carry-over effect is an increase in reaction time on a trial that follows an emotionally salient trial, which may be attributed to difficulties in disengaging attention from the emotionally-relevant information (Schmidt and Schmidt, 2016; Waters et al., 2005).

In the current study, we explore the impact of emotionally-charged images (presented in a block or random trial order) on downstream cognitive processing, specifically cognitive control, using a modified version of the AX- CPT. More specifically, we examined the impact of emotion on reactive control, a cognitive-control strategy that uses last minute environmental information to change action strategies (Braver et al., 2009; Chiew & Braver, 2010, 2011, 2014). We modified the canonical AX-CPT by presenting emotionally-charged images (positive, negative, and relatively neutral) shortly before reactive control was applied. EEG and behavioral data were collected while participants completed the emotional AX-CPT. We hypothesized that the LPP activation would follow the traditional pattern, i.e., highest for negative trials and lowest for neutral trials, with the positive trials somewhere in between. Additionally, we predicted that at least for the negative and positive trials, activation would be greater for the block presentation of trials versus the random presentation of trials, because of the emotional carry-over from previous trials. Also, because of the emotional carry-over across trials, we hypothesized that the N2s would be more negative in activation for the block design (versus random design). Lastly, based on previous studies (Lamm et al., 2013; Lewis et al., 2006, 2007, 2007; Todd et al., 2008), we predicted larger N2s in the negative trials compared to the positive and neutral trials.

2. Method

2.1. Participants

Students taking psychology courses at the University of New Orleans participated in this study. The sample consisted of 130 undergraduate students (79 female) with a mean age of 22.2 (SD = 5.4, range 18–43). This study required a large sample size to allow for all block counterbalancing sequences, e.g., negative then neutral then positive, neutral then negative then positive, etc. No significant block sequence effects were found. The exclusion criteria were self-reported current psychiatric diagnoses, current use of psychoactive medication, and uncorrected visual impairments. The students were compensated with extra credit for their participation in the study. The project was approved by the University of New Orleans Institutional Review Board. A much smaller subsample (N = 75) of this data has already been published by Rawls et al. (2018) focusing on the moderating effect of P2, N2, and P3 activation on the relationship between effortful control and aggression. Furthermore, not only did the Rawls et al. (2018) study address a very different question, it also only incorporated the random design data and not the block design data. Thus, the majority of the current data has not previously been published on. Furthermore, these findings were presented at the Society for Psychophysiological Research conference in

Table 1
Trial count across Block and Random Designs. Trial count is the number of trials that comprise an ERP waveform.

Trial Type	N	Mean	St. Deviation	Minimum	Maximum
Block Picture (LPP)[a]					
Negative	130	74.35	17.50	20	98
Neutral	130	71.12	18.15	16	100
Positive	130	71.35	18.43	11	99
Random Picture (LPP)[a]					
Negative	130	73.37	16.09	18	97
Neutral	130	72.39	15.86	17	98
Positive	130	73.25	16.56	12	99
Block Probe (N2)					
Negative AX	130	43.40	9.140	17	63
Neutral AX	130	43.33	10.148	14	63
Positive AX	130	44.13	8.691	19	59
Negative AY	130	18.22	4.808	10	32
Neutral AY	130	19.30	4.428	10	30
Positive AY	130	19.19	4.595	10	30
Random Probe (N2)					
Negative AX	130	44.32	9.128	15	64
Neutral AX	130	44.97	9.073	16	66
Positive AX	130	45.34	8.725	14	64
Negative AY	130	19.05	4.538	10	32
Neutral AY	130	18.93	4.033	11	28
Positive AY	130	19.16	4.148	10	32

[a] LPP measures were collapsed across AX and AY trials.

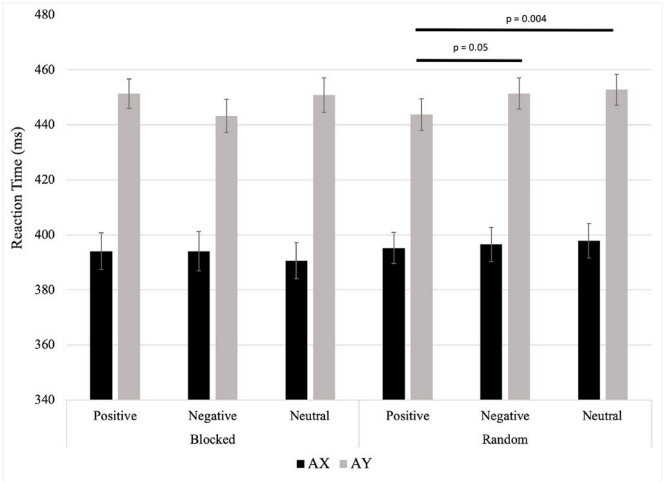


Fig. 2. Shows a main effect of Trial Type and a Trial Type-by-Valence-by-Design interaction for reaction times.

Table 2
Reaction times for valence-specific trials across Block and Random Designs.

	Blocked			Random		
	Positive	Negative	Neutral	Positive	Negative	Neutral
AX	394.079	394.099	390.662	395.302	396.56	397.947
AY	451.343	443.241	450.84	443.734	451.359	452.789

2019 by the primary author (Abid et al., 2019).

2.2. Procedure

As outlined in Rawls et al. (2018), participants were individually introduced to the experimental session after which they provided informed consent. The participants completed a set of questionnaires (not discussed in this paper). After completing the questionnaires, the participants were seated 67 cm from a computer monitor and the electrode sensor net was applied. The participants were given a practice block of 16 trials, which they were permitted to repeat in order to familiarize themselves with the task. Performance feedback was provided during the practice block using a red line, presented for 200 ms, indicating an incorrect or delayed response. Following the completion of the practice block, the participants completed the actual task, the AX-CPT, during which behavioral and EEG data were collected. Upon completion, participants were debriefed and thanked for their participation in the study.

2.3. AX-CPT

The AX-CPT, as described in Rawls et al. (2018), was a modified version of the original AX-CPT (Rosvold et al., 1956) and consisted only of AX and AY trials to limit the length of the task. We piloted the full task, including the BX and BY trial types with three emotion conditions in block and random designs, and deemed the task to be too long to be effective. AX trials were the propensity setting trial type (70% of total trials) and consisted of executing a planned action strategy. AY trials, on the other hand, were less frequent (30% of trials) and required participants to incorporate last minute environmental information to change their action strategy. This task is designed to measure neural activation underlying action change, which is the ability to switch from a high propensity response to a less frequent one. The task consisted of a cue (the letter "A"; presented in blue font) and a probe (the letters "X" or "Y"; presented in white font) event, with a delay period (roughly 1500 ms) between cue and probe events. Emotionally-charged International Affective Picture System (IAPS) images were presented during the delay period (see Fig. 1 for task details; additionally, see Rawls et al., 2018 for more information). The participant was instructed to respond to the cue "A" by pressing the "2" key on a response pad. They were also instructed to respond to the probe by pressing either "3" for an "X" (frequent) probe or "2" for a "Y" (infrequent) probe. The task consisted of two different designs: block and random that varied in image valence presentation. Block design presented the same valence image throughout a set of trials, such that negative (or positive or neutral) emotionally-charged images were repeatedly presented between cue and probe. Alternatively, random design presented emotionally-charged images in a random order, presenting positive, negative, and neutral IAPS images pseudo-randomly (each participant received the same randomized order). There were an equal number of trials and probe events (AX, AY) for the block and random designs, and the only difference between these conditions was the valence of the image presented during the delay period. For the block design, blocks were counterbalanced between participants and block order had no impact on the data. All participants received both the block and random tasks. The task consisted of three blocks of 100 trials (300 total trials, 100 AY trials). Participants were encouraged to take breaks between blocks. The entire task took approximately 40 min to complete.

2.4. EEG data collection and processing

As outlined in Rawls et al. (2018), EEG data were recorded using a 128-channel Geodesic Sensor Net and were sampled at 250 Hz, using EGI software (Net Station, Electrical Geodesic, Inc., Eugene Oregon). Before acquiring data, impedance values for all EEG channels were reduced to below 50 kΩ. At acquisition, all channels were referenced to Cz and later re-referenced using an average reference. Acquired data were filtered using a FIR bandpass filter with a low-pass frequency of 50 Hz and a high-pass frequency of 0.03 Hz. The eye-blink threshold was set to 140 μV and all trials violating this threshold were excluded from analyses. Trials with a maximum threshold (max-min) for the entire segment of 150 μV, and fast transits (max-min) exceeding 140 μV were marked as bad and interpolated. Lastly, trials in which more than 10 bad channels were present were excluded from analyses.

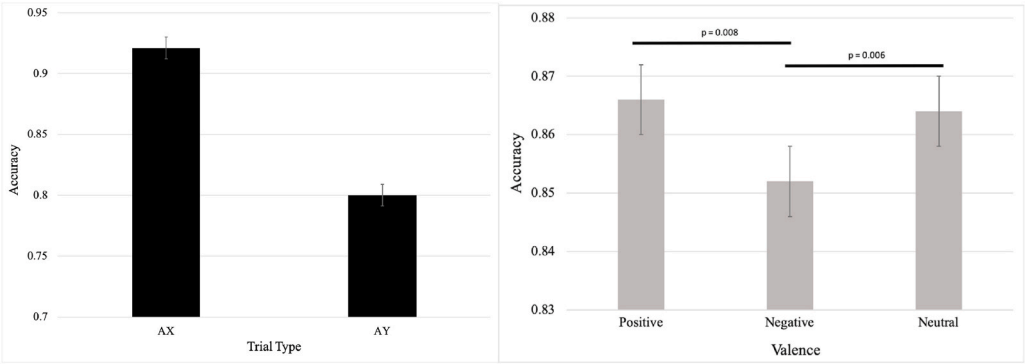


Fig. 3. Shows main effect of Trial Type (left) and Valence (right) for performance accuracy.

Table 3
Accuracy for valence-specific trials across Block and Random Designs.

	Blocked			Random		
	Positive	Negative	Neutral	Positive	Negative	Neutral
AX	0.926	0.914	0.924	0.926	0.914	0.924
AY	0.802	0.788	0.807	0.809	0.792	0.801

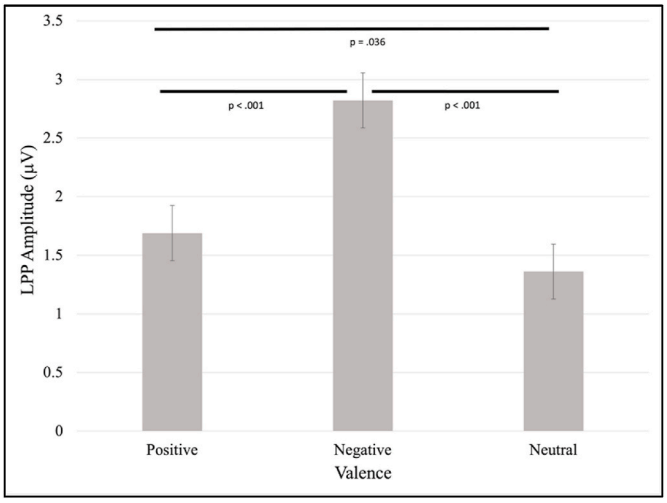


Fig. 4. Shows main effect of Valence for LPP amplitude at electrode Pz.

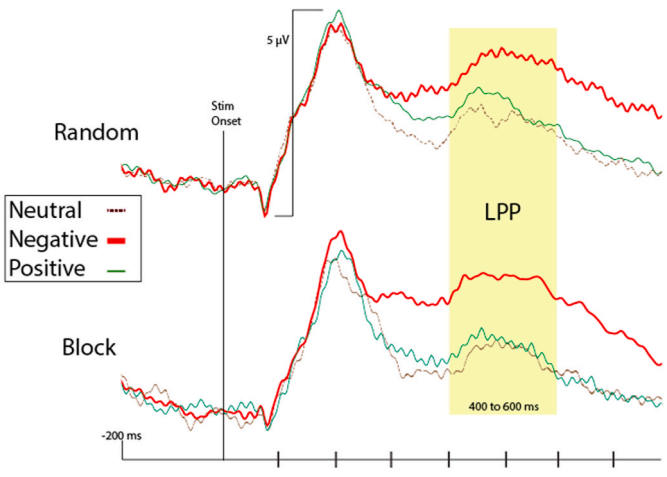


Fig. 5. ERP waveform depicting LPP amplitude at electrode Pz.

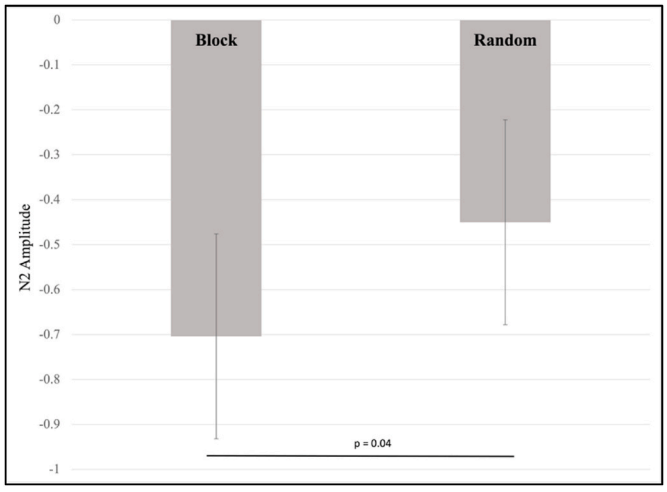


Fig. 6. Shows main effect of Design for N2 amplitude at electrode Fz. More negative amplitude is down.

2.5. Scalp data analyses

Probe waveforms (N2) for correct AX and AY trials were segmented into epochs from 400 ms before to 600 ms after probe (X or Y) onset and baseline corrected for 400 ms preceding probe onset. Picture waveforms (LPP) were segmented into epochs from 200 ms before to 600 ms after image (positive, negative, or neutral) presentation and baseline corrected for 200 ms preceding image onset. In line with Rawls et al. (2018), a data-driven approach was used to identify the time periods for the ERP measurements, such that a grand-average waveform (collapsing across all emotion conditions and trial order) was used to find LPP and N2 activation.

Consistent with the literature (Lamm et al., 2013; Lewis et al., 2006, 2007, 2007; Todd et al., 2008), the N2 was most negative at electrode Fz between 270 and 350 ms after probe onset. Also consistent with the literature (Foti and Hajack, 2008; Pastor et al., 2008; Weinberg and Hajcak, 2010), the LPP was maximal at electrode Pz between 400 and 600 ms after image presentation. Therefore, mean amplitude, across these times, was extracted for N2 and LPP. The mean number of trials comprising correct AX ERPs was 44.2 (SD = 9.2; min = 14; max = 66), and the mean number of trials comprising correct AY ERPs was 18.9 (SD = 4.4; min = 10; max = 32); the breakdown of trials is depicted in Table 1.

2.6. Data analysis

Analyses for the behavioral data (reaction times and performance accuracy) and the N2s consisted of 2 (Design: block, random) by 3

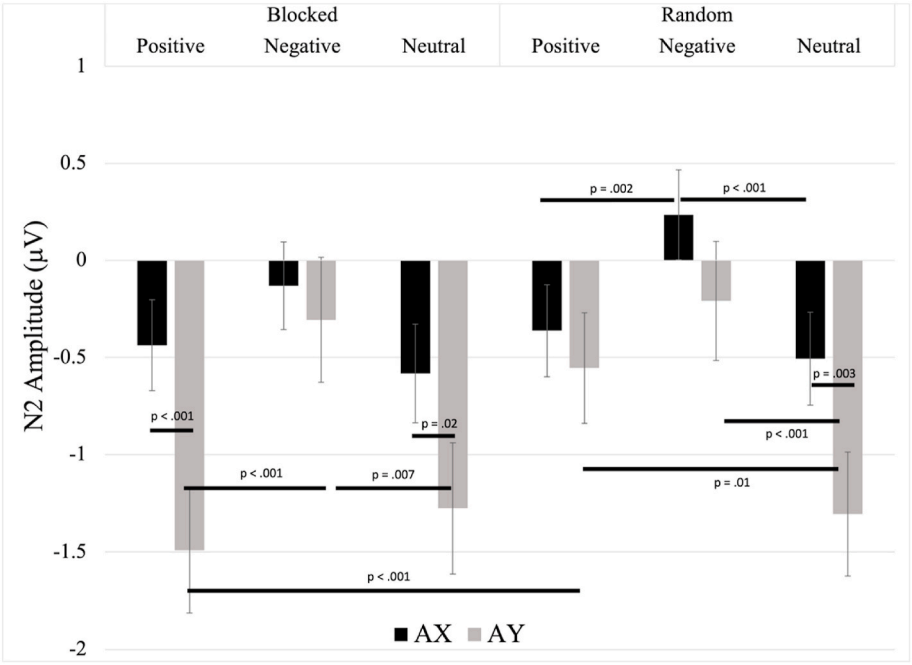


Fig. 7. Shows Design-by-Valence-by-Trial Type interaction for N2 amplitude at electrode Fz. Valence-by-Design was not significant. Larger (more negative) activation is down. Negative images in AX random and AY block conditions produced the least N2 activation, compared to positive and neutral images, suggesting that prior processing of emotional images (as measured using the LPP component) exhausted the neural resources for processing negative images.

(Valence: positive, negative, neutral) by 2 (Trial Type: AX, AY) repeated-measures ANOVAs. Because at the time of the LPP, i.e., participants did not know if a trial would be an AX or AY trial, LPP analysis consisted of a 2 (Design: block, random) by 3 (Valence: positive, negative, neutral) repeated-measures ANOVA. For effects that violated the Sphericity assumption, the Greenhouse-Geisser correction was applied. All post-hoc contrasts are Bonferroni corrected to control for multiple comparisons using Emmeans decompositions. Significant contrasts show p-values, mean differences (MD), and 95% confidence intervals for the difference (CID).

3. Results

3.1. Behavioral results

3.1.1. Reaction times

For reaction time, as expected, we found a main effect of Trial Type, F (1, 129) = 385.57, $p < .001$, $\eta_p^2 = 0.75$, which was subsumed by a Trial Type-by-Valence-by-Design interaction, F (2, 258) = 4.67, $p = .01$, $\eta_p^2 = 0.04$ (see Fig. 2, Table 2). In line with the main effect of Trial Type, AY had longer reaction times than AX for all levels of Valence and Design ($p < .001$; MD = 48.43 to 60.18; CID = 41.63 to 67.27), indicating that the task was administered effectively. Contrasts also showed that in the random design AY condition, positive trials had faster reaction times than both negative ($p = .05$; MD = 7.62; CID = 0.034 to 15.22) and neutral trials ($p = .004$; MD = 9.06; CID = 2.28 to 15.83). However, we did not find a main effect of Design (block versus random), F (1, 129) = 0.33, $p = .57$, $\eta_p^2 = 0.003$.

3.1.2. Performance accuracy

Consistent with previous research (Blair et al., 2007; Braver et al., 2009; Braver et al., 2009, 2009; Chiew and Braver, 2014), we found a main effect of Trial Type, F (1, 129) = 225.68, $p < .001$, $\eta_p^2 = 0.64$, with AY trials showing worse performance accuracy than AX trials (see Fig. 3, left panel; Table 3), again indicating that we administered the task appropriately. We also found a main effect of Valence, F (2, 258) = 7.24, $p = .001$, $\eta_p^2 = 0.05$, with the negative trials showing worse performance accuracy than either positive ($p = .008$; MD = 0.014; CID = 0.003 to 0.021) or neutral trials ($p = .006$; MD = 0.012; CID = 0.007 to 0.010; see Fig. 3, right panel). We again did not find a main effect of Design (block versus random), F (1, 129) = 0.09, $p = .77$, $\eta_p^2 = 0.001$.

3.2. ERP results

3.2.1. LPP

Consistent with the literature (Hajcak et al., 2006; Hajcak and Olvet, 2008; Keil et al., 2002; Schupp et al., 2000), we found a main effect of Valence, F (2, 258) = 63.16, $p < .001$, $\eta_p^2 = 0.33$, with the negatively valenced trials showing larger LPPs than both the positive ($p < .001$; MD = 1.13; CID = 0.79 to 1.47) and neutral ($p < .001$; MD = 1.46; CID = 1.12 to 1.80) trials (see Figs. 4 and 5). Additionally, LPP in response to the positive trials were larger than the neutral trials ($p = .036$; MD = 0.33; CID = 0.02 to 0.64). Consistent with the behavioral data, we did not find a main effect of Design (block versus random), F (1, 129) = 0.52, $p = .47$, $\eta_p^2 = 0.004$.

3.2.2. N2

Interestingly, for the N2, we did find a main effect of Design, F (1, 129) = 4.32, $p = .04$, $\eta_p^2 = 0.03$, with block design showing larger N2s than random (see Fig. 6). Additionally, we found a main effect of Valence, F (2, 258) = 19.45, $p < .001$, $\eta_p^2 = 0.13$, with the negative trials showing smaller N2s than the positive ($p < .001$; MD = 0.61; CID = 0.27 to 0.94) and neutral ($p < .001$; MD = 0.81; CID = 0.46 to 1.17) trials. There was also a main effect of Trial Type, F (1, 129) = 13.95, $p < .001$, $\eta_p^2 = 0.10$, with AY trials showing larger N2s than AX trails (see Figs. 7 and 8). All main effects were subsumed by a Design x Valence x Trial Type interaction, F (2, 264) (2, 258) = 4.06, $p = .02$, $\eta_p^2 = 0.03$. In line with the main effect of Trial Type, AY trials showed larger N2s than AX trials for block positive ($p < .001$; MD = 1.05; CID = 0.61 to 1.50), block neutral ($p = .02$; MD = 0.69; CID = 0.14 to 1.25), and random neutral ($p = .003$; MD = 0.80; CID = 0.27 to 1.33) trials. Contrary to previous research (Lamm et al., 2013; Lewis et al., 2006, 2007; Todd et al., 2008; van Wouwe et al., 2011) contrasts also showed that negative trials had smaller N2s than positive ($p = .002$; MD = 0.59; CID = 0.19 to 1.00) and

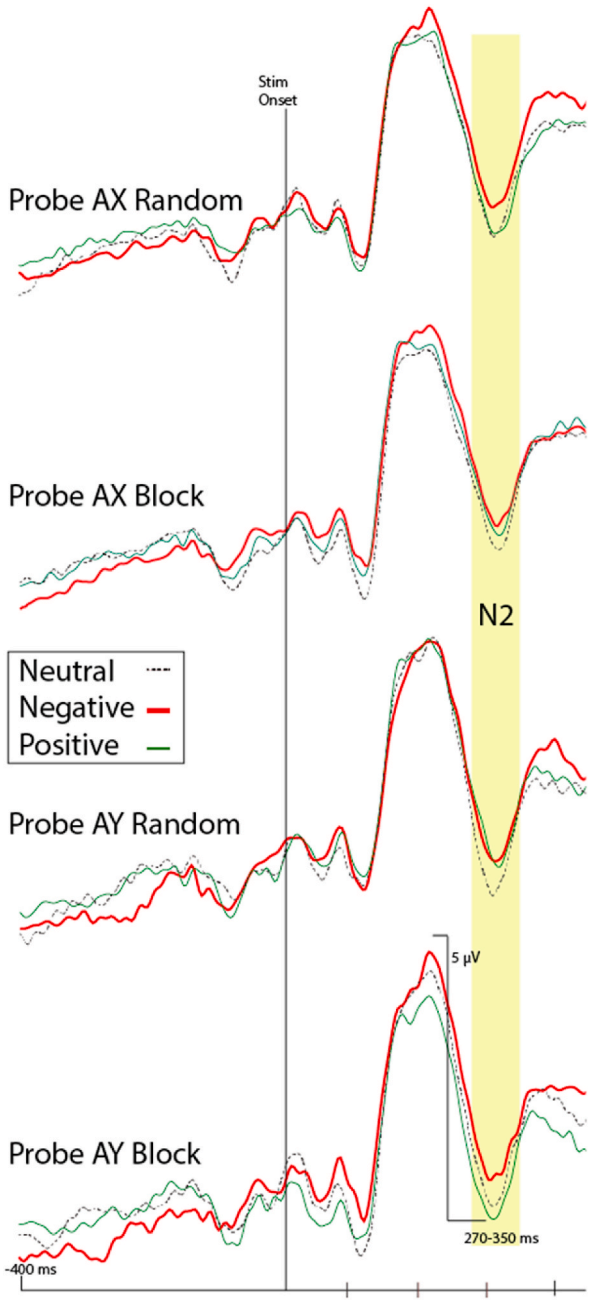


Fig. 8. ERP waveform depicting N2 amplitude at electrode Fz.

neutral ($p < .001$; MD = 0.74; CID = 0.32 to 1.16) trials for AX random trials. Additionally, for block AY trials, negative trials had smaller N2s than the positive ($p < .001$; MD = 1.19; CID = 0.46 to 1.91) and neutral ($p = .007$; MD = 0.97; CID = 0.22 to 1.72) trials. For random AY trials, negative trials ($p < .001$; MD = 1.09; CID = 0.49 to 1.70) and positive trials ($p = .01$; MD = 0.75; CID = 0.12 to 1.38) had smaller N2s than neutral trials. Lastly, in line with the main effect of Design, for AY positive trials, the block design showed larger N2s than the random design ($p < .001$; MD = 0.94; CID = 0.43 to 1.44).

3.3. Regression analysis

The increase in LPP amplitude for negative emotional images, followed by a decrease in N2 amplitude for the Y probe, suggests that neural resources might have been overly taxed by the neural processing of emotional images. To further test this possibility, we ran a regression analysis between LPP and N2 amplitudes, separately for each trial type (AX and AY) and valence (positive, negative, and neutral). We found that for the random design (but not the block design), larger LPP activation was associated with smaller N2 activation (see Fig. 9). Given that N2 activation was the least negative for the random negative condition, it is not surprising that we only found this emotion-induced depletion effect for this condition (both AX and AY). Table 4 outlines the correlation coefficients from the regression analysis between N2 and LPP.

Table 4
Correlation coefficients between LPP and N2 amplitudes.

	Random – LPP					
	AX, Pos	AX, Neg	AX, Neut	AY, Pos	AY, Neg	AY, Neut
Random – N2						
AX, Pos	0.146	–	–	–	–	–
AX, Neg	–	**0.273***	–	–	–	–
AX, Neut	–	–	−0.006	–	–	–
AY, Pos	–	–	–	0.044	–	–
AY, Neg	–	–	–	–	**0.276***	–
AY, Neut	–	–	–	–	–	−0.004
	Block – LPP					
	AX, Pos	AX, Neg	AX, Neut	AY, Pos	AY, Neg	AY, Neut
Block – N2						
AX, Pos	0.142	–	–	–	–	–
AX, Neg	–	0.067	–	–	–	–
AX, Neut	–	–	0.099	–	–	–
AY, Pos	–	–	–	0.071	–	–
AY, Neg	–	–	–	–	0.075	–
AY, Neut	–	–	–	–	–	−0.030

Note: Pos = positive, Neg = negative, Neut = neutral. Dashes signify incompatible correlation.
*p < .01.

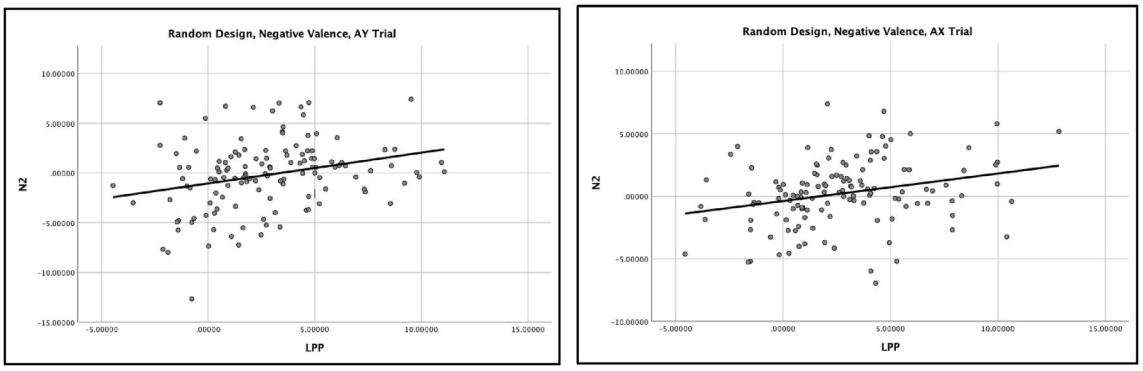


Fig. 9. Positive correlation between greater LPP amplitude and smaller N2 amplitude in the Random design for negative trials, for AY (left) and AX (right) trials. Please note, because the N2 is a negative component, smaller N2s are at the top of the Y-axis.

4. Discussion

In the current study, we explored the impact of emotionally-charged images (block versus random trial order) on downstream cognitive processing using a modified version of the AX-CPT. We found that arousing negative images interfered with cognitive performance, as evident by worse performance accuracy, greater LPP amplitude, and smaller N2 amplitude for negative-valence trials compared with positive and neutral trials. This pattern of results is likely due to negative-emotion-induced LPP enhancement, reflecting more attentional resources utilized, thereby limiting downstream neurocognitive resources as shown by subsequent smaller N2 amplitude.

Consistent with the literature and with our hypothesis, we found the largest LPPs for negative images and the smallest for neutral images, with LPP for positive images in between (Hajcak et al., 2006; Hajcak and Olvet, 2008; Keil et al., 2002; Schupp et al., 2000). Contrary to our hypothesis and prior findings (Lamm et al., 2013; Lewis et al., 2006; Todd et al., 2008), N2s were smaller in response to probes presented after negative images compared to positive and neutral images. This effect is likely due to the availability and allocation of cognitive resources. More specifically, emotion-related activation (LPP) to the negative emotional stimuli reduces the amount of cognitive resources available (N2) for the subsequent cognitive challenge (probe), i.e., resolving response conflict to press the correct button. Contrary to our results, some prior literature has reported the reallocation of resources from emotional processing to cognitive processing (Foti and Hajcak, 2008; Van Dillen et al., 2009; Van Dillen and Derks, 2012; Hajcak et al., 2006, 2009). For example, Van Dillen and Derks (2012) found that a high memory load reduces attention to emotionally arousing stimuli after completing a cognitive task. These divergent results may be due to where the emotionally charged image is presented. The current study presented the cognitive event well after the emotional stimulus. The Van Dillen and Derks (2012) study presented the emotionally charged images after the cognitive element of the task. Other studies, including a recent one by Rawls et al. (2020), present the emotionally charged image at the same time as the cognitive event. While not using emotionally-charged images, Lamm and colleagues conducted a number of studies that found larger N2s in the context of a frustrating block, removal of desired points, compared with a relatively neutral block (e.g., Lamm et al., 2011; Lamm and Lewis, 2010). In these studies, the cognitively difficult events (nogo trials) were also the events that frustrated participants. Thus, task design, i.e., order of events within a trial, can have a dramatic impact on brain activation and potentially lead to contradictory results in the literature.

Although LPP amplitude did not vary as a function of task design (block versus random design), N2 amplitude was significantly greater in the block design, compared to the random design. Interestingly, this effect was greatest for the positive-valence condition, possibly because neural resources in the negative condition were already maxed out and thus could not show more activation for the block design compared with the random design. The correlations between N2 and LPP are in line with this finding because larger LPPs correlated with smaller N2s, specifically for the negative condition in the random design. Although the significance is relatively moderate, the depletion of resources is greater for the random condition than the block condition; therefore, it is not surprising that we only found significance for the random condition. Lastly, this finding is in line with our hypothesis that N2 activation would be greater for the block design compared to the random design, which can also be attributed to the emotional carry-over effect in a block presentation of images (Lamm et al., 2013). In the current study, we found the greatest design (block versus random) differences in the positive condition. This may be due to differences in attentional focus. Specifically, there is some evidence that attention may be less focused in the context of positive emotions compared with other contexts (see Yiend, 2010 for a review). Thus, in our study, participants might have had to recruit additional resources to focus their attention to accurately complete AY trials in the blocked positive condition compared with other conditions. Overall, these findings suggest N2 activation may be modified by trial sequence (block versus random) of emotional stimuli presentation. Therefore, future research should carefully plan the presentation and sequence of cognitive and emotional events.

One limitation of this study was that we did not correct for multiple comparisons for the number of correlations. Given the complexity of the design, in order to test for maximal depletion in the negative condition, we had to run all of these correlations. However, it is unlikely the effects we found are due to a Type I error because these effects were yielded only in the conditions (random negative AX and AY) shown to have the smallest N2s. We should also note that on the grand averaged waveforms for the N2, the negative wave at time zero (stimulus onset) appears to be slightly more positive than the neutral and positive conditions. Before statistical analyses were conducted, we applied several different baseline corrections, but this difference was always slightly evident in the grand averaged waveform. To ensure that our N2 effects were not simply because of this baseline correction issue, we extracted mean activation at time zero and added this to our ANOVAs as a covariate. All effects were still significant after we controlled for time zero activation. Lastly, some of the current results are not supported in the literature, and thus should be interpreted with caution, particularly given the low number of trials and effect sizes.

In the future, this study should be repeated with a clinically anxious population to determine the impact of emotional images on cognitive processing. It is probable that the depletion of N2 activation could be more prevalent in a clinical population. Our N2 and LPP results suggest an emotion-related depletion of neural resources, and that this depletion was slightly more for the random task design. Therefore, when examining neural processes underlying emotion-cognition interactions, future research should pay attention to both the order of trials within a block and stimulus order within a trial when designing tasks.

Credit author statement

Arooj Abid: Writing – original draft, Writing – review & editing, Software. Morgan Middlebrooks: Software. Eric Rawls: Conceptualization, Methodology. Connie Lamm: Supervision, Conceptualization, Validation.

Acknowledgments

Funding for this study was provided by the Arkansas Biosciences Institute (0402-27504-21-0216) to CL. The content is solely the responsibility of the authors and does not necessarily represent the official views of the ABI. Thanks to Mejdy M. Jabr, Carl Armes, Shannin Moody, and Jena Michel for help in data collection.

References

Abid, A., Middlebrooks, M., Rawls, E., Lamm, C., 2019. Block versus Random Design: the Behavioral and Electrophysiological Effects of Emotional Stimuli Order. Poster presented at the Society for Psychophysiological Research's 59th Annual Meeting, Washington, D.C.

Blair, K.S., Smith, B.W., Mitchell, D.G., Morton, J., Vythilingam, M., Pessoa, L., et al., 2007. Modulation of emotion by cognition and cognition by emotion. Neuroimage 35 (1), 430–440.

Braver, T.S., Paxton, J.L., Locke, H.S., Barch, D.M., 2009. Flexible neural mechanisms of cognitive control within human prefrontal cortex. Proc. Natl. Acad. Sci. Unit. States Am. 106 (18), 7351–7356.

Chiew, K.S., Braver, T.S., 2010. Exploring emotional and cognitive conflict using speeded voluntary facial expressions. Emotion 10 (6), 842–854.

Chiew, K.S., Braver, T.S., 2011. Positive affect versus reward: emotional and motivational influences on cognitive control. Front. Psychol. 2.

Chiew, K.S., Braver, T.S., 2014. Dissociable influences of reward motivation and positive emotion on cognitive control. Cognit. Affect Behav. Neurosci. 14 (2), 509–529.

Czekóová, K., Shaw, D.J., Janoušová, E., Urbánek, T., 2015. It's all in the past: temporal-context effects modulate subjective evaluations of emotional visual stimuli, regardless of presentation sequence. Front. Psychol. 6, 367.

Folstein, J.R., Van Petten, C., 2008. Influence of cognitive control and mismatch on the N2 component of the ERP: a review. Psychophysiology 45 (1), 152–170.

Foti, D., Hajcak, G., 2008. Deconstructing reappraisal: descriptions preceding arousing pictures modulate the subsequent neural response. J. Cognit. Neurosci. 20 (6), 977–988.
Fujimura, T., Katahira, K., Okanoya, K., 2013. Contextual modulation of physiological and psychological responses triggered by emotional stimuli. Front. Psychol. 4, 212.
Hajcak, G., Nieuwenhuis, S., 2006. Reappraisal modulates the electrocortical response to unpleasant pictures. Cognit. Affect Behav. Neurosci. 6 (4), 291–297.
Hajcak, G., Olvet, D.M., 2008. The persistence of attention to emotion: brain potentials during and after picture presentation. Emotion 8 (2), 250.
Hajcak, G., Dunning, J.P., Foti, D., 2007. Neural response to emotional pictures is unaffected by concurrent task difficulty: an event-related potential study. Behav. Neurosci. 121 (6), 1156.
Hajcak, G., Dunning, J.P., Foti, D., 2009. Motivated and controlled attention to emotion: time-course of the late positive potential. Clin. Neurophysiol. 120 (3), 505–510.
Hajcak, G., Moser, J.S., Simons, R.F., 2006. Attending to affect: appraisal strategies modulate the electrocortical response to arousing pictures. Emotion 6 (3), 517.
Hilgard, J., Weinberg, A., Hajcak Proudfit, G., Bartholow, B.D., 2014. The negativity bias in affective picture processing depends on top-down and bottom-up motivational significance. Emotion 14 (5), 940.
Ito, T.A., Larsen, J.T., Smith, N.K., Cacioppo, J.T., 1998. Negative information weighs more heavily on the brain: the negativity bias in evaluative categorizations. J. Pers. Soc. Psychol. 75 (4), 887.
Jodo, E., Kayama, Y., 1992. Relation of a negative ERP component to response inhibition in a Go/No-go task. Electroencephalogr. Clin. Neurophysiol. 82 (6), 477–482.
Keil, A., Bradley, M.M., Hauk, O., Rockstroh, B., Elbert, T., Lang, P.J., 2002. Large-scale neural correlates of affective picture processing. Psychophysiology 39 (5), 641–649.
Lamm, C., Granic, I., Zelazo, P.D., Lewis, M.D., 2011. Magnitude and chronometry of neural mechanisms of emotion regulation in subtypes of aggressive children. Brain Cognit. 77 (2), 159–169.
Lamm, C., Pine, D.S., Fox, N.A., 2013. Impact of negative affectively charged stimuli and response style on cognitive-control-related neural activation: an ERP study. Brain Cognit. 83 (2), 234–243.
Lamm, C., Lewis, M.D., 2010. Developmental change in the neurophysiological correlates of self-regulation in high-and low-emotion conditions. Dev. Neuropsychol. 35 (2), 156–176.
Lewis, M.D., Lamm, C., Segalowitz, S.J., Stieben, J., Zelazo, P.D., 2006. Neurophysiological correlates of emotion regulation in children and adolescents. J. Cognit. Neurosci. 18 (3), 430–443.
Lewis, M.D., Todd, R.M., Honsberger, M.J., 2007. Event-related potential measures of emotion regulation in early childhood. Neuroreport 18 (1), 61–65.
Mathalon, D.H., Whitfield, S.L., Ford, J.M., 2003. Anatomy of an error: ERP and fMRI. Biol. Psychol. 64 (1–2), 119–141.
Pastor, M.C., Bradley, M.M., Löw, A., Versace, F., Moltó, J., Lang, P.J., 2008. Affective picture perception: emotion, context, and the late positive potential. Brain Res. 1189, 145–151.
Pegwal, N., Pal, A., Sharma, R., 2019. Deactivation of default-mode network and early suppression of decision-making areas during retrieval period by high-arousing emotions improves performance in verbal working memory task. Cognit. Affect Behav. Neurosci. 19 (2), 231–238.
Raschle, N.M., Fehlbaum, L.V., Menks, W.M., Euler, F., Sterzer, P., Stadler, C., 2017. Investigating the neural correlates of emotion–cognition interaction using an affective stroop task. Front. Psychol. 8, 1489.
Rawls, E., Jabr, M.M., Moody, S.N., Lamm, C., 2018. Neural mechanisms underlying the link between effortful control and aggression: an ERP study. Neuropsychologia 117, 302–310.
Rawls, E., Miskovic, V., Moody, S.N., Lee, Y., Shirtcliff, E.A., Lamm, C., 2020. Feedback-related negativity and frontal midline theta reflect dissociable processing of reinforcement. Front. Hum. Neurosci. 13, 452.
Rosvold, H.E., Mirsky, A.F., Sarason, I., Bransome Jr, E.D., Beck, L.H., 1956. A continuous performance test of brain damage. J. Consult. Psychol. 20 (5), 343.
Schmidt, S.R., Schmidt, C.R., 2016. The emotional carryover effect in memory for words. Memory 24 (7), 916–938.
Schupp, H.T., Cuthbert, B.N., Bradley, M.M., Cacioppo, J.T., Ito, T., Lang, P.J., 2000. Affective picture processing: the late positive potential is modulated by motivational relevance. Psychophysiology 37 (2), 257–261.
Todd, R.M., Lewis, M.D., Meusel, L.A., Zelazo, P.D., 2008. The time course of social-emotional processing in early childhood: ERP responses to facial affect and personal familiarity in a Go-Nogo task. Neuropsychologia 46 (2), 595–613.
Van Dillen, L.F., Heslenfeld, D.J., Koole, S.L., 2009. Tuning down the emotional brain: an fMRI study of the effects of cognitive load on the processing of affective images. Neuroimage 45 (4), 1212–1219.
Van Dillen, L.F., Derks, B., 2012. Working memory load reduces facilitated processing of threatening faces: an ERP study. Emotion 12 (6), 1340.
van Wouwe, N.C., Band, G.P., Ridderinkhof, K.R., 2011. Positive affect modulates flexibility and evaluative control. J. Cognit. Neurosci. 23 (3), 524–539.
Veen, V.V., Carter, C.S., 2002. The timing of action-monitoring processes in the anterior cingulate cortex. J. Cognit. Neurosci. 14 (4), 593–602.
Waters, A.J., Sayette, M.A., Franken, I.H., Schwartz, J.E., 2005. Generalizability of carry-over effects in the emotional Stroop task. Behav. Res. Ther. 43 (6), 715–732.
Weinberg, A., Hajcak, G., 2010. Beyond good and evil: the time-course of neural activity elicited by specific picture content. Emotion 10 (6), 767.
Yiend, J., 2010. The effects of emotion on attention: a review of attentional processing of emotional information. Cognit. Emot. 24.
Zinchenko, A., Chen, S., Zhou, R., 2019. Affective modulation of executive control in early childhood: evidence from ERPs and a Go/Nogo task. Biol. Psychol. 144, 54–63.
Zinchenko, A., Kanske, P., Obermeier, C., Schröger, E., Kotz, S.A., 2015. Emotion and goal-directed behavior: ERP evidence on cognitive and emotional conflict. Soc. Cognit. Affect Neurosci. 10 (11), 1577–1587.
Zinchenko, A., Kotz, S.A., Schröger, E., Kanske, P., 2020. Moving towards dynamics: emotional modulation of cognitive and emotional control. Int. J. Psychophysiol. 147, 193–201.